A Robotics Roadmap for Australia 2022

ROBOTICS
AUSTRALIA GROUP

This National Roadmap is brought to you by Robotics Australia Group, the voice of Australia's robotics industry.

Our Vision is to build a sustainable robotics industry in Australia. We do this by supporting the entire robotics ecosystem, from the companies building robots, to those researching and developing new robotic technologies, robotics educators and enthusiasts, and the companies looking to adopt robots and robotic-related technologies.

As the peak body for Robotics in Australia, Robotics Australia Group was established to facilitate the growth of a sustainable and internationally competitive national robotics industry.

Robotics Australia Group will align current robotics activity and create a focussed, collaborative approach between industry, research, government, start-ups, investment and education to build a robust and world-class robotics ecosystem.

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Introduction

VISION: Robots as a tool to unlock human potential, modernise the economy, and build national health, well-being and sustainability

1.1 Why Australia needs a robotics industry

Robotics will impact every sector of the Australian economy and has the potential to achieve enormous social and environmental good. Creating robotic technologies will lead to the jobs of the future through creating new possibilities.

The application of these technologies will help protect our environment, provide equity in service access for rural and remote communities, reduce the cost of healthcare, supply safer and more fulfilling jobs, and maintain our living standards. But only if we invest in keeping the talent and technologies we are developing in robotics, here in Australia. We must be ambitious and seek to build homegrown global companies that export to the world.

The economic benefits of adopting robotics and automation are well-understood and reasonably well-supported by Australia's current government policies. Surprisingly, current economic theory does not address the uplift generated by being a country that creates robotic technologies but it is self-evident when considering the jobs, roles and industries that will be created. COVID-19 highlighted the importance of being able to rely on sovereign supply chains and developing our own technologies is a crucial component of this as well as a matter of national security. Australia invests heavily in cybersecurity ($1.67b in 2020[1]) but does not make a concomitant investment in technology creation. This forces Australia to be a nation of renters, who own nothing and pay to use technologies created by other countries. We must reverse the trend towards being passive consumers of these technologies and define our role as value creators.

> Australia invests heavily in cybersecurity but does not make a concomitant investment in technology creation.

In the last twenty years, tech companies have come to dominate the world's top 10 companies by market capitalisation. In 2019, seven of the top 10 were technology companies.[2] None of Australia's top 10 companies by market capitalisation are technology companies, with the list dominated by mining companies and the 'big four' banks, however fintech company AfterPay, cloud accounting company Xero and implantable device company Cochlear are moving up the list.[3] Australia should take advantage of its strong performance in developing technology companies for financial services, healthcare, agriculture, resources, transport and logistics.

Roadmap Version 2

This is the second edition of the Robotics Roadmap for Australia. The first was published in mid-2018 by the Australian Centre for Robotic Vision, an ARC Centre of Excellence, which concluded at the end of 2020. Responsibility for creating a second edition of the roadmap has been taken on by the new not-for-profit entity Robotics Australia Group, which is the peak body representing the robotics industry in Australia.

Robotics Australia Group, through the Robotics Australia Network, brings together a community of more than 800 people from industry, government and research institutions. Interest in the emerging area of robotics has grown since 2018, shown by the increase from 92 participants in roadmap consultation sessions in 2017 to 1,058 participants in 2020. Consultation extended to include participants from New Zealand, who have been producing their own national roadmap. Unlike the first version of the roadmap, only two roadmap workshops (Resources and Healthcare) were able to be held in person before COVID-19 restrictions were enforced. The next thirteen workshops were held virtually and can be watched on Robotics Australia Group's website and YouTube channel.

The number of case studies from industry submitted for inclusion in the roadmap has grown, from 58 in 2018 to 98 today.

The roadmap was also a key driver for the establishment of both the Queensland Robotics Cluster and RoboWest (WA). Robotic (and drone) testing grounds are being developed at Neerabup in WA, and Cloncurry in Queensland, smart mobility precincts are being established in Joondalup (WA) and Redland (QLD), while Australia's expertise in remote operations and robotics is recognised by two WA-led initiatives: AROSE (Australian Remote Operations for Space and Earth)

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The five key principles of the 2018 roadmap remain the same for 2021

Jobs matter	Time matters	Safety is imperative	Regional service delivery	Certainty counts
A robotics industry will enhance Australia's economic competitiveness, create meaningful jobs and, with the right policy settings, help adapt existing jobs	The right use of robotics eliminates workplace routine, improves efficiency and allows workers to dedicate time to interesting and more fulfilling tasks while also boosting productivity	Robotics reduces the risk of workers being placed in hazardous situations	Robotics can be the force multiplier necessary to ensure better and more consistent services are able to be provided to Australia's regional and remote areas	As the robotics industry becomes more established, investment will follow, attracted by the critical mass of talent and technologies we are continuing to develop

and SPaaRC (the Australian Space Automation, Artificial Intelligence and Robotics Control Complex). The establishment of Robotics Australia Group – also a direct result of the first roadmap – is recognised on the international stage, with RAG becoming a founding member of the International Alliance of Robotics Associations (IARA).

The rationale for writing a second version of the roadmap is to further leverage and build on the momentum gained since the first, which was written when Australia's Robotics industry was highly immature and fragmented. It is also in response to the record investment we are seeing other countries make in robotics and more broadly AI. The US alone has invested more than US$250b in recent times to ensure the competitiveness of the US tech industry.[4]

Outside Australia, other countries are developing and executing detailed strategies around both robotics and AI that are having immediate impact. China is a key example – in 2018, China published a national robotics strategy with the ambition to become self-sufficient in the production of industrial robots and to become the world's number one in terms of robot population density,[5] a measure of the number of industrial robots per 10,000 employees, by 2020.

The rationale is to ensure China has a sovereign supply of the robots it requires for use in its manufacturing industry and it went about achieving its target aggressively, accounting for 38% of the world's industrial robot purchases, while also buying the German robot manufacturing company, Kuka Robotics.

> Australia's robot population density is 75, while the world average is 113. We are being left behind.

While China has not met its target, in less than 10 years it has grown from a robot population density of 15 (in 2010) to 187 (in 2019).

The world's number one country in terms of robot population density is Singapore, with 918 robots per 10,000 employees (in 2019). Australia's robot population density is 75, while the world average is 113.[6] We are being left behind.

This document is structured to give an overview of what robotics looks like in Australia. Each chapter focuses on the distinctive requirements of different sectors of the Australian economy, and is informed by the robotics companies that service those sectors. Over the next decade a range of new technologies will see robots become even more useful tools, having more sensitive touch (tactile perception), being more capable of interacting with their physical environments, being able to work more closely in collaboration with humans, and also to be more robust, reliable, and self-sufficient. Robots will also take on many different forms, suiting them for new and unexplored functions. This roadmap is a guide to the future of robotic technologies, providing insight into what Australia is already doing in this space, and demonstrates how we can achieve gains from robots across all sectors of the Australian economy.

The raw ingredients for a successful robotics industry are all here in Australia. The first robotics roadmap showed a highly competent but relatively immature and fragmented industry, this second edition shows signs of growth and maturity but with much work still to do. In 2018, the total venture capital investment (tracked from publicly available sources) in Australian robotics and drone companies was just $6.5m total (not annual). Since that time there has been an additional $130m worth of investment in Australia and $28m investment in New Zealand. In 2018, we estimated robotics companies were worth $12b in revenue to the Australian economy, in 2021 we estimate they produce annual revenue of $18b. We continue to graduate more Mechatronics graduates each year from Australian universities, with graduates almost doubling to 668 between 2016 and 2019.[7] It is undeniable the sector is growing along with Australia's capability in the space.

Australia needs to back itself to be not just a consumer but a creator of robotics and robotics-related technologies. Such ambition will see us realise the full benefits of these emerging technologies and ensure we have sovereign capability across all of our important supply chains. It will also open up new export markets in this high growth sector, where average Compound Annual Growth Rate (CAGR) for field robots, one of Australia's areas of niche expertise, is 31%.[8]

Our vision is for Australia to have a sustainable homegrown robotics industry. We provide recommendations on how to achieve that vision and harness the new and emerging technologies being developed here in Australia today.

Australia needs to back itself to be not just a consumer but a creator of robotics and robotics-related technologies.

Robotics is an interdisciplinary field that includes, mechanical and electrical engineering, computer science, design and, increasingly, the social sciences, creative arts and law. The development of robotic technologies will lead to the creation of new companies, new jobs and will address a range of issues of national importance including our ageing population, servicing regional and remote communities, and dealing with labour shortages, such as those generated by the COVID-19 pandemic.

Dr Sue Keay
Chair, Robotics Australia Group

Image courtesy of Robusty.

1.2 Policy recommendations

OBJECTIVE

Establish Australia as a global leader (as measured by export value) in the supply of trustworthy robotics and artificial intelligence (AI) products and services by 2030.

ACTIONS

Develop and release a 10-year Australian Artificial Intelligence and Robotics Strategy by early 2022.

Add 'Artificial Intelligence and Robotics' to the Australian Research Council Science and Research Priorities.

Update the Australian and New Zealand Standard Industry Classification scheme to enable the measurement and tracking of Australia's technology sector – with specific categories for robotics and robotics-related technologies (notably AI). Release dedicated statistics on Australia's technology sector by June 2023 at the latest

Priority

Substantially increase the number of Australian-based high growth robotics and AI companies to improve sovereign capability and drive Australia's technology export market.

Actions

- Identify additional policy mechanisms to support Australia's startup ecosystem, with a focus on robotics and AI.
- Review state/territory and national government procurement protocols and procedures to further support Australian robotics and AI startups.

Priority

Improve the investment and funding environment for robotics and AI in Australia.

Actions

- Reduce barriers to foreign direct investment, with a view to see robotics investment increase to $500m per annum by 2024.
- Incentivise Australian superannuation funds to invest in high capital expenditure ventures related to robotics and robotics-related technologies, such as hardware.
- Provide improved access for Australian technology startups to international mentors.

Priority

Increase research and development and improve commercialisation of locally developed intellectual property in robotics and robotics-related technologies.

Actions

- Reduce barriers to global robotics companies establishing research and development hubs in Australia (compared to existing sales offices).
- Establish and fund robotics-related industry knowledge priorities to ensure existing and emerging industries research and development programs are structured and delivered to support robotics research and commercialisation.

Priority

Accelerate and amplify the development and adoption of Australian made robotics and AI solutions.

Actions

- Introduce tax incentives for companies who adopt and deploy locally developed robotics and AI.
- Refocus Australia's digital transformation to target the development and adoption of Australian developed robotics and robotics-related technologies.
- Establish a national government body to expedite the approval and adoption of new technology applications for commercial use across key industries (such as healthcare). The body would be further tasked with collaborating with other state and national government agencies, industry and unions to expedite and incentivise the path toward commercialisation for Australian technologies.
- Introduce an AI and robotics-first use strategy for federal and state/territory governments to lead by example and accelerate government transformation. Such a requirement will further accelerate and support domestic capability and expand the domestic market.
- Support the creation of robotics clusters and "living labs"/technology precincts to showcase Australian solutions and enable testing and development with Australian industry and government.

Priority

Significantly increase Australia's technology workforce and expand community literacy in robotics and AI.

Actions

- Provide dedicated funding and policy support to improve digital and technology literacy for the general public, with a focus on robotics and AI.
- Provide funding and resources to review and update national curriculums across all education levels to provide greater focus on digital and technology skills.
- Identify and introduce strategies to attract and retain skilled migration specialising in robotics and AI.
- Develop a national training and incentive program to encourage workforce transition to the Australian technology sector.
- Develop a national retraining and upskilling program to improve workforce resilience across all sectors by leveraging tools such as micro-credentials.
- Launch a national competition to develop leading robotic solutions for key challenges to spur industry growth.

Priority

Develop and adopt governance systems to ensure robotics and AI solutions improve Australia's well-being and protect democratic values.

Actions

- Develop and/or adopt appropriate standards to ensure the safe deployment of robotic technologies which meet appropriate ethical, legal and regulatory frameworks.
- Review and update regulatory frameworks to address and enable robotics and AI.
- Fund interdisciplinary research to address social and cultural issues and concerns relating to the development of robotics to establish a social licence for robotics.
- Fund an awareness campaign across industry, government and the wider community on the benefits of adopting robotics and robotic-related technologies (such as improved service delivery in remote areas, productivity gains, safety, job creation and supply chain security).

WHAT IS A ROBOT?

Robots are autonomous machines that can move within their physical environment and manipulate objects. Robots have four essential characteristics: sensing, movement, energy and intelligence. In general we use the word "robotics" to encompass ALL robotics-relevant fields such as computer and machine vision, sensors and sensing systems (IoT), artificial intelligence (AI) and machine learning (ML) as well as automation and autonomous systems.

Robots are often described in terms of two classes of robots, industrial or service, depending on their intended application. Industrial robots are used in industrial automation applications while service robots are not. Service robots may be for personal/domestic use or for use in professional settings, e.g. concierge robots in hotels. Statistics on the number of robots produced in the world each year are divided into these two broad categories by the International Federation of Robotics (IFR). In 2019, 373,000 industrial robots[6] (down 12% from 2018) and 23.4 million service robots[8] (up by 34% compared to 2018) were manufactured by more than 900 companies worldwide.

1.3 What do we need to develop sovereign capability in robotics?

Australia is a global leader in field robotics; however, we have many barriers to fully taking advantage of our capability and experience.

Data and benchmarking in robotics

Like many parts of Australia's tech sector, robotics is not recognised as an industry in the Australian and New Zealand Standard Industrial Classification scheme (ANZSIC), used by the Australian Bureau of Statistics to collect industry relevant data for benchmarking purposes. As robotics is not recognised as an industry in its own right, it is difficult to obtain consistent measurements of the size of the industry (how many companies), how many people it employs, how much revenue it generates and how much it contributes to Australia's export income. Robotics and robotics-related technology companies will variously fall under different divisions such as manufacturing or other specific sectors where the technology is applied and may be seen as support services, engineering services, software, consulting or repair and maintenance. There is no Australian government department, except broadly the Department of Industry, which takes responsibility for policy on sovereign robotic capability, adoption of robotic-related technologies by existing industry or on regulating these technologies.

Robotics introduces a different way of working and measuring success both at a country- and firm-level. Mentally and business-wise these concepts can be hard to explain without describing them in terms of the business benefits/ risks for the target industry. As most robotics technology can be applied across all industry verticals this is a level of domain-specific knowledge that is challenging for most robotics companies.

Incentives to invest in robotics companies and to support adoption

While the investment landscape has improved in Australia since the first roadmap was published in 2018, universal feedback from our national consultation sessions suggested that access to capital was still a major hindrance to the ongoing development of Australian technologies onshore. The path to commercialisation is still seen as a key weakness in transitioning robotics from the R&D stage to market-ready product. While some innovations in Australian robotics have market potential, they often require significant capital to commercialise, unlike software. Often, the Australian market is not large enough to justify the development of high capital expenditure (capex) technologies.

Policy initiatives, such as tax incentives, can help facilitate the transition of high capex technologies to markets in and outside of Australia. Investment (of time and resources) should be focused on areas that show high potential to expand within the local market. Given Australia's strength in field and service robotics, incentives for companies to develop and adopt robotic technology in the Construction, Defence, Resources, Agriculture, Environment, Space and Services sectors will have direct impact on the development of sovereign robotics capability. For example, significant gains have been made in mining automation to the benefit of the Australian economy and similarly, scalable technologies are being developed in the AgTech sector. However, Australia does not develop industrial robots so incentives that encourage adoption of such robots in sectors such as manufacturing do not have the same uplift potential as other sectors of the economy that rely on locally-produced robots.

Shared infrastructure in robotics

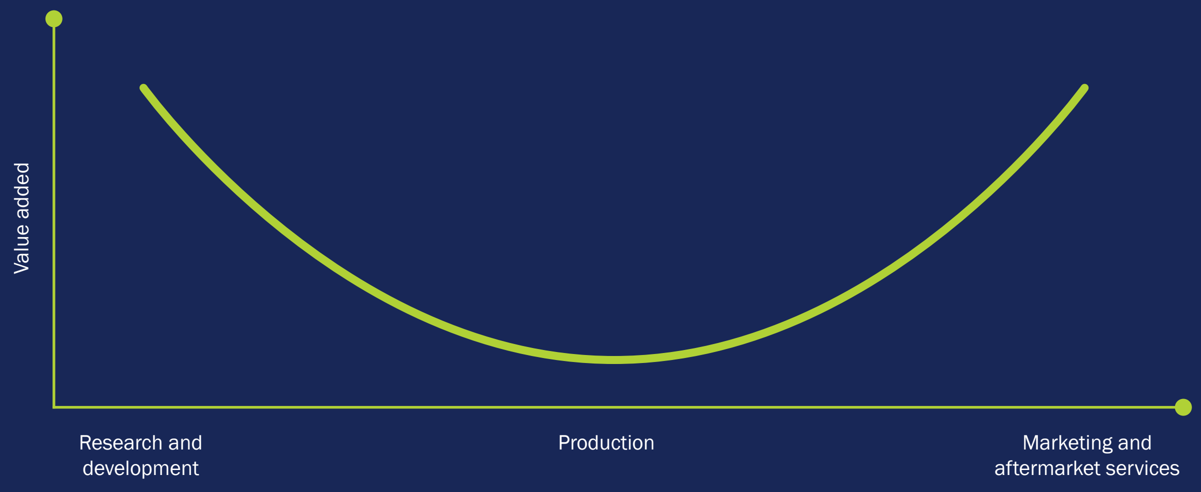
The creation and maintenance of large-scale robotic testbeds, or experimental facilities, to support the development of robotic technologies is necessary for commercialisation success. To date, Australia does not have these facilities. Testbeds can act as ways to take R&D from theory to proto-type and then to a minimum viable product that can be tested in the market. While testbeds are resource-intensive, this makes them well-suited to a shared and even remote-access format. To be successful such testbeds need to cater to a variety of robot systems that can be used to test the utility of algorithms and to supply modular interoperable hardware (plug-n-play) for remote testing against physical and virtual benchmarks. They also require validation, which exposes the need for frameworks (standard test methods and metrics) to assess the quantitative performance of different robotic technologies.

The Robotics Venture Factory

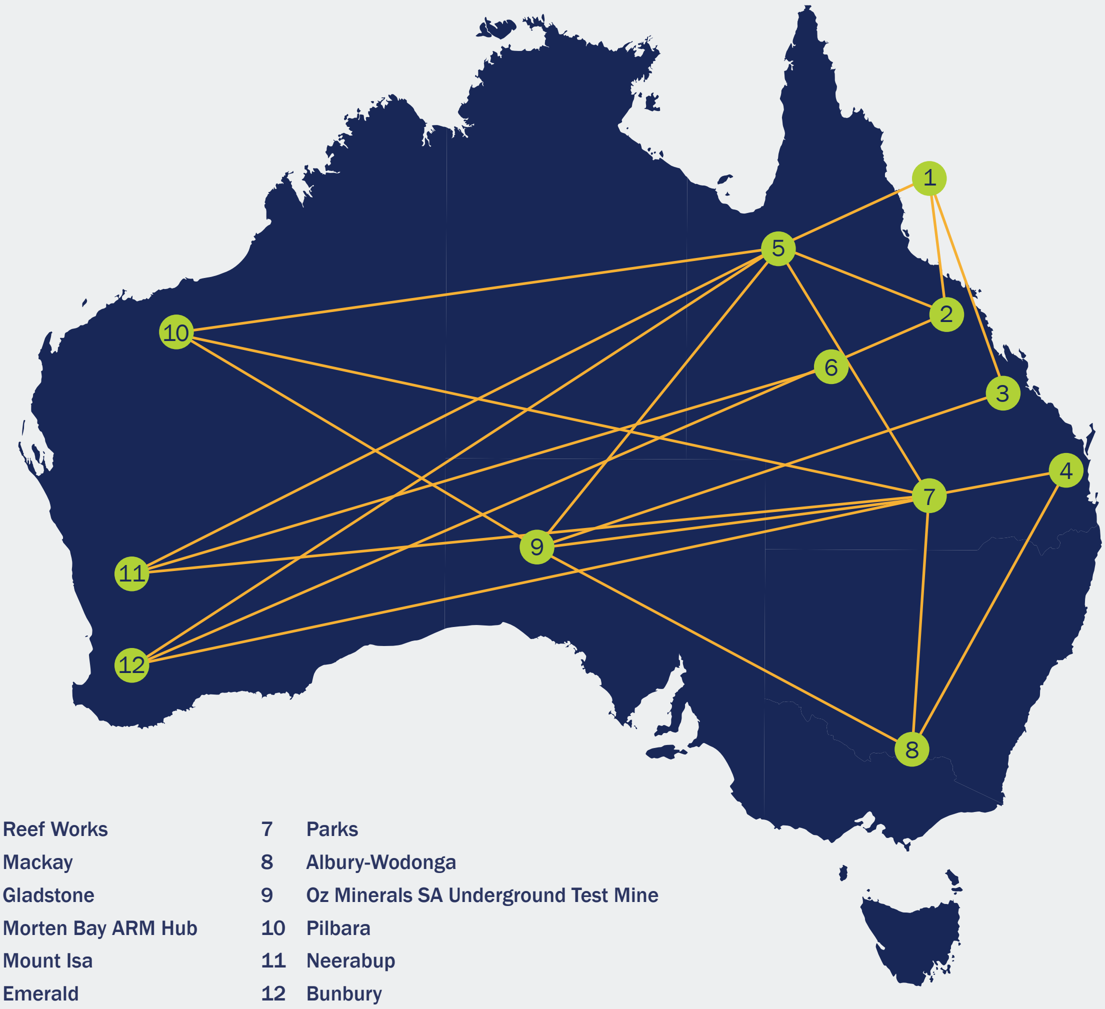
One potential solution that Robotics Australia Group is promoting to address some of the challenges outlined above, is the development of a robotics venture factory. The factory concept is designed to build infrastructure that accelerates the creation of Australian made robotic solutions for a variety of sectors. It fills a gap that exists currently for robotics companies to navigate the last step of solution commercialisation (TRL7 and TRL8) and scaling manufacturing into operations (TRL9).

The factory forms the necessary connective tissue between innovators, inventors, creators and researchers to investors, manufacturers, parts/component suppliers (both national and aggregated international supply chains), fabrication facilities, and existing test and development environments. It supports local robotics companies to scale and create global businesses that access international markets, by providing resources to strengthen service delivery as well as support and advisory services.

Considering the manufacturing **"smiling curve"**, the **Robotics Venture Factory** is focused on robotics production and professional services, but will **connect with other robotics test and demonstration beds and global R&D efforts.** It creates a portal entry for the **acceleration of the manufacture of robotics** and the **acceleration of industry uptake of automation and robotic solutions** for those sectors that benefit from the development of service robots such as field robots.



Australian robotics venture factory
Nationally interconnected test grounds



1 Reef Works
2 Mackay
3 Gladstone
4 Morten Bay ARM Hub
5 Mount Isa
6 Emerald
7 Parks
8 Albury-Wodonga
9 Oz Minerals SA Underground Test Mine
10 Pilbara
11 Neerabup
12 Bunbury

The Factory will form the heart of an innovation hub precinct with all the necessary materials and equipment for local robotics companies to build, test and validate prototypes and look to scale operations. It will be connected into a national ecosystem of robotics test bed grounds – each with their own unique end user applications. The Factory concept draws on knowledge from similar initiatives in both Europe and the US, but with a focus on field robotics, where we have a global leadership position.

The Robotics Venture Factory concept incorporates plug-and-play, pack and ship, unpack and deploy services, as well as testing and demonstration capabilities. With a shared dedicated workshop space including manufacturing equipment and engineering services, the factory enables rapid prototyping in a supported environment with calibrated, shared communications infrastructure as well as remote operations capability to support monitoring and tele-remote solutions. Implementation of the concept will increase our sovereign capability in the development of robotic technologies, increase jobs (particularly in regional areas), provide meaningful career pathways for mechatronics graduates and also increase exports.

Global robotics benchmarks

As robotics continues to expand to more application domains, the development and maintenance of suitable experimental facilities are becoming bottlenecks in the innovation process. In fact, there is a significant gap between the theoretical foundations that are being broadly pursued, and a focused, application- driven transition from small-scale experiments to robust and high impact developments. This gap is both scientific and practical.

By having researchers from different institutions, disciplines, and backgrounds come together around a common testbed, there is potential to accelerate innovation and to build on past findings in a more effective manner than what is currently being done. The development and maintenance of meaningful, large- scale robotic testbeds is a resource-intensive undertaking, which is why it is practically well-suited to a shared an even remote-access format.

— US Robotics Roadmap 2020

Footnotes

1 Department of Home Affairs (2020) Australia's Cyber Security Strategy 2020.

2 Desjardins, J. (2019) A Visual History of the Largest Companies by Market Cap (1999-Today) Visual Capitalist Visual Capitalist. Accessed 27/06/2021 https://www.visualcapitalist.com/a-visual-history-of-the-largest-companies-by-market-cap-1999-today/

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4 Zakrzewski, C. (2021) The Technology 202: The Senate approved a massive investment in U.S. tech competitiveness, The Washington Post. https://www.washingtonpost.com/politics/2021/06/09/technology-202-senate-approved-massive-investment-us-tech-competitiveness/

5 Tobin, F. (2017) China's strategic plan for a robotic future is working: 500+ Chinese robot companies, The Robot Report.. https://www.therobotreport.com/chinas-strategic-plan-for-a-robotic-future-is-working-500-chinese-robot-companies/

6 Müller, Christopher; Kutzbach, Nina: World Robotics 2020 – Industrial Robots, IFR Statistical Department, VDMA Services GmbH, Frankfurt am Main, Germany, 2020.

7 King, R. (2021) Professional Engineering Graduates by Branch of Engineering, Australian Council of Engineering Deans ACED Report May 2021.

8 Müller, Christopher; Graf, Birgit; Pfeiffer, Kai; Bieller, Susanne; Kutzbach, Nina; Röhricht, Karin: World Robotics 2020 – Service Robots, IFR Statistical Department, VDMA Services GmbH, Frankfurt am Main, Germany, 2020.

The development of robotic technologies in Australia will lead to the creation of new companies, new jobs and will address a range of issues of national importance including our ageing population, servicing regional and remote communities, and dealing with labour shortages, such as those generated by the COVID-19 pandemic.

Dr Sue Keay
Chair, Robotics Australia Group

2

Trust and Safety

As autonomy in robotics increases, trust in safety and assurance processes systems is more important than ever

2.1 Introduction

As robots become widespread, digitally connected, and implemented in increasingly autonomous settings, existing safety and assurance processes will be challenged across industries. To continue to make progress and innovate, ensuring that these systems have been designed responsibly and robustly will be key to safeguarding trust.

While not a definitive guide, this chapter explores existing and emerging frameworks, research, and methods in robotics in Australia promoting trust and safety in robotics and autonomous systems (RAS) with increasing artificial intelligence (AI), collectively referred to as 'RAS-AI'.

While automation and automation safety has been a feature across industries in Australia for decades, the scope of tasks automated systems can complete has been enabled by the growth of digital, networked technologies and artificial intelligence. This transition – from primarily human-operated to increasingly system or machine-operated systems – has necessitated new ways of thinking. Predicting and mitigating failures must take into account not only technical failures – such as errors in sensor measurements or system decision paths – but also human errors, both in robot design, and in interacting with robots.

> As robotics become increasingly semi-autonomous or autonomous, the technical issues for trust and safety magnify.

This chapter considers existing processes, systems, research methods and policies and those emerging required to continue to make progress in RAS-AI. To that end we examine gaps in trust and safety between what currently exists, and what may be required in the future. As robotics become increasingly semi-autonomous or autonomous, the technical issues for trust and safety magnify.

Regulating trust and safety

Existing regulatory domains: Just as new assurance methods are needed for varied technological developments, reform of how regulators operate will also be needed. The law requires that risk be minimised by engineering first, before reliance on administrative controls, i.e. human behaviour.

Workplace health and safety regulations in Australia require that risk controls "so far as is reasonably practicable" be applied. This directs technologists to standards for methods of achieving safety by design.

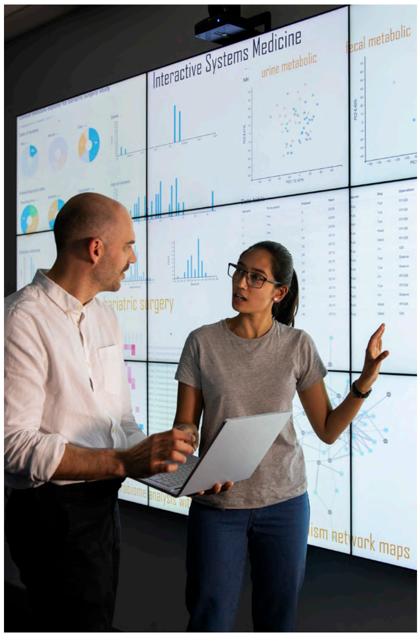
Robotic standards and regulation: We may need more than ISO standards in order to evolve rapidly enough to manage assurance of robotic autonomous systems.

Agile and Adaptive Regulation: We need to approach regulation differently if we are to successfully adapt current regulation to autonomous systems. Regulation will never keep pace with technology, therefore regulation and codes of practice refer to use of the latest standards for guidance to achieve safety, so far as is reasonably practicable.

Human values

Designing democratic AI: we need to find a way to represent human values in AI – can we embed ethics in code?

Using systems approaches to design robots: exploring designing for trust through trans-disciplinary systems methods incorporating humanities and STEM (STEAM)[1].



AUTONOMOUS AUTOMATED AI-ENABLED: WHAT'S IN A NAME?

As the breadth and application of semi-autonomous and autonomous systems continues to expand, the definitions of these terms evolve. There is no general consensus on these terms across disciplines. There are a few reasons for this: one being differing industry needs and approaches to describing and regulating systems nationally and internationally; the other being that some of these terms have histories and applications that predate robotics.

In 2018, the US Society of Automotive Engineers (SAE) Standard J-3016 addressed this complexity directly in defining a taxonomy and levels of automation for self-driving vehicles. The SAE observed that "autonomous", a term long used in robotics to describe systems with the ability and authority to make decisions independently, had broadened to encompass entire system functionality, becoming synonymous with "automated" (section 7.1). In doing so, the term "autonomous" came to obscure dependencies systems can, and do, have on communication and cooperation with other entities, e.g. for network connectivity or data collection, or maintenance. Recognising that outside of robotics, the term "autonomy" also referred to a capacity for self-governance, the SAE observed that automated driving technologies fell short of that definition of autonomy, even when operating at level 5 – full driving automation – they still operated based on algorithms and subject to the commands of users (e.g. to go to a destination). As such, the SAE elected not to use the term "autonomous" in their taxonomy, preferring to describe five defined levels of automation.

Notwithstanding the complexity of the term, there are continuing efforts to establish a framework for levels of robot autonomy in human-robot interaction.[2] In this chapter, we recognise the popular usage of the term "autonomous" to **describe systems operating independently or semi-independently in conditions of significant uncertainty**. Automation refers to the execution of a pre-defined task within an environment of high certainty.

For brevity, throughout this chapter, the terms 'autonomous robots' or robotics, autonomous systems and artificial intelligence 'RAS-AI' will be used interchangeably to refer to both semi and fully autonomous robots. We define system assurance as providing justified confidence that increasingly autonomous systems will perform reliably and robustly, which includes safe operations.

2.2 Safety and assurance

There is a long history of safety in the robotics industry. The landscape is continually changing, as new technologies emerge, societal expectations change, and incidents happen. In some heavily regulated industries, safety is highly sophisticated, such as industrial robotics in car manufacturing. In emerging industries, where safety is physical and digital, there is under-investment in systems safety.

There are several well-developed ISO and IEC standards for safety-related control systems for machines and machine specific standards including robots, AGVs and other vehicles – see Appendix A: Standard and/or project under the direct responsibility of the ISO/TC 299 Secretariat (Standardization in the field of robotics, excluding toys and military applications). For the industrial robot sector (ISO 10218 series) these have already been adopted as Australian Standards under the primary machine safety standard series AS4024.

The safety control system standards base the control system design on risk variables and lead to architecture changes in the control system as the risk increases. At the higher levels of risk this requires redundant controls with fault detection. This approach for machine safety control systems has been in place for around 25 years. International standards are also in place for service and personal care robots. Similar standards are in place and evolving for autonomous and self-driving vehicles. Current safety standards in certain industries are evolving but need investment to extend their application to new environments, use across industries, and for more than one purpose.

Robotic safety is often ensured by limiting operations to protected spaces. So, for example, drones are tested in indoor areas with mesh nets to prevent either drone or human error, but also to reduce the workload associated with bespoke regulatory compliance. Self-driving vehicles are tested with cautious collision-avoidance thresholds. “Robot Wars” robots are encased in thick Perspex gladiatorial arenas so that human spectators are safe from shrapnel or collisions. Humans are kept apart from robots in operation wherever possible to limit the risk of harms from accidental errors – either internally driven within the robot, human error, or due to unexpected environmental constraints. Nevertheless, collaborative robots are increasingly used across industry. The application of this type of robot allows humans to work beside them without physical guarding. The term “collaborative robot” has been widely debated, since a low speed, low force robot can still cause harm dependant on the end effector. Therefore, this term is evolving to become “collaborative application”.

Mechatronics Engineers Rhys McKercher and Tim Cassell Remotely Operate UFRloader. Image courtesy of Universal Field Robots.

Best practice safety management focuses on *system safety*.[3] System safety refers to risk management of an engineered system that enables balancing of safety and operability. Systems safety applies systems engineering and systems management to identify and manage hazards in systems. It enables a systems-level risk analysis for products or services.

Safety Management Systems (SMSs) are the natural expansion of system safety concepts to an organisational level. ICAO describes an SMS as, 'a systematic approach to managing safety, including the necessary organisational structures, accountabilities, policies and procedures'.[4] A particular emphasis of SMSs is to imbue an organisation with a safety culture, which is 'the way safety is perceived, valued and prioritised in an organisation. It reflects the real commitment to safety at all levels in the organisation'[5]. Whilst these processes (system safety and safety management systems) are proven to drive better safety outcomes, the underlying guidelines, standards and practices associated with automation and autonomy do not exist, and is an active area of research.

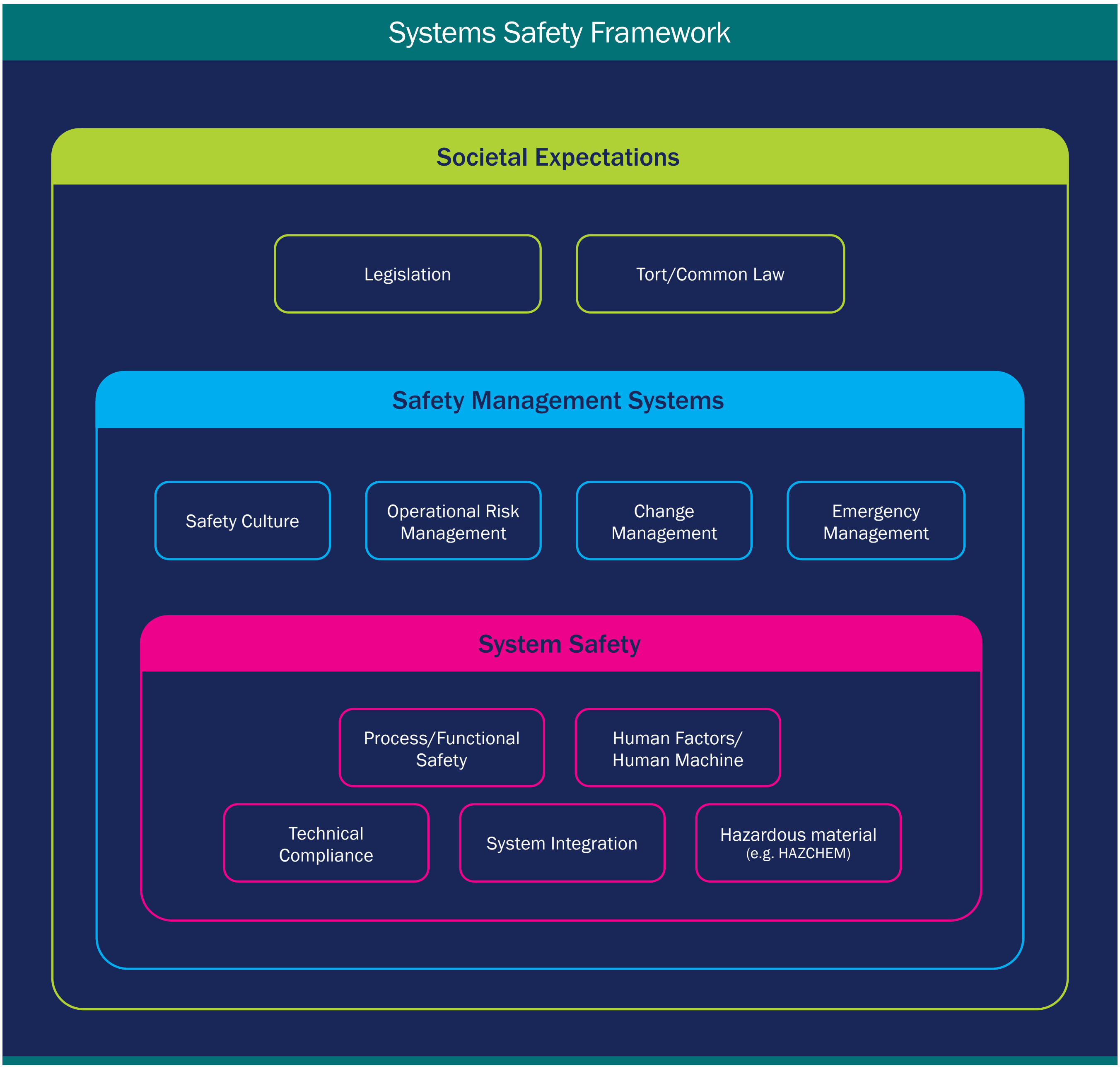


TABLE 1 DEFINING SYSTEM SAFETY

Components of system safety	
Functional safety	The part of overall safety that depends on safety functions, the use of hardware and software or firmware, to minimise risk and keep people and assets safe (e.g., obstacle detection, collision avoidance)
Human factors	The role of people within broader systems and how the system can influence human performance. It is considered in the design of the interface between people and system, including processes, screen design and workload
Systems of systems	How complex systems interact dynamically. A system safety approach deals with the complex behaviours resulting from their interactions
Interactions between disciplines	Consideration of how parallel disciplines such as operational safety management, cybersecurity, resilience, change management, emergency management, and occupational health and safety interact with system safety
Evolution over time	The exploration of how systems evolve over time and how to maintain safety throughout this evolution
Systems integration testing	Critical to the overall safety of the system of systems, model-based testing can be applied to alleviate some of the difficulty of “in the field” testing
Other administrative controls	There is a host of other administrative controls that are essential to confirm safety of an automated system

What system and functional safety protect	The safety of the system relies on
• Safety of operator and maintainer • Safety of other vehicle operators • Safety of any person in the vicinity of operation • Asset loss from damage to truck or collision with other vehicles • Environmental spills through damage	• Safety in design • Engineering controls • Periodic testing of safety functions • Reliability of the system • Competence • Well-understood failure modes • Periodic testing of safety functions • Clear roles and responsibilities • Products and their development • Ongoing maintenance and monitoring • Effective change management

2.3 Emerging issues in assuring autonomous robots

The assurance of RAS-AI is a complex problem, increased by conditions of uncertainty.[6]

Autonomous robots differ from most machines because of the computational components that lead to their intelligence and control. They also differ from most existing software systems because of their integration with physical machines. RAS-AI relies on observations perceived by sensors to decide how they should behave and control themselves, which is then translated to actuators, enabling robots to change behaviour, or state, and change in response to their physical environments.

A reliable and robust autonomous robot must be able to plan and make strategic decisions about behaviour and control, despite enduring uncertainty plaguing the physical world. At the very least, these systems must be able to handle the following three types of uncertainty – non-deterministic effects of actions; partial observability due to errors and limitations in a system's sensors and perceptions; and lack of information about the environment and its dynamics.

The enduring nature and variety of uncertainty affects all components of an autonomous robot, prompting the need to assure a system at a range of levels.

Algorithms

Algorithms are computational methods that govern how an autonomous robot processes sensor data and makes decisions about its behaviour and control, so as to operate reliably and robustly to achieve pre-specified tasks[7] Assurance for this component implies the need for approaches that could account for uncertainty and provide a useful guarantee of the quality of the solution proposed, and the required computational resources to compute the solution, including time and memory. State-of-the-art algorithms in autonomous systems evaluate the effects of actions prior to execution via simulation. Such approaches raise questions as to how to develop high-fidelity simulators, and how to bridge the potential discrepancy between simulators and the real world. Moreover, the high computational cost of running a high-fidelity simulator has raised questions as to whether multi-level fidelity could be used to provide the necessary quality assurance while keeping computational cost low.

> The high computational cost of running a high-fidelity simulator has raised questions as to whether multi-level fidelity could be used to provide the necessary quality assurance while keeping computational cost low.

Software

It is important to differentiate between algorithms and their software implementations. Poor implementation of powerful algorithms will result in poor performance of an autonomous robot. Therefore, developers need to follow good software engineering practices. Software creation for safety related control systems of industrial robots is well described in standards such as IEC61508 and the machine specific version IEC62061. In aviation, the standard used for software design assurance onboard crewed aircraft is RTCA DO-178C (and associated supplements). Furthermore, software testing should include whether the implementation of an algorithm satisfies the properties of the algorithms, both in terms of correctness and computational complexity. Examples of dangerous faults due to poor programming practices are abundant, including the unintended acceleration issue in Toyota vehicles, causing fatal crashes and a recall of multiple Toyota models.[8]

Hardware components

New types of hardware, such as soft and compliant robots, pose new difficulties in assurance. Such hardware is designed to increase safety. However, the dynamics of these robots depend on the interaction between the robot and their environments, which in turn raises questions on how to properly assure such machines.

Integrated robotic system

This assurance should ensure the system remains reliable in the event that one or more of its components are erroneous, including on seemingly minor issues, such as when the battery is low. System safety processes, such as SAE Aviation Recommended Practice 4761,[9] are being updated to focus on the complex interactions between systems, rather than at the subsystem level.

Assurance requirements pose multifaceted issues

1

Novel technical approaches for those assurances are required. The ability for users to easily update algorithms and software, which alters the performance of a system, implies that traditional machine assurance performed prior to deployment or sale, will no longer be viable. Moreover, the high frequency of updates implies that traditional certification that requires substantial time will no longer be practical.

To alleviate these difficulties, automation of assurance will likely be needed – something like 'ASsurance-as-a-Service' (ASaaS), where APIs constantly ping RAS-AI to ensure abidance with various rules, frameworks, and behavioural expectations. There are exceptions to this, such as in contested or communications denied environments, or in underground or undersea mining, and these systems need their own risk assessments and limitations imposed. Indeed, self-monitors are already operating within some systems.

2

The assurance process will require stakeholders to possess sufficient technological and computational skills. Therefore, to ensure safe operation of future robotics systems, Australia needs to educate and prepare its technology developers, certifiers, and general population for more sophisticated assurance processes.

3

What would be the suitable regulatory environment for autonomous systems? The next section deals with the existing regulatory environment for various domains and how this is evolving, or needs to evolve, with the introduction of more autonomous systems.

2.4 Regulation in air, maritime and land

The regulation of RAS-AI in Australia is different depending on whether a system moves on land, flies in the air, or travels on or under the sea. Each domain has faced different levels of uptake in RAS-AI, and has different regulatory challenges.

Arguably, the most developed is in the Air domain, with CASA facing an ever-increasing variety of flying robots. Land, with the greatest risks of human harm and most diverse rule-sets per state, is perhaps the least advanced when it comes to allowing RAS-AI on public roads – noting that the land domain does have some of the most sophisticated robots deployed in sectors such as mining in remote locations on private land, and agricultural applications such as autonomous tractors, harvesters etc. Maritime has its own opportunities and challenges. There are fewer humans on the sea than on land, reducing the risk of RAS-AI, but there are also greater communication challenges, such as those faced by submariners.

Maritime domain

The Australian Maritime Safety Authority (AMSA) is the Australian authority responsible for maritime safety, protection of the marine environment from pollution, and search and rescue. As part of these responsibilities, AMSA regulates vessels operating within Australia's Exclusive Economic Zone (EEZ), including vessels capable of autonomous and remote-controlled operation.

The laws, Marine Orders, and standards that apply to all commercial vessels were written for traditional crewed vessels, but remotely operated and autonomous vessels must also comply with them. As the uncrewed vessels generally cannot comply with the design, construction, equipping and survey requirements applied to traditional vessels, and there are no tailored standards available to use, operators must seek exemptions in order to operate. This reliance on exemptions may not be feasible beyond the short term, due the administrative burden and delays it creates for operators and AMSA.

AMSA's challenge is to adapt long standing regulatory and operational arrangements to provide for the safe operation of uncrewed vessels, in a way that will be effective in the short, medium and long term. AMSA is taking a collaborative approach and is actively engaging with leaders and key stakeholders in the fields of autonomous and remotely operated vessel design, technology, operation, and regulation. These stakeholders include TAS, which has a program underway to explore assurance of autonomous systems and identify accreditation pathways. AMSA will leverage its experience and that of its stakeholders, to identify the best way to provide effective regulation, ensure the safety of people and vessels, and protect the marine environment in Australia.

Once an improved regulatory approach is implemented, the assurance and accreditation process will be streamlined, provide a more appropriate match of risk to regulatory overlay, and it will no longer be a barrier to the uptake of emerging technology in the maritime domain.

Air domain

The Civil Aviation Safety Authority (CASA) is the Australian authority responsible for the regulation of civil aviation, including uncrewed aircraft.

CASA's classification hierarchy for Uncrewed Aircraft Systems (UAS) (see below).[10]

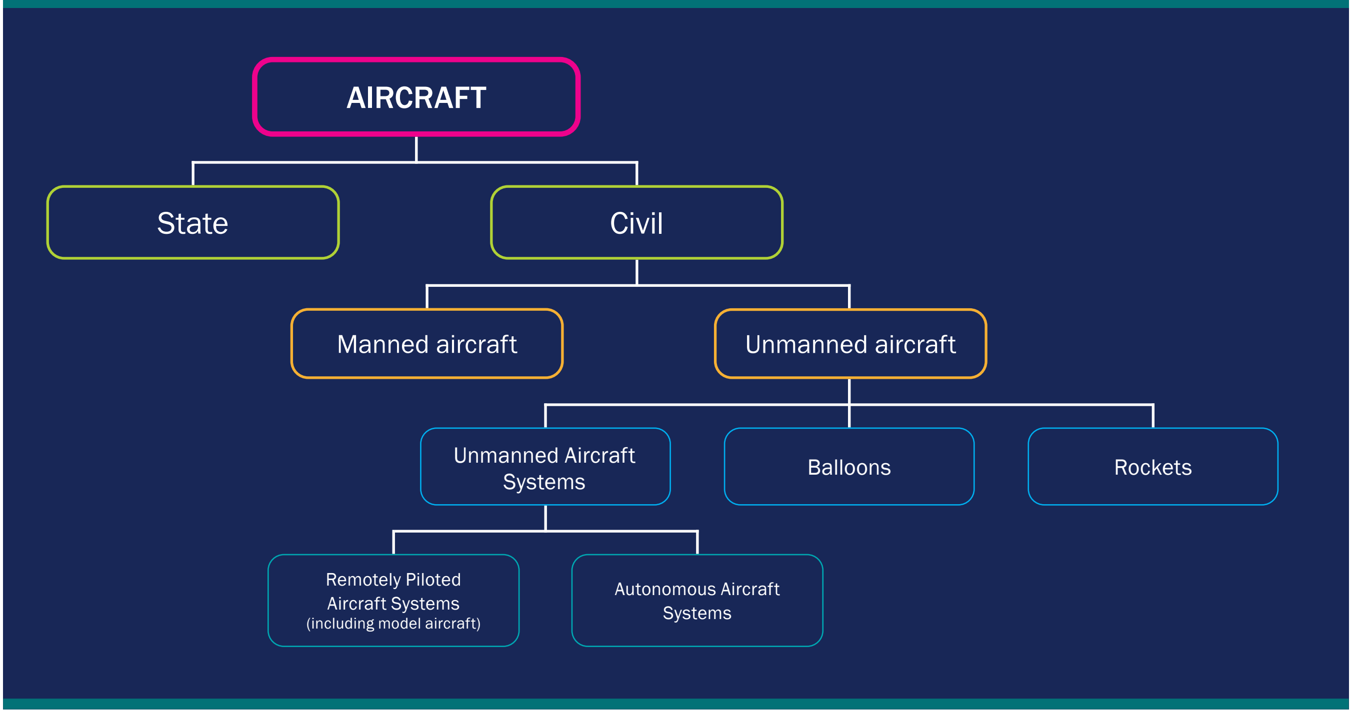
Remotely Piloted Aircraft (RPA) are included in the Civil Aviation Safety Regulation Part 101 (Uncrewed Aircraft and Rockets), and are the subject of CASA guidance material. While there is a regulatory provision specifying that a person cannot release an autonomous aircraft without approval from CASA (regulation 101.097 of CASR 1998) there is no specified content for Autonomous Aircraft Systems (AAS). Current practice sees the requirements for RPA applied to all UAS, without reference to level of autonomy or correspondingly graduated requirements. Therefore, it can be implied that the existing guidance is a blanket set of standards for all RPA, ranging from remotely piloted hobbyist drones to fully autonomous aircraft flying in civil airspace.

This lack of graduated approach will pose a challenge for CASA, as the needs and requirements of an RPA being controlled by a human will differ dramatically to that of a fully autonomous aircraft. The human-in-the-loop component will influence a number of elements, including communication interface, visual capabilities, potential safety risks, intent, etc. As autonomous aviation technology continues to progress, a more robust regulatory framework will need to be developed in parallel.

A benefit of the current regulatory framework is that it is extremely risk based: one of the overarching requirements to operate outside of the standard operating conditions is to ensure that there is no adverse risk to aviation safety. Guidance to ensure that the regulatory requirements are met is found within the Joint Authorities for Rulemaking on Uncrewed Systems (JARUS) Specific Operations Risk Assessment (SORA) process, which CASA has adopted as a risk assessment methodology for uncrewed aircraft.[11]

An additional challenge will be safely and responsibly integrating autonomous aircraft with crewed aircraft, such as regular passenger transport (RPT) services. At this stage, RPA usually operate in low-level segregated airspace. However, with the anticipated expansion of the industry it can be foreseen that RPA and crewed aircraft will eventually need to operate within the same airspace, considering the full breadth of possible applications of autonomous aircraft, e.g. medical services, delivery services, passenger transport, etc. A common communication interface between RPA, crewed aircraft and air traffic controllers will be required for safe and seamless integration of autonomous aircraft in the existing civil aviation system.

CASA's classification hierarchy for Uncrewed Aircraft Systems (UAS)[12]



Land domain

Private land: mining

The mining industry is highly regulated, due to the significant safety risk. As the robotics industry grows, and more robotic applications are developed or applied, the concept of safety by design is critical to the success and growth of industry. There are many lessons, experiences, and collaborations across industry sectors in the field of robotics and autonomous capability.

Australia's deployment of autonomous production drills and Autonomous Haulage Systems (AHS) in key locations like the Pilbara over the last 25 years is world-leading in large scale adoption and use of autonomous vehicles.

The relationship between the mining companies and the regulator in Western Australia is strong and there was a proactive effort by the mining companies to engage early on establishing a code of practice to be used by the industry.[13] This guide is now used all over the world – it has even been quoted by mine operators in the Oil Sands of Canada as being "the Bible for safe operations of autonomous equipment".

Functional safety, as originally defined in IEC61508, is a key component of systems safety and has been actively adopted by the leading mining companies that have deployed autonomous systems (Autonomous Haulage Systems and Autonomous Drilling). The Global Mining Guidelines Group recently published a guideline for applying functional safety to autonomous systems in mining, which originated from the work on the Implementation Guideline for Autonomous Systems (version 1, version 2 is currently in development).[14]

This guideline outlines layers of an overall autonomous operating environment, and although this has come from a mining sector perspective, it can be applied across the board to a wide variety of robotic capabilities. There is a consideration from a product lifecycle perspective, and how this interacts with the specific operating environment – the application lifecycle.

Public land

While the licensing and operation of motor vehicles is regulated at a state and territory level, there is Federal oversight, particularly at a broader policy and reform level. The National Transport Commission (NTC) and Austroads are instrumental in the development of Australia's policy in relation to RAS-AI for land transport. However, they have advisory capacity only and cannot make regulation or enforce compliance.

Some of the key organisations involved in the policy and reform for autonomous vehicles are set out in the table on the following page.

Automated vechicle decision making and priority setting[15]

Transport and Infrastructure Council

Makes decisions on national reforms to improve the efficiency and productivity of Australia's infrastructure and transport systems. Sets national reforms priorities. Current priorities include removing barriers to innovation and capitalising on new and emerging technologies.

Transport and Infrastructure Senior Officials' Committee

Advises and assists the Transport and Infrastructure Council on all non-infrastructure priorities.

Australian Government Automated Vehicle Roles and Responsibilities

Department of Infrastructure, Transport, Cities and Regional Development	National Transport Commission	State and territory transport and road agencies	Austroads
Office of Future Transport Technology Co-ordination across portfolios. Land transport technology policy framework and action plan. **Vehicle Safety Standards Branch** Importation and first supply of automated vehicles. Review of Australia Design Rules. International standards harmonisation.	Develop and propose national law reform to enable the commercial deployment of automated vehicles. Current automated vehicle reforms: • In-service safety for automated vehicles • Government access to vehicle generated data • Motor accident injury insurance and automated vehicles	Responsibilities include: • In-service vehicle regulation • Vehicle registration • Road rules and driver licensing • Road management • Approval/regulation of automated vehicle trials	Conducts road and transport research to inform policy development and guidance on the design, construction and management of the road network and its associated infrastructure. Current automated vehicle projects: • Infrastructure changes to support automated vehicles on rural and metropolitan highways and freeways • Pavement marking for machine vision • Integrating advanced driver assistance systems in driver education

In addition to the above stakeholders, the Australian Road Research Board (ARRB), an Australian/New Zealand government research and advisory organisation, is heavily involved in this field. In 2016, ARRB established the Australian New Zealand Driverless Vehicles Initiative (ADVI) which has over 180 members from industry, governments, academia, and international organisations.

The NTC, working with the various stakeholders, is leading an Automated Vehicle Program, with the goal of providing end-to-end regulation to support the safe commercial deployment and operation of automated vehicles at all levels of automation in Australia.

The current taxonomy for levels of automation is based on the Society of Automotive Engineers (SAE) International Standard J3016 (see table below).

The SAE Standard sets out the differing levels of control required from either a human driver or an automated driving system, or combinations of both, at each specific level of automation. Levels 3 and 4 highlight the shifting responsibility for control and/oversight of the Automated Driving System (ADS) and is where problems (legal and otherwise) for failure to warn, or failure to heed warnings, situate.

The most significant challenges identified by the NTC are based on unknowns around vehicle automation, including:

- The timing of deployment
- Applications that will be deployed
- The mix of technologies that automated vehicles will use
- How automated vehicles will change vehicle ownership and business models.

In order to address these challenges, the NTC aims to ensure that:

- Reforms are outcomes based, with safety as the key outcome, allowing industry to determine how best to achieve those outcomes
- Reforms are neutral as to the technologies, applications and business-models that industry develop
- Reforms are nationally consistent and internationally aligned.[16]

The ARRB predicts that the likely future land transport and mobility environment will be an ecosystem of operations under the current prescriptive regulatory and operational requirements, together with a variety of automated and autonomous operations in private, public and commercial transport permissioned under a safety assurance system.

Readiness for uptake of RAS-AI in Australia requires changes in technology as well as infrastructure (signals, signs and lines, pavements, lighting, connectivity, data security, etc), drivers and other road users (education, licensing, including the “autonomous driving entity”), and regulation and operational frameworks (drivers’ licences, parking policy, overtaking, gap setting and traffic movement protocols, accident investigation, national traffic information dataset, data custodians, etc).

Levels of vehicle automation[17]

	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
VEHICLE'S ROLE	Nothing	Accelerates and breaks OR steers e.g. cruise control	Accelerates and breaks AND steers e.g. automated reverse parking	Everything, only under certain conditions e.g. specific locations, speed, weather, time of day	Everything, only under certain conditions e.g. specific locations, speed, weather, time of day	Everything
HUMAN DRIVER'S ROLE	Everything	Everything but with some assistance	Remains in control, monitors and reacts to the driving environment	Must be capable of regaining control on request when vehicle is driving	Nothing when vehicle is driving, but everything at other times	Nothing

2.5 Robotics standards and regulation

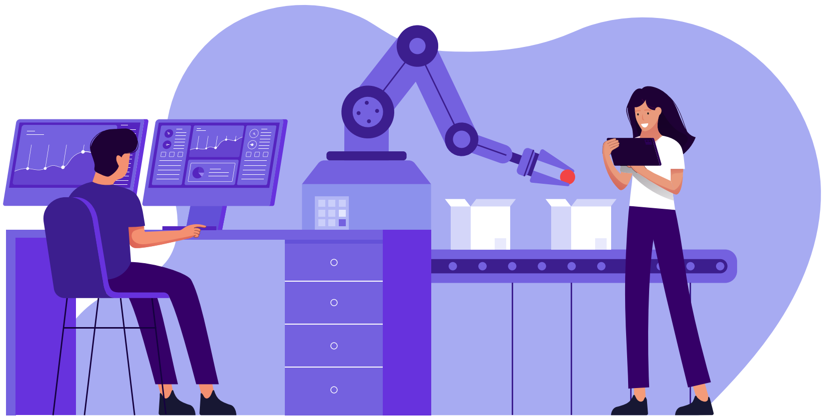
Frameworks to systematically and efficiently accredit RAS-AI do not yet exist, as evidenced through domains briefly explored in the previous section and emerging for new domains. Existing standards and assurance mechanisms may not be suitable for autonomous systems as they may either require human operators to be in constant control, or for robots to be kept physically separated from human operators (e.g. industrial robots).

As we have seen, technology is regulated differently depending on the sector. Currently, there are many standards and regulations emerging to govern robotics and software systems. ISO standards, for example, give assurance to industries and the community that they can trust products that have met those standards. There are a number of ISO standards applicable to robotics – see Appendix A.

The ISO group responsible for global robotics standards is ISO/TC 299.[18] At this stage, these standards cover safety requirements for industrial robots and robot systems. They are relevant to robot manufacturers, integrators and users. The standards provide good guidance for industrial robots, along with some guidance for personal care robots and medical robots. What these standards do not cover are the more diverse robotic industries and robotic software and learning systems. Software development for functional safety of industrial control systems is covered in IEC61508, IEC62061 and ISO 13849-1.

Specific assurance frameworks for different technology types are made more complex by the regulatory frameworks and legal definitions inherited from domains where they are deployed.

The challenge for the Australian robotics industry is to identify, adopt and promote trust and safety frameworks that align to a manageable assurance framework, are accepted by society, and are pragmatic for robotics industries to incorporate and abide by.



A number of initiatives and models have been proposed, or are being explored, to illustrate notions of trust and safety in autonomous systems. Some industries have *trust marks* that indicate that various security and safety requirements have been met. Trust marks have been proposed as measures to encourage more responsible technology design practice, e.g. in relation to sensitive data sharing.[19]

As mentioned earlier, ASsurance-as-a-Service (ASaaS) is a "helicopter parent" approach to trust, where an API constantly pings a robot in operation and requests status updates with regards to what it is doing and why it is doing it. ASaaS could contribute to challenges identified in previous sections where a rapidly changing robot operates independently in an uncertain environment. An effective and robust communications network might allow for faster intervention if a robot did behave outside the parameters of authorised operations.

It may be that more than discrete new kinds of interventions, a complete re-evaluation of existing regulatory approaches, might be needed.

> The standards provide good guidance for industrial robots, along with some guidance for personal care robots and medical robots

2.6 New ways of thinking about regulation

In order for the robotics industry to thrive, a regulatory response that adapts, protects, engenders community trust, while accounting for rapidly evolving industrial environments, is essential. This is an area where investment can lead to improved outcomes for the whole robotics sector, and position Australia as a world leader.

The current regulation of autonomous and remotely operated vehicles requires in-depth regulatory engagement, meaning it can take much longer than usual for a manufacturer or operator to get approvals from the relevant authorities. As noted above, existing laws and regulation of land and aerial vehicles, and maritime vessels rely on a human operator to be responsible for the platform, and for the platform to meet specifications intended to provide for human, platform, and environmental safety. Robotic platforms must therefore seek exemptions from some or all of current requirements to operate.

> Modern approaches are moving towards being risk based, responsive, and anticipatory.

The exemption process can be long when the operator does not understand the regulatory framework, does not have prior operational data to illustrate safe operations, and the regulator does not understand the platform or the technology that will enable safe operation. This is exacerbated when an operator identifies the use of an AI-based system to mitigate an operational risk but does not explain how it works or provide evidence of its efficacy.

While traditional regulatory approaches could be characterised as prescriptive and inspection based, often reacting to problems that have occurred, more modern approaches are moving towards being risk based, responsive, and anticipatory, proactively taking opportunities to support positive innovation. Where a regulator needs to rely on exemptions, because the regulatory framework cannot keep pace with technology, it is an indicator that change is needed.

The future of adaptive regulation will mean changing the existing processes of regulation and the factors that might be considered as relevant to the regulatory process. Technologies are no longer based on highly deterministic systems. Regulators will need to consider society's appetite for risk and ethical expectations. To this end, Australia has adopted ethical AI principles that facilitate dialogue and design of robots — see Appendix B: Australia's AI Ethics Principles

The concept of anticipatory regulation is inclusive and collaborative, future-facing, proactive, iterative, outcomes-based and experimental – see below.

Central to the concept of anticipatory regulation is a focus on "co-design", where the regulator and industry work together to co-design standards and regulations that are fit for purpose and achieve the required outcomes. This approach focuses on the system and

Anticipatory regulation[20]

A system is safe when people can rely on it not to harm them and others, or damage things they care about.

how to influence it. It is consistent with the concept of regulatory stewardship, whereby regulation is seen as an asset managed proactively and collaboratively to help things happen effectively. If Australian safety regulators could incorporate such approaches, and work towards becoming adaptive regulators, it may dramatically improve their ability to keep pace with technological change.

Designing democratically legitimate AI systems

Trust, safety and assurance are all values that depend on other values as well as reliable critical infrastructure.[21] People can trust a system when they believe that it will act in conformity with shared values as well as being technically robust. A system is safe when people can rely on it not to harm them and others or damage things that they care about. A system provides assurance when it provides robust evidence of its safety and trustworthiness. To design robotic systems with Trust, Safety, and Assurance in mind there is still basic research needed to design such values into automated systems more generally.

But which values? How can morally justified robotic systems be designed, given how much moral disagreement there is in society?

Designing automated systems holistically for trust and safety

Complex learning systems today carry a range of hardware and software safety issues to consider, as acknowledged in 'Emerging Issues in Assuring Autonomous Robots'. Considering direct harms that could arise from complex learning systems, as well as indirect harms or unexpected consequences, necessitates new, creative ways of thinking about sustaining safety and trust.

The 3Ai, an innovation institute based at the Australian National University and founded by Distinguished Professor Genevieve Bell, is exploring ways in which cybernetics – the transdisciplinary framework that influenced disciplines as diverse as systems engineering, artificial intelligence and management science in the mid 20th century – could be extended or revised to account for complex learning systems today. While cybernetics has itself undergone several transformations, its central preoccupation with feedback loops – both within technical systems, and between systems and their physical, human and bureaucratic environments – provide an interconnected, nuanced way of exploring complex concepts like "trust" and "safety".

Establishing and communicating that a system is "safe" invokes a range of interventions and practices, touched on across this chapter – laws, regulations and standards; audit, verification and validation processes; forms of independent monitoring and review; workplace training and process; and broader safety culture. Cybernetics, and the range of disciplines 3Ai staff come from – including systems engineering, nuclear physics, computer science, medical anthropology, journalism and data science – have enabled 3Ai to explore the connections between these practices. 3Ai combines science, analytics, history and art to explore complex systems.

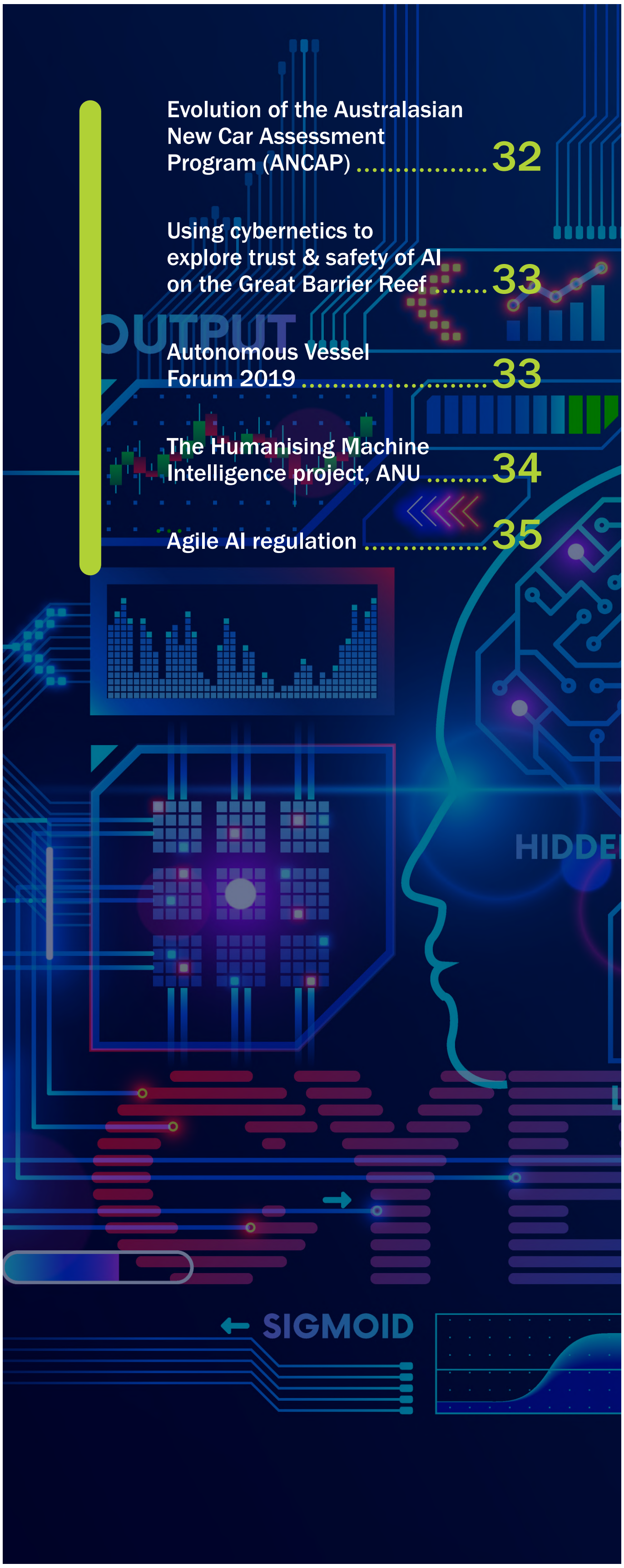
2.7 Conclusion

Robotics in Australia has a long history of conforming with safety standards and risk managed practises.

This chapter articulates the current state of trust and safety in robotics including society's expectations, safety management systems and system safety, as well as emerging issues and methods for ensuring safety in increasingly autonomous robotics.

The future of trust and safety will combine standards with iterative, adaptive and responsive regulatory and assurance methods for diverse applications of RAS-AI. Robotics will need novel technical and social approaches to achieve assurance, particularly for game-changing innovations. The complexity of RAS-AI calls for transdisciplinary collaboration across technical, scientific and humanities disciplines, as well as outreach to stakeholders of human-RAS-AI interaction.

Case studies



Evolution of the Australasian New Car Assessment Program (ANCAP)

When autonomous robots become consumer products, reliability and robustness must be conveyed in an accessible manner to consumers. An example of such information is the ANCAP rating for passenger vehicles. Aside from helping consumers, such a rating increases the safety standard of the entire industry: From 2002 to 2014, the percentage of vehicle types sold in Australia with a 5-star ANCAP rating has grown from 0% to 75%, as car manufacturers attempt to ensure the competitiveness of their vehicles.

It seems natural to bring such safety ratings to autonomous robots, however, this is not easy. Existing rating mechanisms were designed for slowly changing systems. In contrast, autonomous robots depend on algorithms and software that learn and adapt their output regularly. Work has started on developing a more suitable rating mechanism for autonomous robots, such as the Euro NCAP Driver Assistance Systems and a project of the ANU in collaboration with York University in the UK, under the Assuring Autonomy International Programme.

Many other issues and potential solutions are being explored, compiled, and developed as a Body of Knowledge for the Assurance of Robotics and Autonomous Systems, including questions on who should perform the test and how often? A balance between convenience and reliability is necessary, which includes considering what kind of training should be provided to the evaluator and what level of expertise would be suitable? Higher requirements mean fewer qualified evaluators, increasing the difficulty for regular re-testing.

AEB (car-to-pedestrian) Toyota Hilux. Image courtesy of ANCAP.

Using cybernetics to explore trust & safety of AI on the Great Barrier Reef

With the Australian Institute of Marine Science (AIMS), 3Ai explored the design and implementation of automated underwater systems monitoring the health of the Great Barrier Reef. 3Ai explored the influences behind this transition to more autonomous technology in addition to the impact on the practices and expectations of AIMS as an organisation.

The Great Barrier Reef Marine Park is one of the world's largest marine protected areas, and the proper management and protection of this world heritage site, across an area the size of Italy in conditions that are often challenging, requires AIMS to continue to improve its monitoring and data collection practices. AIMS is exploring using above water and underwater cyber-physical systems to monitor the reef environment without increasing human involvement.

3Ai combined interviews with AIMS scientists and technicians with origin stories, organisational discourse analysis and critical systems heuristics to explore the design and deployment of automated systems. 3Ai and AIMS have been exploring a range of effects, including relationships between trust in data collected by automated systems, as compared with data traditionally collected by humans.

3Ai observed that a human diver's lived experience, the ability to draw on common sense to identify mistakes, engendered a degree of trust in diver collected data that resulted in an inherently higher level of confidence and trust in comparison to the automated equivalent.

SeaSim at AIMS uses models of ocean conditions to automatically simulate conditions in tanks, in order to observe coral behaviour.
Credit: Roslyn Budd, image courtesy of AIMS.

Autonomous Vessel Forum 2019

The Autonomous Vessel Forum 2019 explored the challenges, opportunities and risks in regulating autonomous and remotely operated vessels. Hosted by the Australian Maritime Safety Authority, in partnership with TAS, the Autonomous Vessel Forum 2019 saw 135 domestic and international experts from industry, academia, navy, and government, come together to share their knowledge and learnings in automation and digitalisation.

The Autonomous Vessel Forum 2019 marked a positive step towards regulator and industry collaboration to ensure thorough testing, trials and safe use of the systems, infrastructure and technology gaining traction in Australia's maritime industry. The forum also reinforced the vital roles that professional seafarers will continue to have in Australia's maritime industry.

The key forum themes were: Collaboration and partnership; Environmentally-friendly solutions and commercial efficiency; Better safety for people and protection of Australia's marine environment; Understanding risks and implementing risk controls for remotely operated and autonomous vessel technology; Building assurance in the behaviours and functions of a system; Enabling testing, trials and safe failure; Flexibility and objective-based solutions; Seafarers are essential to the success of automation and remote operation; Regulating the need to detect, respond and recover from a cyber-attack.

Ocius Bluebottle on Lake Burley Griffin at the Autonomous Vessel Forum 2019. Image courtesy of Ocius.

The Humanising Machine Intelligence project, ANU

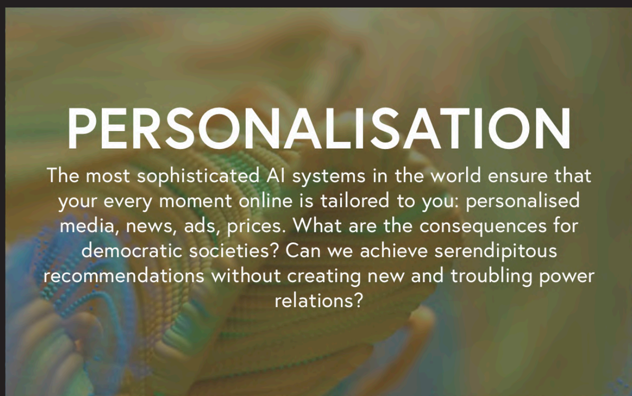
The Humanising Machine Intelligence (HMI) project at ANU aims to provide actionable, theoretically well-grounded answers to the moral questions faced by designers of AI and robotic systems. Its guiding principle is that we should select the values designed into AI systems by invoking society's existing methods for resolving other evaluative conflicts — namely democratic deliberation and debate. Its core research task is to unite the multi-disciplinary expertise needed to both identify the salient values, and implement them in highly complex AI and robotic systems.

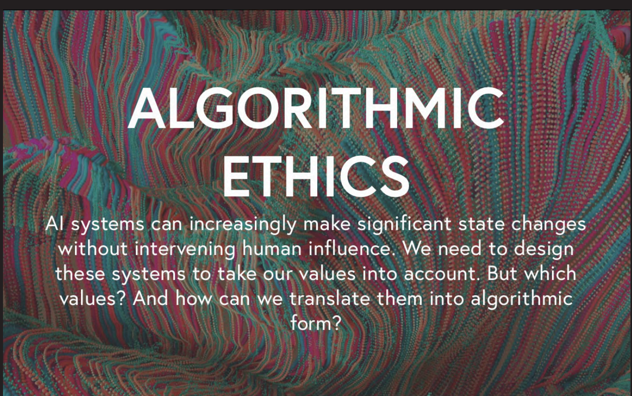
HMI draws on expertise in computer science, philosophy, political science, law and sociology. Its research has focused on four key themes—governance of and by AI systems; the role of AI in personalising online services and the implications for privacy, autonomy and other values; the challenge of modelling moral considerations in a manner that can be implemented within planning and machine learning systems; and a novel approach to human computer interaction, drawing on sociology and philosophy as well as traditionally associated fields.

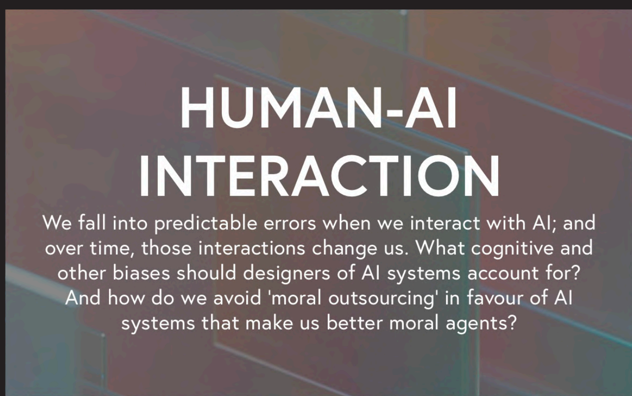
In each research area, the project combines empirical, theoretical, and technical approaches, drawing at each stage on guidance from the others. The project starts with empirical disciplines explicating the opportunities and risks associated with particular applications of data and AI. Theoretical disciplines then provide the moral diagnosis of that empirical data, and articulate both what we should be aiming at, and how to resolve fundamental theoretical questions that must be answered for technical implementation to be possible. Technical disciplines then build on this to create democratically legitimate data and AI systems.

The Humanising Machine Intelligence project focusses on four key research themes: Automating governance, personalisation, algorithmic ethics and human-AI interaction.[22]

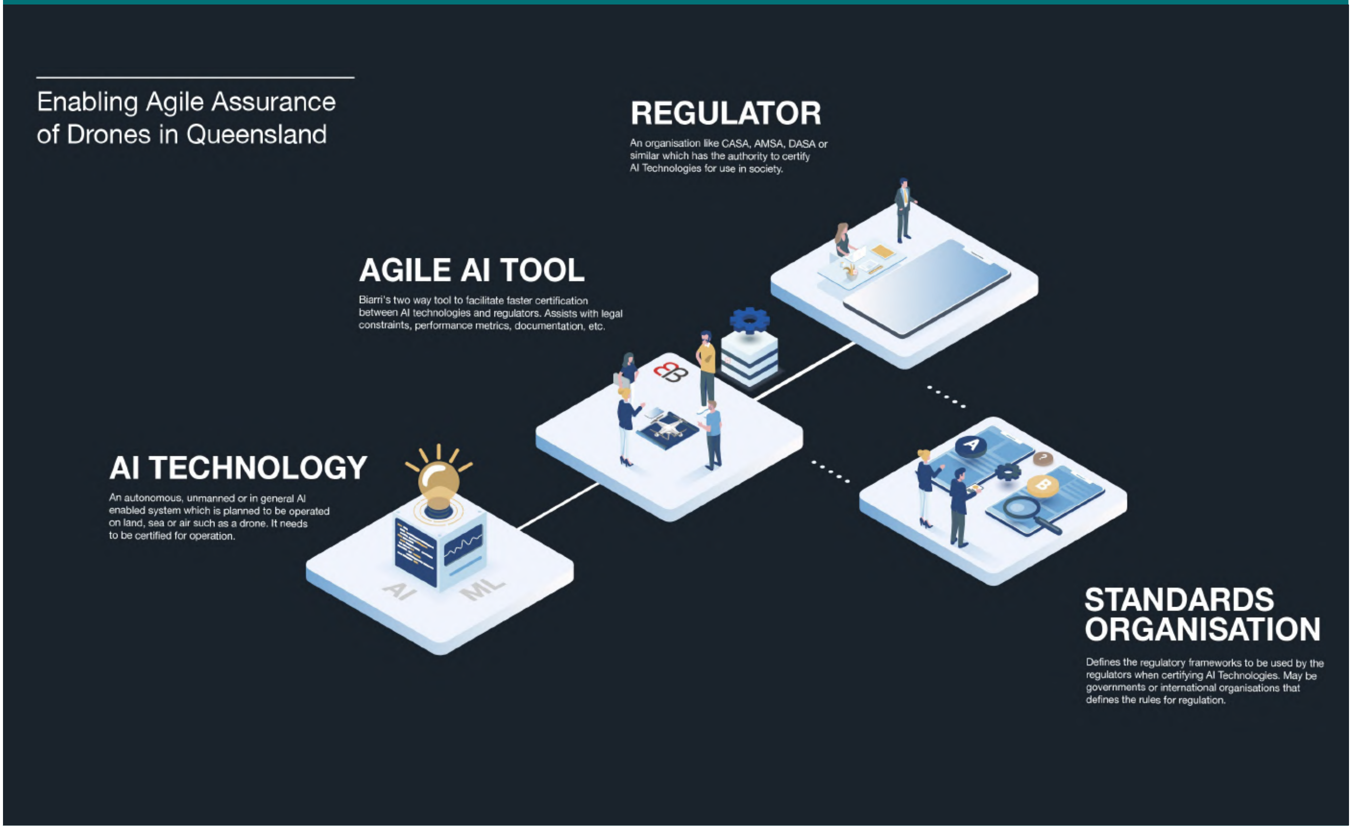
RESEARCH







Agile AI regulation



Trusted Autonomous Systems and QUT Law are developing digital tools for faster innovation cycles for AI enabled products by speeding up the development, certification and assurance of robots and autonomous systems in highly regulated industries. Currently, certification and assurance processes can take years in several industrial sectors such as aviation, maritime and more. Coupled with low sales volumes in such industries, this can significantly stifle growth and innovation. Therefore, a need exists for a set of software tools which accelerate and simplify entire certification processes – via leveraging digital platforms which are tailored to the requirements of regulating AI enabled products. These types of software tools have revolutionised many other industries and so the timing is right to disrupt the regulation industry via digital transformation. By enabling more innovation, such tools can catalyse the next wave of autonomous systems to solve large scale global challenges.

The emergence of AI systems suggests two challenges for the future of robotic safety. The first is the immediate context around regulating the application of novel AI technologies that drive robotic and autonomous systems. This, on the surface, is about identification of desirable outcomes and ends, and the deployment of an appropriate mix of regulatory strategies directed to those outcomes and ends. However, the emergence of AI is more significant. AI enabled robotic systems have the potential to be an important regulatory strategy in their own right. This second challenge has been the focus in recent computational law literature examining how AI enabled systems can be developed as regulatory instruments.

QUT Law sees this project as highly innovative as it is located exactly at the nexus between the regulation of AI and AI as regulation. This extends to a variety of fields. First it connects to recent work on smart and agile regulation; through examining how to build automated digital systems that allow confidence and trust between regulators and regulatees; in this project – specifically between the AUX innovators and transport safety regulators. Second, it engages with the core project of computational law on the theory and practice of translating established legal forms into digital platforms through the process of digitalising Australian maritime safety regulations. Third, it will explore how sandbox design and concepts familiar in the “fintech” space, could be used to enhance confidence and trust between AI transport innovators and Australian regulators.

The Agile AI tool will connect the regulated and the regulator for faster assurance of AI.

Contributors

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Chapter can be viewed on arxiv https://arxiv.org/abs/2104.06512 and referenced as Devitt, S., Horne, R., Assaad, Z., Broad, E., Kurniawati, H., Cardier, B., Scott, A., Lazar, S., Gould, M., Adamson, C., Karl, C., Schrever, F., Keay, S., Tranter, K., Shellshear, E., Hunter, D., Brady, M., & Putland, T. (2021). Trust and Safety. ArXiv, abs/2104.06512.

Footnotes

1 Bernstein, J. H. (2015). Transdisciplinarity: A review of its origins, development, and current issues

2 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5656240/ .

3 According to NASA, “System Safety is the application of engineering and management principles, criteria and techniques to optimize safety within the constraints of operational effectiveness, time, and cost throughout all phases of the system life cycle”: https://sma.nasa.gov/sma-disciplines/system-safety.

4 Annex 19 to the Convention on International Civil Aviation, 2nd Edition, ICAO 2016

5 https://www.skybrary.aero/index.php/Safety_Culture.

6 It is arguable that autonomy only exists under conditions of uncertainty – otherwise it is automation: See generally, Hussein A Abbas, Darryn J Reid and Jason Scholz (Eds) Studies in Decision and Control 117 (Springer Open, 2018).

7 See EASA/Daedalaen paper on Learning Assurance, which details issues associated with certain machine learning algorithms and a learning assurance process https://www.easa.europa.eu/document-library/general-publications/concepts-design-assurance-neural-networks-codann.

8 Toyota Unintended Acceleration and the Big Bowl of “Spaghetti” Code. https://www.safetyresearch.net/Library/BarrSlides_FINAL_SCRUBBED.pdf, 7 November 2013.

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12 CASA Advisory Circular AC101-01 v3.0 “Remotely piloted aircraft systems – licensing and operations” published December 2019. https://www.casa.gov.au/sites/default/files/101c01.pdf.

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15 NTC Automated Vehicle Program, National Transport Commission, October 2019. https://www.ntc.gov.au/sites/default/files/assets/files/NTC%20Automated%20Vehicle%20Reform%20Program%20Approach%20%28October%202019%29%20-%20Public%20version.pdf.

16 National Transport Commission, Automated Vehicle Program, (October 2019) 7.

17 National Transport Commission, Automated Vehicle Program, (October 2019) 8.

18 ISO Technical Committee (TC) 299.

19 https://www.alrc.gov.au/publication/for-your-information-australian-privacy-law-and-practice-alrc-report-108/31-cross-border-data-flows/trustmarks/.

20 Anticipatory regulation see Nesta – formerly National Endowment for Science, Technology and the Arts. https://www.nesta.org.uk/feature/innovation-methods/anticipatory-regulation/

21 See arguments pertaining to networks, data, systems in The Department of Home Affairs Consultation Paper ‘Protecting Critical Infrastructure and Systems of National Significance’ (Aug 2020) https://www.homeaffairs.gov.au/reports-and-publications/submissions-and-discussion-papers/protecting-critical-infrastructure-systems

22 https://hmi.anu.edu.au/research.

3

Construction

A pre-pandemic study done by the McKinsey Global Institute states that 44% of work within the construction sector has the potential to be automated while using human labour solely for essential tasks[1]

Cathal O'Rourke
Hub Managing Director
Laing O'Rourke Australia

3.1 Foreword

The Australian construction sector, like many others, has experienced significant disruption from the COVID-19 pandemic. At Laing O'Rourke, we have been lucky to be able to continue to operate across many parts of the country through a combination of remote working, digital collaboration, and strict adherence to COVID Safety Plans.

As we continue to move into this new way of working, we believe it is essential to use technology as an enabler for increased productivity, efficiency and keeping our people safe, while continuing to deliver excellence to our clients. We see the introduction of robotic technology as a key driver in accelerating our capabilities during this unprecedented time of investment in the construction infrastructure.

Australia is a world leader in robust, reliable, and capable robotic solutions and Laing O'Rourke has continued investment in robotic and peripheral technologies to accelerate our skills in this space. Examples of this include the deployment of fully autonomous vehicles on site, using artificial intelligence to assist in site diary management and claim documentation, and the spin out of a startup which delivers an advanced sensing and perception system for situation awareness.

Our investment in robotic technologies will continue to grow as we move towards our 2025 mission to become the recognised leader for innovation and excellence in the construction sector. The technology surrounding artificial intelligence, machine learning and rugged field robotics is advancing at a pace that we can now utilise robotic solutions to create real, tangible value for our industry.

We are excited about the enormous potential for new technologies to help us overcome some of the significant challenges facing our sector and our broader community. As we continue to adjust to living and working in a COVID-19 world, we believe robotic solutions play a key role in driving greater outcomes for all our people, supply chain, delivery partners and clients.

Cathal O'Rourke
Hub Managing Director
Laing O'Rourke Australia

Snapshot | Construction: What's changed since 2018?

A study covering 54 countries and 78% of the global labour market states that 44% of work within the construction sector has the potential to be automated while using human labour only for essential tasks.[1] The global construction market is expected to reach $16.6 trillion by 2025, growing at a CAGR of 7%.[2] Robotics can solve the construction skills shortage if handled well.[3]

Strengths[4, 5]

- Governments investing in large-scale infrastructure projects
- Robotics systems already in use
- Use of drones and autonomous vehicles for tasks
- Construction-focused venture capital firms + start ups

Wins

- Sector is opening its opportunities to robotics and automation
- Leadership from within driving change forward
- Australian companies are penetrating this sector
- Significant venture funding and government support
- American-founded companies have launched operations in Australia

New opportunities[4, 5]

- Develop more prefabrication facilities locally
- New technologies in the industry = less reliance on imports
- Reduced staffing levels on site is an opportunity to experiment with robotics, automation and remote operations
- Opportunities in the realms of sensing and perception for application such as situational awareness, inspection, asset tracking, and quality assurance
- Significant interest in embracing new technologies
- Opportunities in the realms of data interpretation and decision making
- Opportunities in the realms of physical systems for direct work whether it be assembly, remediation, construction, earthworks

Challenges

- Sector is highly risk averse
- Extreme regulatory requirements
- Subcontractors – increasing contractual risk
- Highly fragmented structure
- Rising prices for material and labour
- Pressures and associated penalties
- Project-based and hence "siloed" operations
- Large and complex legacy systems
- Likely severity of failure
- Thin profit margins
- Complexities in delivering change management for personnel

Realistic 5—year goals

- 3D printing of construction material on site
- Large scale autonomous earthworks
- Drone-based large physical size and time history site awareness
- Robotics systems for inspection, quality assurance, building elements, prefabrication, scaffolding, and rebar cage preparation
- Use of simulations to train workers either onsite or offsite

3.2 Australia's construction industry

Construction is worth $360b to the Australian economy (9% of GDP) and employs almost one million people.[6] The sector is heavily fragmented, with more than 369,000 businesses operating in the industry, which covers heavy industry, civil construction, residential and non-residential building, structure and completion services and installation trade services.

The largest single entity in the sector, CIMIC Group Ltd, owns two major construction companies, Leighton and Thiess, and has substantial engineering services across every sector. Despite this, CIMIC accounts for only a 2.6% share of overall revenue.[6] Most businesses in the sector are small-scale non-employer companies made up of sole proprietors and partners. The contribution of microbusinesses (0-4 people) to IVA (industry value added) in construction has grown by 13.8% during COVID-19 while the IVA contribution of small businesses (5-20 people) has shrunk by 19.3%.[7] This contraction in company size, but increase in number, of businesses involved in construction presents a considerable opportunity for cross-organisational boundary initiatives with few large single entities to resist disruption.

While construction remains labour-intensive, technology is increasingly being integrated in construction processes although core technologies have not changed significantly over time due to hesitancy within the industry and the associated regulatory bodies. Instead, incremental changes have occurred in construction design, management techniques and materials used. Building information modelling (BIM) software is used to control time, cost and design, while computer-aided design (CAD) and computer-aided manufacturing (CAM) are applied to precision manufacturing of buildings and components. There is also a continuing trend towards greater use of subcontracting of trade services as well as a shift from onsite construction to onsite assembly and installation of prefabricated products such as concrete slabs and metal building frames.[6]

BuiltView, the newest technology from Laing O'Rourke's innovation group, uses a dedicated 360° camera and bespoke platform to create an immersive virtual site access. Image courtesy of Laing O'Rourke.

Construction companies have increasingly been demanding employees with TAFE or apprenticeship qualifications, rather than relying on traditional on-the-job training. The introduction of new technologies has lengthened the working life of many skilled tradespeople, as technological advances have reduced the physical demands of some occupations. Construction is the most gender segregated industry in Australia, with a low ratio of women to men (1:8), which has worsened over the last 20 years (in 1998 13.8% of the construction workforce was female compared to 12.0% in 2018).[8] It is also the largest employer of young full-time workers (aged 15 to 24), which has some benefits in terms of changing company mindset towards acceptance of digital innovation.[9]

Despite a strong safety culture, construction remains a dangerous industry with 150 worker fatalities in 2015 and more than 14,000 claims of work-related injury.[10] This is down 54% compared to 2007, however, the number of fatalities and serious injuries is thought to be lingering around this number, albeit with year to year variation. Construction sites are busy places. Many contractors work side-by-side, in noisy and distracting environments all while heavy vehicles come and go. In this environment, consultation, cooperation and coordination are essential to ensure the health and safety of everyone on site.

3.3 Impact of COVID-19

Before COVID-19 the construction industry was driven by growth in apartment and non-residential building, while demand for non-building construction diminished. These trends have been reversed by the pandemic. COVID-19 negatively impacted the demand for new houses and apartments, reflected in the 3.4% decrease in the value of building work done in Australia from 2018-19 to 2019-20.[11]

However, construction has shown the most significant increase in GDP (4.4%) since COVID-19 – driven by a 6% increase in dwelling construction, 3.1% increase in building construction, and 1.5% rise in heavy and civil engineering construction driven by investment in infrastructure (roads, bridges, railways etc).[12] Supply chain disruptions for construction equipment, building materials and skilled labour have negatively impacted the industry, which has had to adjust operations to comply with physical distancing during the pandemic.[6] In general, construction is considered an essential industry and has operated through lockdowns but often with significantly reduced numbers of staff on site.

Construction has shown the most significant increase in GDP (4.4%) since COVID-19 – driven by a 6% increase in dwelling construction, 3.1% increase in building construction, and 1.5% rise in heavy and civil engineering construction due to investment in infrastructure.

3.4 Robotics and the construction industry today

The global construction industry is considered poor at fostering and adopting innovation as it is highly fragmented and there is low tolerance for risk. In Australia, innovation is restricted to some of the large building companies which tend to explore downstream innovations where they control the supply chain, and hence can directly benefit from the innovation. For example, Laing O'Rourke owns an offsite precast concrete business.[13] Many construction companies choose not to invest in R&D as it is hard to create standardised solutions that can be applied across a large number of projects.

While construction is generally considered a laggard compared to other industries in adoption of new technologies, there was $100m investment in construction technology startups in Australia in 2016-17 alone.[9] These startups serve as an addition to internal efforts from tier one construction firms, tackling issues that can be addressed without requiring high capital costs. Some of these new technologies include: computer vision systems for improved worker safety; 3D printing of building materials (and buildings); use of drones for site inspections, progress monitoring and hazard identification; autonomous heavy equipment; and robotics and augmented reality/virtual reality for onsite/offsite training of personnel.

> Through the introduction of new technologies, the working life of many skilled tradespeople can be increased.

Robotic systems are being used in construction for a variety of applications including: autonomous earth-moving; materials handling (robotic cranes and mobile robots); materials shaping; structural joining (assembly); and robotics 3D concrete printing. Often automation is divided between prefabrication tasks (offsite) and structural joining (onsite).[14] These applications are driven by the need to reduce costs while simultaneously increasing consistency, predictability, environmental sustainability and safety.[9]

The main driver for the application of robotic technologies in the construction sector is to reduce injury and fatality rates. Injuries can often be caused by an inability to see obstacles, and robotics can help with the identification of objects to reduce safety incidents. In recent times, Australia has experienced a decline in productivity in the construction sector which can be reversed through clever application of robots and automation.[15] Due to the scale of many construction projects, even a small improvement to the efficiency of a process can result in a substantial cost saving. Australia's strength in field robotics (the application of robotics in large, unstructured outdoor domains) can also be applied to improving the increasingly poor productivity in the sector, allowing the collection and interpretation of complex real-time data to enable performance towards outcomes to be measured across difficult environments.

> Robotic technologies in the construction sector can reduce injury and fatality rates.

Robotics and automation also provide a more repeatable, consistent, precise and uniform quality product[16] that involves less waste and can be offset by renewable energy schemes.[17] There is an ongoing skills shortage in the construction industry. Through the introduction of new technologies, the working life of many skilled tradespeople can be increased as they can offload repetitive manual tasks to machines, and many of their skills can be at least partially encapsulated within robotic systems for ongoing use. The adoption of robotics and automation, if it follows similar trends seen in the resources sector, will also increase the take-up of construction roles, increase the number of women and the younger generation of future workers in the construction sector, and increase participation by older workers.[17]

3.5 The future of robotics in the construction industry

The use of advanced robotics to enable autonomous construction is expected to be important in the future to speed up construction in a reliable and safe way. Global trends show increased demand for construction and demolition robots, with Australia seeing a doubling in unit sales between 2018 and 2019.[14] Construction sites, unlike factories, still face the challenge of being unstructured, cluttered and congested, making them challenging for robots to operate in.

The advent of new technologies allowing customisation, rapid take-up of additive manufacturing processes, networked manufacturing equipment and increasing data integration, means that construction robotics is getting closer to being adopted. Robotics is also increasingly seen as an enabler for architectural design, allowing custom, one of a kind, sometimes additive, built-up, complex structures.

> Advances in underpinning technologies will continue to see robotics tackling increasingly complex physical and cognitive tasks.

The trend towards the automation of heavy machinery, reported in the Robotics Roadmap for Australia 2018, has continued in the pursuit of improving the safety and efficiency of construction operations, which involve complex tasks in a range of unstructured environments. Motion control, navigation, computer vision and other typical robot technologies are becoming more ubiquitous in previously crewed platforms (e.g. cranes). Advances in underpinning technologies will continue to see robotics tackling increasingly complex physical and cognitive tasks.

The strong industry need for regulation technology (RegTech) persists and will be instrumental to enable robotic and vision systems that can be deployed to monitor and enforce worker safety, and identify and ameliorate potential hazards.

Construction is predominantly an operational excellence business where every bit of excess must be trimmed and every process optimised – the thin margins within the sector necessitate that things are done better, faster and for less.

Construction, at its core, is a group of relatively smaller tasks that are designed, planned and sequenced to converge into a physical, built outcome.

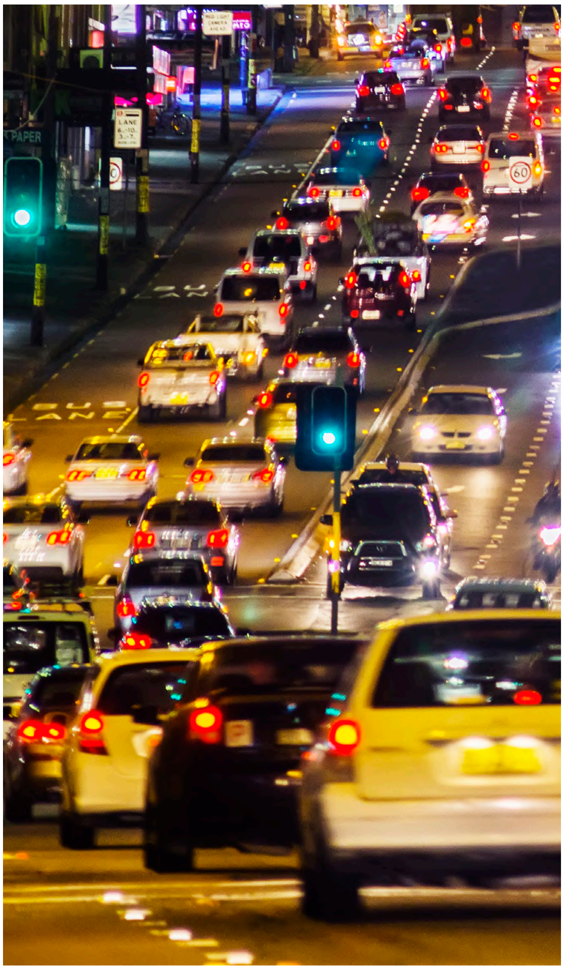
These fundamentally intertwined tasks encompass considerations from the perspectives of business, technical, and human – social, workers and community. As such, the formulation of potential solutions to construction industry needs must be cognisant of this and adequately service these perspectives. For instance, solutions without clear advantages to the core business, task outcome and operational realities around its execution, have perhaps insurmountable barriers to widespread adoption into business-as-usual. The likelihood of widespread adoption is also low if workers are perturbed, feel threatened, or perhaps simply don't see the benefit or utility of the offering.

3.6 Main findings for robotics in the construction industry

Australia's population (currently 25 million) is set to increase by 11.8 million people over the next 30 years, and our buildings and infrastructure will need to expand to cater for this increased population. Australia's construction sector faces many future challenges including an increasing and ageing population, expensive housing, a shortage of social housing, urban sprawl, increased congestion, changing climate, and security risks.

Robotics will help to overcome these challenges by providing a cost-effective and safe means to build, manage, maintain and decommission structures, especially in remote areas. Advanced robotic technologies play a crucial role in reducing injury and fatality rates and improving productivity.

Typical robot technologies such as motion control, navigation and computer vision are increasingly integrated into previously crewed platforms, and advances in technology will see robotics tackling increasingly complex physical and cognitive tasks. There will also be a strong industry need for regulation technology and robotic and vision systems that can be deployed to monitor and enforce worker safety, and identify and ameliorate potential hazards. Robotics is increasingly seen as an enabler for architectural design allowing custom, one of a kind, sometimes additive, build-up of complex structures.



Case studies

Robotics in architecture and custom construction

Founded in Brisbane in 1992, UAP is an international specialist manufacturer focusing on large scale public artwork and custom architecture. UAP collaborated with the Innovative Manufacturing Cooperative Research Centre (IMCRC) in the Robotic Vision Project, with the core goal of utilising vision enabled robotic polishing to pre-polish the cast bronze panels prior to welded assembly.

A 10m long cast bronze sculpture of smooth flowing form was an excellent candidate for robotic polishing as the traditional process of polishing by hand is labour intensive and comes with a health risk due to repetitive strain. By using vision technology to map the sculptural surface on the fly and reconfiguring a COBOT arm to perform robotic polishing, UAP aim to achieve considerable time and cost savings on large scale polishing activities. Leveraging this newly developed technology will also unlock team members to work on higher skilled areas. This development project is ongoing at UAP with the aim of scaling the system to multiple COBOTS working as a team and extending vision enabled robotic manufacture to other capabilities such as plasma cutting and potentially surface texture creation.

UAP Forman, Greg Delchau and Head of Finishing, Matteo Fantini working on vision enabled robotic polishing of bronze with a UR10 COBOT from Universal Robotics. Image courtesy of UAP photography by Edwina Fox.

Who is Laing O'Rourke's Technology & Innovation group?

Australia is embarking on an unprecedented period of investment throughout the construction sector. Governments are investing billions into large-scale complex infrastructure across the country, and demand is only expected to increase.

While this is a unique opportunity for the sector, this record number of projects in the pipeline will place increasing pressure on skills, productivity, and quality control, impacting an already encumbered industry.

Laing O'Rourke is committed to transforming the construction industry through leveraging the experience of our people and purposeful technology to deliver certainty for our clients.

As an industry leader in innovation, we see robotics as playing a critical role in the transformation of our sector and have continued to invest in new technologies that make our sites safer, our people more productive, and our delivery more efficient.

One of our recent ventures is the Toolbox Spotter, an artificially intelligent computer vision system designed to eliminate accidents on site through seeing, understanding, and communicating dynamic site operations in real-time.

Due to the overwhelming success of ToolBox Spotter, the product has since rolled out to portfolio company, Presien, with Laing O'Rourke as minority shareholder. The next iteration of Toolbox Spotter, now known as Blindsight, is currently undergoing field trials where it is expected to continue to support site safety across heavy industries.

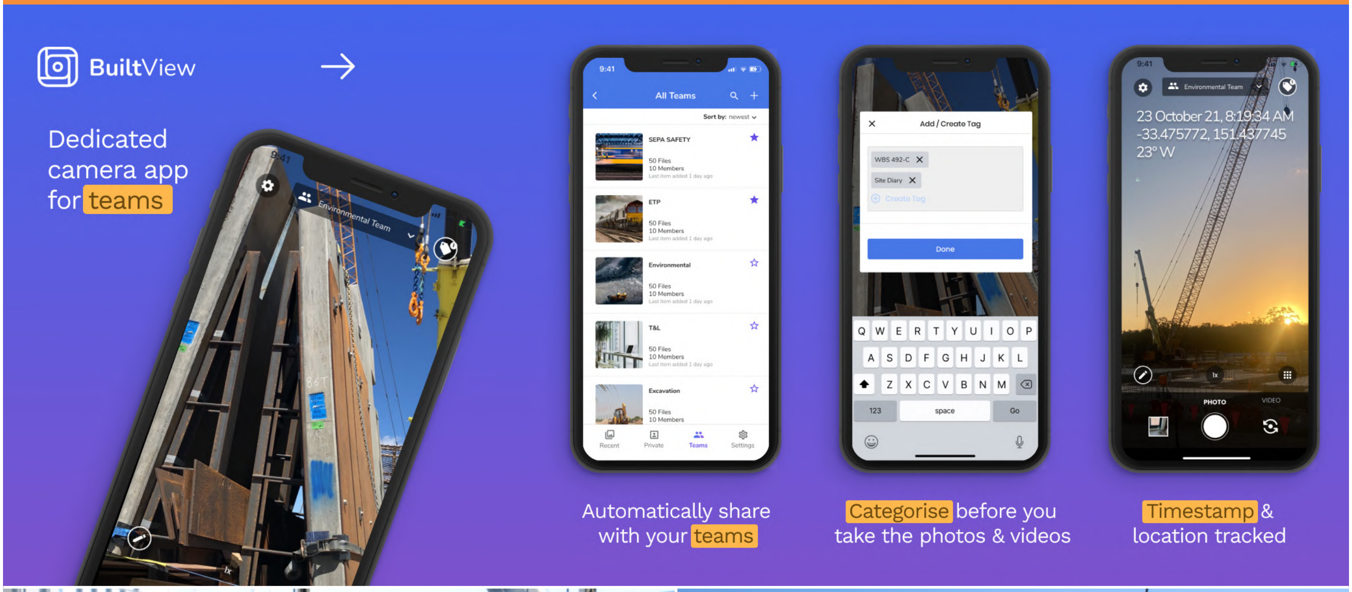
We have also leveraged robotic principles like artificial intelligence and machine learning to help our people stay safe and productive amidst the restrictions during the COVID-19 pandemic.

BuiltView, an in-house tool, developed in response to pandemic restrictions, provides virtual site access to our people and clients across our projects, delivering real time data to our teams located at home or in the office across the country. Since restrictions have eased in most parts of Australia, this tool continues to support a more flexible way of working for our people.

Advances in robotic vision in the Australian construction sector will provide safer, more fulfilling jobs as the industry continues to deliver essential infrastructure for our communities. Delivering a roadmap for such developments, we believe, is an essential step forward for the future of Australian infrastructure.

Image courtesy of Laing O'Rourke.

Sensing and perception technology set to solve productivity problems in Construction



Requirements for complex infrastructure and buildings are growing. Now more than ever we need to find new ways to create efficiencies and drive productivity to continue to deliver at the rate that is necessary. For an industry that has averaged just 1% productivity growth each year over the last two decades, this proves a significant challenge. Laing O'Rourke is tackling productivity challenges by leveraging artificial intelligence for virtual site walkthroughs.

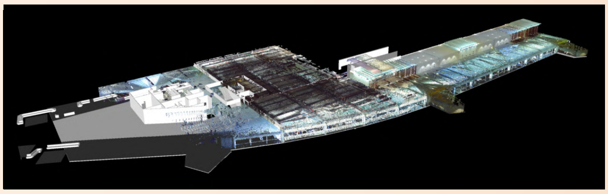
BuiltView is the dedicated camera app for construction teams, creating access to site irrespective of location. Within the BuiltView app, users can capture photos and videos, or handheld, car mounted, or drone mounted 360° cameras. Footage from site activity is stored on a centralised, sharable platform and, using special tags and markers, videos can be easily interrogated and shared with stakeholders. BuiltView drives faster project decisions with clear and actionable data. Site teams can automate daily planning of subcontractor resourcing, plant, and materials to maintain project momentum. Construction managers can track progress against the schedule by automating calculation of key construction metrics. Quality managers can inspect defects virtually, removing the need to travel to site, reducing program delays.

Left: BV360 makes site diaries simple, workers can simply walk through site, talking about progress and BuiltView does the rest. Image courtesy of Laing O'Rourke.

Upper-right: BuiltView, the newest technology from Laing O'Rourke's innovation group, uses a dedicated 360° camera and bespoke platform to create an immersive virtual site access. Image courtesy of Laing O'Rourke.

Lower-right: BuiltView drives faster project decisions with clear and actionable data. Image courtesy of Laing O'Rourke.

Construction tool to solve quality assurance issues



Global spending on rework in the trillion-dollar industry of construction is estimated at $570b of direct costs and $440b indirect costs. The cost of rework is on the rise, with half of project cost increases due to rework, mainly caused by quality deviations in design and construction. Advances in digital engineering technology provide a solution to this; through analysis of digital twins, quality defects can be identified before they impact the construction program.

Laing O'Rourke is trialling a new digital platform to automate deviation analysis by comparing site captured point clouds against the digital engineering model. Through seeing the as-built construction status and comparing it to the digital design, BIM Compare can quickly identify objects that are out of tolerance, allowing the opportunity to rectify before it impacts the construction program.

Deviation analysis can be conducted consistently throughout the project lifecycle, producing almost real-time quality reporting and ensuring the integrity of the project at every stage. BIM Compare can identify defects in completed elements such as floor flatness, structural, precast and MEP. Through rapid quality feedback, project managers can be certain that any quality defects are identified, keeping projects on time and within budget.

BIM Compare - the newest construction tool that recognises and evaluates out of tolerance works to solve quality assurance issues. Image courtesy of Laing O'Rourke

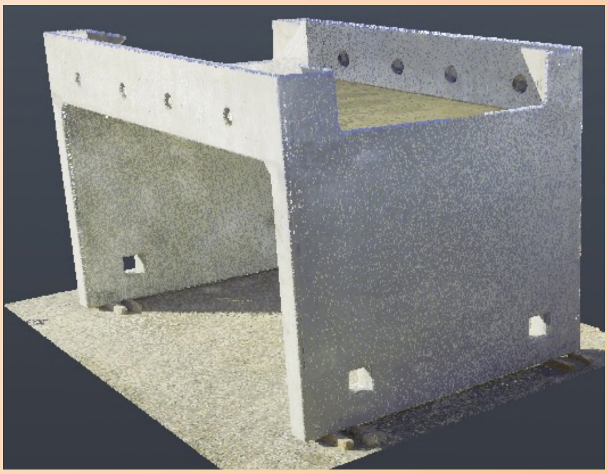
Manufacturing tool used to validate offsite components, creating big savings in DfMA

Quality assurance is essential to Design for Manufacture and Assembly (DfMA) - each component must be built within specification prior to leaving the factory. Unfortunately, this is often not the case. Issues are identified after field installation, creating extensive wasted costs in component build, logistics, and installation. This poses a significant challenge for the construction industry. Laing O'Rourke is responding to this challenge with BIM Compare, an automated deviation analysis tool that has been trialled to support inspection and defect detection before leaving the warehouse.

BIM compare uses industry-leading algorithms and advanced LiDAR technology to automatically compare point clouds with design models to rapidly identify and categorise out-of-tolerance components. By automating manual processing, BIM Compare makes quality assurance effortless, ensuring smarter, faster and more accurate assembly. Through seeing the as-built component status and comparing it to the digital design, BIM Compare can immediately identify components that are out of tolerance, allowing the opportunity to rectify before it impacts the assembly program.

Using BIM Compare, Laing O'Rourke realised significant cost savings from 40 bridge culverts on a $200m road bridge project. By detecting defects in a single culvert before leaving to site, BIM Compare allowed for the quick rectification of the precast elements prior to attempting to install 40 of the same elements.

Using BIM Compare in the design of bridge culverts. Image courtesy of Laing O'Rourke.



Deployment of fibre optic sensors with applied AI to optimise infrastructure maintenance

Traditional methods for structural monitoring have relied on visual inspection, costly gauges that have limited duration and scheduled maintenance as opposed to as-required basis, resulting in excess labour and resourcing. Through a partnership between University of Sydney, and Cambridge University, Laing O'Rourke pioneered an Australian-first deployment of novel fibre optics technology on a post-tensioned footbridge to assess real-time structural behaviour.

This innovative technology is easier to install, less complex to operate, and more cost effective compared to current alternatives such as strain gauges. The world leading research to come from Laing O'Rourke's UK research centre utilises fibre optic monitoring systems to provide intelligent insights into structural performance throughout the infrastructure lifecycle.

Deployed fibre optics result in a real-time long-term monitoring system that produces essential data on strains as well as static and dynamic load responses. When paired with AI and machine learning, the data can be used for a variety of applications. In the immediate term, structural data analysis removes the need for labour intensive visual inspections and extensive structural health monitoring techniques.

In the near term, extended asset performance and advanced capex planning through prediction and optimisation of operation and maintenance. In the mid to long term, historical data can be used for optimisation of future design and automate the validation of novel and complex designs of structures and building components.

Post-tensioned footbridge at University of Sydney's Engineering & Technology Precinct building. Image courtesy of Laing O'Rourke.

Mobile robotic blocklaying

FBR® is a robotic technology company developing and commercialising digital construction solutions to address global needs. The first application is Hadrian X®, the world's first mobile robotic blocklaying machine and system, capable of safely working outdoors in uncontrolled environments with speed and accuracy. Hadrian X® builds block structures from a 3D CAD model, producing far less waste than traditional construction methods while dramatically improving site safety and is capable of building the walls of a house in situ in as little as a day, with no human involvement.

Hadrian X® removes all manual labour from a construction site during the structural build process; eliminating the repetitive work, stress and injury that many bricklayers suffer due to years of hard labour. Due to the use of construction adhesive, there is no exposure of cement and sand dust while mixing mortar - both contain silica which has been recognised as a serious industry hazard. Less workers are required on site during the construction period and a faster turnaround results in less trips to site.

The team at FBR® have achieved a breakthrough in technology and mindset, pushing the boundaries in the conventional methods of the construction industry to provide a safer work environment.

In July 2020, Hadrian X® constructed FBR's first four-bedroom, two-bathroom home in the suburbs of Western Australia. Image courtesy of FBR.

Pipeline trenching using robotic excavators

Across Australia, thousands of kilometres of trench are excavated annually to allow oil, gas, or water pipelines to be buried. This excavation task is very repetitive and well-suited for automation. A collaboration between MPC Kinetic and Built Robotics has seen the deployment of robotic excavators to dig these trenches, improving the productivity of workgroups and allowing skilled excavator operators to focus on higher complexity tasks, leaving the mundane and repetitive work to the robots.

Built Robotics' robots are equipped with industry-leading safety systems, work without any onsite human supervision and continue working into the night further enhancing project productivity and bolstering utilisation of expensive capital equipment.

MPC Kinetic was the first to utilise the technology in Australia in 2019, with Built Robotics upgrading a number of the pipeline construction company's existing excavator fleet for the purpose of automated trench excavation. A 1-2 day retrofit unlocked autonomous capability for the company's machinery and upfront capital expense was mitigated through the use of machines already working in the field. Built Robotics and MPC Kinetic continue to work together to train local equipment operators and field technicians in the deployment, operation and maintenance of robotic machinery. The result of the collaboration has been an enhancement of skills for existing workers on these projects and creating a new class of worker – Robotic Equipment Operators (REOs).

Built Robotics' technology allows trenching using robotic excavators. Image courtesy of Built Robotics.

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This chapter was based on a virtual workshop held on 30 April 2020 with contributions from the individuals listed below:

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Footnotes

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4

Resources

Mineral, oil and energy resources are vital to sustaining Australia's ongoing economic prosperity, directly contributing more than 8% of Australia's GDP

4.1 Australia's resources sector

The resources sector is responsible for an estimated 10% of Australia's GDP and contributed to almost 35% of Australia's GDP growth in 2019.[1]

Mining directly employs around a quarter of a million people, or 2% of Australia's workforce,[2] and supports more than one million jobs in related industries.

The remoteness and vast distances between resources operating sites has presented considerable challenges for the industry, which in turn has led Australia's push into robotics over the last decade.

In more recent times there has been a focus on the application of digital technologies including the Internet of Things (IoT), Data Analytics, Artificial Intelligence (AI) and Machine Learning, and further deployment of Automation and Autonomy, and Robotics development along the entire value chain from exploration through to shipping and rehabilitation of mined land.[3]

> The resource sector is facing increasing challenges around social licence to operate, particularly its impact on global climate change.

Mineral, oil and energy resources grew from $205b in 2018 to $310b in 2020-21[1] and still dominate Australia's export income with Asia being the main market.[4] These exports have led to massive investment in regional infrastructure, the development of an extensive industry support network and providing substantial direct and indirect employment, particularly in regional areas of Australia. The resource sector is facing increasing challenges around social licence to operate, particularly its impact on global climate change. The consequences of the COVID-19 pandemic have already had a negative impact on the economies of the world, the flow-on effects to the mining industry, to date, have largely been on the supply chain.[1] Commodity prices of minerals remain buoyant although demand for oil has seen the price for oil and gas drop significantly.

The true impact of COVID-19 on the resources sector and related technology development is yet to be felt, however world economic growth forecasts continue to be revised up.[5] The restricted movement of goods and people, and the global supply chain model, have to some

Snapshot — Resources: What's changed since 2018?

Strengths

- More sophisticated inspection robots in the oil and gas space
- Growth in the supply chain
- Newmont's Boddington operation and Roy Hill have started mining operations with autonomous haul trucks
- Higher level capability and greater demand for inspection robots

Wins

- WA state government investment into the Neerabup automation and robotics precinct
- WA state government support of Westrac's testing facility in Collie and the Mackay Resource centre for excellence

New opportunities

- COVID-19 has had a limited impact on business in Australia
- There are new companies entering the autonomous vehicle market locally.
- Large push in the resources sector to electrify mobile equipment
- Australia has also embraced a more digitally connected and remote workforce
- Australia is becoming increasingly important as a location to test and develop new systems

Challenges

- Lack of skills
- Uneven adoption of technology
- Mine sites are technologically outpacing their communities
- Regulation outside of the mining industry has not kept up with the industry
- Lack of a skills pipeline
- Enabling mixed autonomous fleet compatibility
- Technology is outpacing regulatory reform
- Drop off in locally commercialised technology is not creating critical mass
- Fixed or service robots and not been integrated supply chain or directly into resources companies themselves
- Lack of systems and standards for coordination and collaboration of robots and autonomous equipment
- Delayed roll out of electric equipment impacting new autonomous models
- Developing appropriate teams of knowledgeable government officials
- Ownership of data and OEM permission required
- Limited number of sufficient startups and investors
- Lost opportunities to create cross-sector capabilities and growth of the overall supply chain
- Offshore development of technology and a weak local supply chain

Realistic 5—year goals

- Electrification of mobile mining equipment begins in scale leading to more automation
- Improved simulation approaches to training for workers, including virtual reality and augmented reality
- 3D printed parts on site and 3D additive repair to equipment on site.

extent broken down. This has led to a significant uptake in working remotely, which in turn has fuelled a pivot to digital online tools and remote services. This provides further incentives for robotics and automation, yet the current COVID-19 disruption in the global supply chain makes it harder for companies to acquire the technology. This provides local opportunities to develop more technology and has led to such initiatives as the Western Australian Government's $20m investment in an Automation and Robotics Precinct in the northern Perth suburb of Neerabup.[6] This push for localised services emerged even before COVID-19, with Westrac's proving ground in Collie, Western Australia, being approved in 2019 and completed in June 2020.[7] It is the only Caterpillar proving ground for its Autonomous trucks outside of the USA.

Australia has abundant supplies of mineral resources, oil and gas, including the world's largest reserves of lead, nickel, uranium and zinc. It is one of the top exporters of bauxite, alumina, iron ore, zinc, coal and the world's largest exporter of liquid natural gas (LNG).[8] Australia is a secure source of critical minerals[9] – Rare Earth Elements (REE) and lithium, critical in the supply chain for modern transport and consumer goods. For example, REE are required for the magnets used in electric motors (modern cars), while lithium is required for use in batteries. Australia is the leading global supplier of mining-related software and mining-related consulting services. Australia also has considerable capacity in general mining services, mining construction (ECPM Services), after-market engineering services and contract mining services. Leading original equipment manufacturers (OEMs) such as Caterpillar, Komatsu and Epiroc see Australia as the ideal testbed for advanced autonomous mining equipment.

Australia's resources export mix is changing, with increasing exports of LNG, critical minerals (such as lithium) and renewable energy. During 2019, Australia rivalled Qatar as the world's largest exporter of LNG.[10] Fresh investment in the mining and processing of lithium and rare earth minerals will grow Australia's role in the supply chain for electric vehicles and hightech devices. Meanwhile, Australia's dominantly coastal population and sunny climate have seen the use of wind and solar power soar. Australia has the highest solar radiation per square metre of any continent on Earth.[11] Today, wind and solar account for half of Australia's renewable energy generation.[4]

Resource-based primary companies are likely to significantly embrace automation and robotics solutions over the next 15 years, which will have a positive effect on the overall productivity of the industry. By 2030 this trend could add $74b in value to the Australian economy and over 80,000 new jobs if it develops a local supply chain in automation and robotics.[12] This uptake in robotics generates indirect social and economic benefits that include environmental and improved safety performance. The export potential that Australia could create with a robust robotics supply chain grown from the METS sector is likely to add tens of billions of dollars to the economy.[3] If Australian METS companies are unable to support miners and energy producers in their drive to automate large parts of their operations, these companies will continue to import robotic technologies and services from overseas. This is unlikely to happen organically and will require a high level of collaboration between primary resource companies, METS companies, research institutions, universities and the government.

UFR AutoLog. Image courtesy of Universal Field Robots.

4.2 Robotics and the resources sector today

Robotics in the resources sector is still mainly applied in surface mining, including: robotic digging, robotic dozing, autonomous haulage systems, robotic rock breaking, autonomous terrain mapping, underwater digging and robotic drilling systems. Most of these systems are maximised for scale, that is, the size of mining equipment tends to be as large as feasible to maximise the utility of the operator. In the future, as autonomous systems become more common, the benefits of scale diminish and we will see more and smaller autonomous machines operating on mine sites.

COVID-19 has led to a larger 'appetite' for automation/semi-automation due to physical distancing constraints, and restrictions of access to site, especially by contractors/externals. However, those restrictions have also led to additional challenges for new technology to be developed and tested on site, which could lead to opportunities for locally developed capability.

To achieve operational efficiencies, resources companies must increasingly rely on integrated sensing, interoperability, automation, robotics and advanced data analytics, with METS Ignited[3] defining industry priorities as:

- Advancing sensors and connectedness, e.g. for improving asset health, productivity, environmental and safety performance
- Advancing data/information/systems interoperability
- Advances in data analytics applied within and across the mining value chain (e.g. predictive/prescriptive asset health monitoring, numerical optimisation, etc.) towards truly integrated operations including addressing cultural, organisational and educational challenges
- Developing more effective human/machine interfaces and systems for providing remote presence, augmented reality, and situational awareness
- Advancing mine autonomy, equipment/process mechanisation and automation, including operator-assist systems, and maintenance

> In terms of vehicle autonomy, following the sustained success of autonomous haul trucks in surface mining and autonomous trains, OEMs have focussed some development efforts on other types of vehicles essential to the extraction process.

The last few years have seen an increased use of Uncrewed Aerial Vehicles (UAVs, also known as drones) on mining and oil and gas sites, where they are regularly used for tasks such as mapping site construction, monitoring fumes and pollution, blast monitoring, general surveillance and monitoring of operation. A notable example of the further development and maturation of drone technology for the resources sector is that of Emesent, a startup founded in 2018 to commercialise the Hovermap technology, capable of producing high-accuracy, large-scale maps of mine or industrial sites using a drone. The rapid success and growth of Emesent illustrates the potential for this type of technology and the appetite from the sector.

Mining companies and OEMs have also been testing specific applications of AI for recognition tasks such as segmentation of rock fragmentation. In terms of vehicle autonomy, following the sustained success of autonomous haul trucks in surface mining and autonomous trains, OEMs have focussed development efforts on other types of vehicles essential to the extraction process. For example, Rio Tinto is deploying the world's first fully autonomous water trucks, developed in collaboration with Caterpillar, in one of its iron ore sites in the Pilbara.[13]

4.3 The future of robotics in the resources sector

According to a global survey of mining companies, the underlying technologies predicted to have the biggest impact over the next 15 years are robotics and automation, artificial intelligence and analytics and sensing and data.[14] The big enablers for robotics since 2018 have been around the development of offsite testing facilities and a focus on developing stronger local supply chains.

If this trend continues then it will support the development of Australia's sovereign robotics industry. Other megatrends, such as the electrification of mobile mining equipment, is likely to have a positive impact on speeding up the adoption of autonomous equipment. Recent collaborative efforts around electrification by two separate groups of prime companies and suppliers, the Electric Mine Consortium and Charge On innovation challenge, are good examples of the development of sovereign capability.

The development of the Robotics Australia Network and robotics clusters, including the Queensland Robotics Cluster, Sprint Robotics and RoboWest are signs of a maturing market. The government will still need to play a role to support the local supply chain and increase its effort in keeping pace with regulatory reform.

Mining in Australia has largely escaped the disruptions from COVID-19 at mine sites. Most changes have impacted city based employees with Working From Home (WFH) being established by nearly all mining and METS related companies. While this has brought in some changes, these have largely been limited to off site activities.

4.4 Impact of COVID-19

1. **Telepresence more accepted when working from home**
2. **Remote technical assistance from OEM's as travel is restricted**
3. **Expansion of remote working with limited travel creating a surge in more remotely operated equipment**
4. **Remote servicing of equipment and off site maintenance interactive facilities**
5. **More focus on reducing the human footprint on a remote site**
6. **Use of drones are now ubiquitous, however, they still often require multiple operators per unit. There is demand for significantly reducing this requirement and seeing a ratio operator to device of much less than one (i.e. one person operating/monitoring multiple units at once)**

Another opportunity that is highly relevant to the resources sector comes with the creation of the Australia Space Agency (ASA) and the associated ambitions of Australia (and partners) in space activities. The world-class track record of Australia in remote operations and robotics, especially in the resources sector, has inspired the ASA to centre a number of aspects of its roadmap on the use of robotics for tasks such as resource exploration and extraction. This is an important opportunity for robotics and the resources sector in Australia, not only to be involved in future space missions including the Moon to Mars program, but also to fundamentally revisit many of the processes of exploration, extraction, transport and processing as they are currently executed on Earth. The new concepts that will be required for space resource applications are likely to have a flow-on effect on the resources sector on Earth, as this has happened in the past for various sectors of engineering thanks to space research and development.

In general, the future of robotics in the resources sector will exploit opportunities for increased safety (removing humans from dangerous activities) while also leveraging developments in robotics technology that see the development of small and many interoperable systems that can team and take advantage of ever-increasing computer processing power, miniaturisation of sensors, improved battery efficiency, lightweighting, increased robustness, and rapid prototyping.

Some areas where robotics will play a key role in the future of the resources sector include:

- In-Situ Resource Utilisation (ISRU) including for exploration, extraction and mineral processing – in-situ with nano-bots, also requiring the development of robust heat and pressure resistant robots
- 3D printing of mine infrastructure supported by digital twins of everything, even 3D printing of healthy food for mine workers
- Self-healing assets with maintenance by self-building and self-repairing robots
- All mobile equipment having an electric and autonomous ready option
- Compatible mixed autonomous fleets and robots that collaborate together automatically – plug and play
- Robotic exoskeletons for use in heavy lifting tasks.

Some of the key activities that need to happen to support the use of robotics in the resources sector include: the development and support of a local supply chain; investment in education and skills; greater collaboration with other sectors to work on integration and interoperability; regulatory reform to support technology creation, adoption and commercialisation; the development of more testing locations; incentives for larger firms to invest locally into R&D; and, while encouraging Australian robotics companies to export and be global in ambition, we also need to promote and attract global robotic companies to establish a manufacturing or R&D (not sales) presence in Australia.

4.5 Main findings for robotics in the resources sector

The resources sector remains one of the most important industries in Australia and one that benefits most from the adoption of robotics and automation.

The COVID-19 pandemic has led to an even larger 'appetite' for automation/semi-automation due to physical distancing constraints, and restrictions of access to site and travel, and this appetite is likely to remain significant for a number of years to come. However, it has also led to additional challenges for the development, deployment and testing of new technologies. Australia remains well placed to lead the world in the development of robotics technology for mining and oil and gas, given sufficient investment in R&D, skills development, and support for technology adoption. The rapid electrification of equipment is a substantial opportunity to integrate further automation and robotic technology into the new designs.

The COVID-19 pandemic has led to an even larger 'appetite' for automation/semi-automation due to physical distancing constraints, and restrictions of access to site and travel.

Case studies

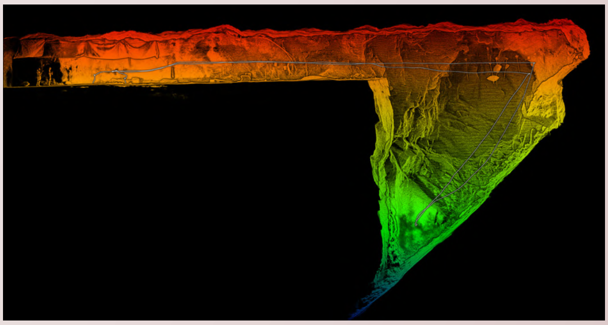
Reducing exposure to safety risks through intelligent assets

Woodside aims to be an industry leader in health and safety outcomes to protect people, communities and environments. Building on remote operating capabilities in subsea, not-normally-crewed platforms and LNG plant processes, Woodside entered a collaboration with the US National Aeronautics and Space Administration (NASA) in late 2016. NASA has loaned Woodside a Robonaut 2 system to test ideas from operators, engineers and maintenance workers to make work safer. Woodside is currently exploring these insights in onshore and offshore robotics site trials.

Recently, Woodside joined BHP and Deakin University's Institute for Intelligent Systems Research and Innovation on a pre-emptive, remotely-operated robotic intervention to release pressure in a standpipe at a Nickel West mine site. The team iterated strategies, designed solutions and tested prototypes. Ultimately, a Deakin robot was successfully deployed, severing the pipe to release the built-up pressure. The robot was controlled from a safe distance, eliminating human exposure to an uncontrolled release of pressure, shrapnel or gases. The experience was a live demonstration of how higher-risk activities might be supported by technology- based solutions. It also underlined the value that comes from different industries uniting with each other, and the tertiary sector, around a common challenge. Collaboration allows us to arrive at better solutions, faster

Woodside's 'Ripley' robot which was used to test strategies during a simulated incident response at a Nickel West mine site in Western Australia, June 2018. Image courtesy of Woodside.

Mapping the inaccessible



Brisbane-based company Emesent, a spin-off from the CSIRO, specialises in drone autonomy, LiDAR mapping, and data analytics. Their flagship product, Hovermap, is a smart mobile scanning unit that automates the collection and analysis of data in challenging, inaccessible environments, such as underground mines. Uniquely versatile, it can be drone or vehicle mounted or used for walking scans.

Data collection creates significant safety and operational challenges in underground mines. Deep and high-stress conditions make mining inherently high-risk environments for personnel, equipment, and infrastructure. Laser scanners are used to capture data in underground areas so that mining and geotechnical engineers can understand the effect of mining-induced and tectonic stresses on the rock mass, and maintain safe and efficient operations. However, the data collection process can be hazardous. Mapping areas using a traditional cavity monitoring system is time-consuming and increases safety risks for personnel, who have to control a boom-mounted sensor in exposed unsupported ground.

Hovermap reduces these risks by keeping personnel at a safe distance and minimising the time taken to map any hazardous or inaccessible area. Drone-mounted, Hovermap enables autonomous flight and collision avoidance capability to produce shadowless, high resolution scans of any underground area. Mining or geotechnical engineers can quickly and safely inspect stopes, drives or drifts with minimal disruption to production.

Hovermap scan of a mine stope, with drone flight path showing surveyors were able to operate the system a safe distance from the stope edge. Image Courtesy of Emesent.

Blueprint Lab — Changing the landscape of remote operations in harsh environments

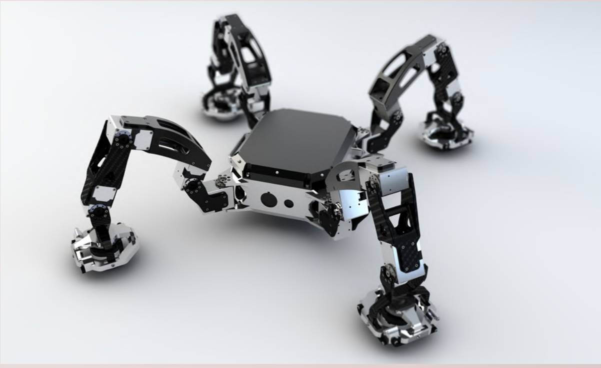
Blueprint Lab designs and manufactures advanced, robotic arms for harsh environments. These state-of-the-art, remotely operated robotic arms allow users to mimic a human arm and undertake dangerous tasks from a safe distance, vastly reducing risk to human operators (such as Navy divers and EOD Operators) and improving overall mission success.

Blueprint Lab's products are utilised by the US Navy, as well as offshore oil and gas and marine research industries. They are used to conduct tasks including pipe and tank inspection, object placement and complex retrieval as well as handling of delicate live organisms. The robust manipulator technology features high accuracy and interchangeable, task-specific tooling options while still being lightweight and compact for portability and ease of operation. A user-friendly imitative controller is used to manipulate the robotic arms movements and joint positioning. This minimises training requirements, allowing operators to more rapidly deploy the field-ready robotic arms.

Blueprint Lab saw a capability gap in the global market for inspection class ROVs, where complex, high-risk tasks were reserved for larger, less portable vehicles. By addressing this gap, the Australian owned and operated business has established global market traction, providing employment to close to 30 employees and bringing in revenue from exports.

Blueprint Lab's Reach Alpha Robotic Arms conducting a simulated complex recovery mission by the US Navy. Image courtesy of US NAVY (Naval Information Warfare Center Pacific DISTRIBUTION STATEMENT A. Approved for public release.).

Magneto — Reducing confined space entry inspections through robotic technology and better data capture



Nexxis have established a collaboration agreement with CSIRO's Data61 to develop the innovative robotic platform, Magneto. The multi-limbed inspection robot's focus is to solve the issues around dexterity and manipulation, which will allow the transition for working robots to perform inspections with complex geometries.

Nexxis is currently architecturally designing Magneto's road map to incorporate an expanding integration of sensor technology to allow autonomous operation. While the development of close proximity 3D SLAM and simulation technology for inspection planning and autonomous navigation are also forming part of its future plans.

Magneto will deliver safer workplaces by removing the need for humans to enter hazardous work environments, such as confined space entry and working at heights. Currently, the Magneto platform is performing trials for major companies within the resources sector also looking to achieve the goal of reducing confined space entry on their assets.

Other Nexxis robotics apply to various aspects of infrastructure inspections that require leaner and more efficient operations to cope with ageing assets. They can be used to enhance safety while improving productivity and operational efficiency, especially in hazardous environments. For example, they can have gas sensors to detect leaks, high-definition cameras to read gauges, and infrared cameras to measure temperature. On rotating equipment, robotics use microphones to detect abnormal noises and vibration sensors to detect excess movement.

Magneto 2020. Image courtesy of Nexxis.

Working with robotics technology to improve safety, reliability and efficiency in high-risk and remote environments

Woodside is an Australian oil and gas company with a global presence, recognised for its world-class capabilities – as an explorer, a developer, a producer and a supplier of energy. Woodside seeks to enhance its competitiveness through innovation and applying technology that improves safety, reliability and efficient operations in the high-risk and remote environments where they operate.

In mid-2017, Woodside took delivery of one of NASA's Anthropomorphic Robonauts, which is on loan for a five-year deployment in Perth, Western Australia. The NASA Robonaut project will explore how robotic technology can be used to unlock value from Woodside's assets. The project complements Woodside's own robotics program that includes machines capable of conducting tele-operated and semi-autonomous patrols and inspections that were suggested by their operational staff.

The first site trial of Woodside's patrol and inspection machines took place in November 2017 at the Pluto LNG facility. In addition to performing repetitive or high-risk tasks, the robots are also acting as mobile sensor platforms - streaming visual, thermal, ultrasonic, and light detection and ranging (LIDAR) data into Woodside's existing cognitive and analytics programs. The data gathered is processed and sent to operations and maintenance teams to assist them in identifying equipment faults, errors or where capacity improvements exist.

NASA's anthropomorphic Robonaut in use at Woodside. Image courtesy of Woodside.

Premron CHS — A continuous haulage solution to improve gateroad development

In 2013 the Australian Coal Industry's Research Program (ACARP) commissioned Premron to adapt their patented Enclosed Belt Conveyor System (EBS) from a static application, to a dynamic autonomous monorail-mounted conveying machine. This system uses multiple pairs of conveyor belt of drives, instead of the conventional single drive, which allows the belt to track around 90 degree corners. The belt is a Fire-Resistant Anti-Static (FRAS) wedged conveyor belt that forms into a 'tear drop' shape, allowing dust free conveying.

The narrow body allows the 200m long system to be installed against a rib (wall) and allow other mining vehicles and personnel to access down the side, while the machine is hauling. It will remove product from the face (behind a Continuous Miner) and transport the payload directly to the Panel Belt Conveyor, removing the requirement for the conventional batch haulage system (Shuttle Cars) and providing the Australian Coal Industry with a Safe and 'Continuous' Coal Haulage System (CHS) with possible improvements of up to 25% being modelled at some mines.

The CHS has several features in its control system that allow it to operate semi-autonomously. These include such things as ultrasonic sensors to detect the panel belt and any obstructions under the belt whilst the machine is tramming, belt-rip sensors, encoders to detect if the belt is slipping, potentially causing a fire and a proprietary load sharing algorithm, which allows the belt to maintain correct tension while running around corners and tramming.

To overcome the challenge of detecting and following the development unit autonomously, Premron teamed up with the CSIRO in 2019 to integrate their patented Ex Scan LIDAR system. Using the data from the Ex Scan the CHS will "follow" at a user configurable distance, indicate correct positioning to personnel installing roof bolts for hanging monorail ahead of the CHS, and give corrections for the position of the pivoting conveyor loading out into the throat of the CHS, reducing operator interaction.

Top: CHS conveying around a 90 degree corner. Image courtesy of Premron Pty Ltd.
Right: Operating CHS during surface trial. Image courtesy of Premron Pty Ltd.

Operating Coal Haulage System (CHS) during surface trial

Cathode Manufacturing — Glencore Technology, Townsville Copper Refinery

Years of experience with automation and robotic systems made Scott the ideal automation partner to build and install a new robotic handling and welding system for Glencore Technology. This system would enable production of their new Cathode plate, ISAKIDD™, and their traditional range of plates in bulk quantity.

Described as "an elegant, yet methodical ballet of productivity, with every move calculated for quality and efficiency" in Mount Isa Mine's Resourceful, the system allows parts to go direct from stillage to a completed plate stacked in the outfeed without the need for operator involvement.

Glencore is currently manufacturing plate orders with around 16,000 plates, including its first ISAKIDD™ cathode plate order, produced in the six months following commissioning. Glencore's Engineering Superintendent, Noel Kimlin, says "Automating this process means we make more reliable, high quality plates while having the ability to synchronise outputs with production demand."

The Scott system installed at Glencore resulted in a number of benefits. Operator exposure to gases, toxic fumes and welder's flash reduced while production increased. All of Glencore's requirements, including a higher output were met with the system marking the start of a new era in production for their Townsville Copper Refinery.

Overview of the materials handling and automated welding system installed in Townsville. Credit: Glencore Technology.

Universal Field Robots and IMDEX collaborate to successfully deliver BLAST DOG™

Universal Field Robots' (UFR) E20C is an Australian manufactured 2-ton robotic platform that operates UFR Autonomy and can be equipped with attachments to perform a variety of tasks. UFR collaborated with another Australian company IMDEX Limited to deliver BLAST DOG™, an autonomous system that helps optimise blasting based on high-resolution three-dimensional material models built from sensor data.

To perform the sensing, the machine drives to blast holes, uses robotic vision to verify the blast hole location and winches a wireline sensor down the blast hole to collect data. The sensor data is used by drill and blast engineers to lower the cost of blasting, while improving safety and productivity and reducing risk.

The IMDEX BLAST DOG™ product is significantly contributing to the digital transformation of mining and will be manufactured in quantity and exported to mining locations around the world. UFR is further developing complementary products to solve various mining problems and has global engagement, including current testing in Chile and enquiries for sales in South Africa. UFR business is growing to be a new manufacturing industry class for Australia and is employing the next generation of leaders in engineering and mechatronics, providing high value and high satisfaction employment opportunities.

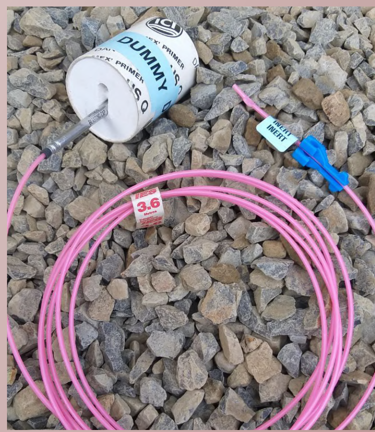
IMDEX was particularly interested in engaging Universal Field Robots due to the requirement of developing a mine operational prototype in a 6-month period and a commercial prototype within 18 months. Credit: Lestrade Digital.

An explosive cartridge/detonator handling hole charging robot for mining and t unneling

Designing and building an explosive cartridge/detonator handling robot for Mining and Tunneling is an ongoing research project that started a thesis for David Broadbent's Post Graduate Diploma of Robotics at Monash University. From conception of the initial design using 87C51CPU, the processing power of embedded microprocessors has 'exploded' in capacity.

Also, tactile, position and vision sensors with algorithms to match, have vastly improved. David's 1990-2010 multiple attempts at creating a suitable end effector gripper (hand) proved these dual grippers needed to be of a humanoid form. With the advent of low cost 3D printing this "hand" is now achievable.

David's end product solves the challenge of finding trained 'powder monkey' personnel and it reduces the significant hazards in underground mines and tunnel projects where cartridge explosives are used, in Australia and globally, which occasionally result in death. This robot: Moves to the work face after the drilling jumbo has finished drilling; Synchronises data with the drilled hole data from the drill jumbo; Selects and inserts a detonator into an explosive cartridge; Charges the predrilled blast holes with the primed cartridge explosive; Repeats until all the drill holes are charged; Ties off all the detonator cables in a predefined pattern, followed by a safety review; Completes the final connection of the linked detonator 'chain' to the primary firing device; Retracts automatically to a "safe" location prior to the shot firing.



The robot selects and inserts a detonator into an explosive cartridge. Image courtesy of David Broadbent.

Contributors

This chapter was based on a workshop held in Perth, WA, on 25 February 2020 with contributions from the individuals listed below:

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Thierry Peynot (QUT/Mining 3)
Andrew Scott (METS Ignited)

Footnotes

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5

Manufacturing

As an early adopter of robotic technology, the manufacturing industry is the ideal proving ground for new robotics and automation systems and concepts, as they can be tested by experienced people in structured and controlled environments

Global manufacturing in the 21st century has been trending towards centralising mass production in countries with lower cost structures – that is, lower labour cost, lower skill operations. This has led to an exponential uptake of automation to replace labour and produce larger volumes for global consumption. However, the weakness in this strategy has been exposed by the COVID-19 pandemic.

As such, many countries are seeking to re-shore manufacturing capability. Re-shoring will lead to a global need for technology that supports lower volume production runs and more flexible operations. This need is consistent with the manufacturing needs in high wage countries ever since off-shoring became prevalent.

Australia is no different. The Australian manufacturing sector is receiving additional support from the Commonwealth following the COVID-19 pandemic, supporting re-shoring of local production and strengthening supply chains for essential goods, including medicines and medical products, resources and critical minerals, food and beverages, recycling and clean energy, defence, and space. This support could be targeted to both satisfy Australia's internal needs and also address the global challenge to create a significant technology export opportunity. The vision is for Australia to be recognised as a high-quality and sustainable manufacturing nation that helps to deliver a strong, modern and resilient economy for all Australians.

Snapshot — Manufacturing: What's changed since 2018?

Strengths

- Manufacturing was the first industry to utilise robotics (primarily for speed, lifting, repetition and precision)
- Manufacturing is the ideal testing ground for new systems and concepts in robotics and automation. offering structured, controlled environments, and experienced people
- Manufacturing is the largest user of automation and provider of business cases, therefore reducing the risk to other industries
- Identifies unknowns involved with utilising automation and new technologies such as Industry 4.0

Wins

- Renewed focus, interest and investment in manufacturing as a result of the Australian government's "Modern Manufacturing Strategy"

New opportunities

- Identify strategy to create unifying series of robotic and automation capabilities and products that propel business
- Dedicated, well-funded policy will reinforce this initiative by unifying the sovereign efforts in the underlying enabling technologies such as robotics
- Skill-multiplying automation systems, human-machine/cobotic technologies, and simulation systems to advantage small run production, will assist in the growth of manufacturing in Australia
- Government has invested $1.3b into their Modern Manufacturing Initiative in which key industries all list robotics and automation as a major strategic enabler

Challenges

- Many of the challenges faced by Australia's manufacturers are the same as those faced in 2018: difficulty accessing skilled labour, relatively high energy costs, high freight cost, lack of collaboration, lack of resources to invest in technology adoption, risk aversion & difficulty achieving economies of scale compared to international competitors
- By not building industrial robots in Australia, we are benefitting overseas suppliers and failing to capitalise on the the creation of our own robotic technologies
- The COVID-19 pandemic has also highlighted the fragility of supply chains with shortages of silicon chips, plastics and many other items sourced overseas
- Fragmented objectives cause competition between initiatives. We need to work together to achieve goals that benefit Australian manufacturing
- The adoption of robots by Australian manufacturers benefits overseas suppliers
- The closure or transfer of local large scale operations puts emphasis on smaller production operations
- Smaller operations require more skill to complete, requiring long term infrastructure investments

Realistic 5—year goals

- Educate local suppliers in "skill-multiplying" cobotics, so they can best allocate human, robotic or shared operations in completion of tasks
- Enhance automation simulation capabilities (humans and machines) allowing for the application of synthetic data to ensure successful and sustained process improvement
- Development of more capable collaborative robots (cobots)
- Design and prototype a $2,000 "skill-multiplying" robot through modern sustainable technologies

5.1 Australia's manufacturing sector

Manufacturing in Australia is worth 6.1% of GDP, responsible for 8% export share[1] and supporting ~915,000 jobs,[2] with another ~350,000 indirectly employed in R&D, logistics and sales and service.[3] Currently, about 80% of the value of Australian manufacturing comes from four major sub-sectors: food and beverages (27%), chemicals (19%), machinery and equipment (18%) and building materials (15%).

Overall, the manufacturing sector has gone through a major structural change in the last three decades, where production related to food and beverage, metal and machinery, and equipment has increased significantly. Manufacturing is dominated by SMEs (1-199 employees) responsible for 50% of the total value added to the industry and 66% of jobs in 2018-19.[4]

Australia is a world leader in niche manufacturing for several high-value industries, including medical technology and aerospace, but is yet to fully embrace the fourth industrial revolution (Industry 4.0). Consistent with emergent global needs, Industry 4.0 promises a new era of manufacturing where mass customisation and decentralised production are normal. Australian manufacturers increasingly need to compete on value rather than cost, developing innovative products, components or services within global supply chains.[5]

Manufacturing employs many skilled and unskilled workers and employs more than 272,000 regional Australians.[6] The skills developed by manufacturing industry employees are the core skills that every modern economy depends upon. The manufacturing sector trains many technical and professional people with the skills necessary to install and maintain our telecommunications, energy, water and transport systems. This includes engineers, technicians, welders, fitters and turners. Manufacturing is a net supplier of these skills to other industries, especially the resources sector. Without the skills training that occurs within the manufacturing industry, skill shortages would become more intense.[7] During the past decade there has been a structural shift in employment of qualified engineers away from manufacturing and into service-based industries as "non-core" business is contracted to other business entities, mainly engineering consultancies.[8]

With such a skilled and influential workforce, Australia should seek to create, internally distribute and exploit, and export and profit from, skill-multiplying technologies. To further enhance this prominent national resource, new and diverse talent needs to be attracted and planned for. Despite its increasingly high-tech nature, modern manufacturing in Australia has an image problem. A majority of Australians (65%) see the manufacturing sector as important to the Australian economy, however younger Australians are interested in careers that offer a high degree of job security and the majority believe this is not offered by manufacturing.[5] The sector is characterised by an ageing workforce (median age 43 years)[9] and poor gender diversity with only 29.5% female employees in 2018 (an increase of 4% over the last 20 years).[10] The manufacturing industry also has a high number of work-related fatalities, injuries and illnesses, with 8.4 serious claims per million hours worked in 2018-19, the second highest of any industry in Australia.[11] To succeed in the future, Australian manufacturers have to become places where young people want to work. By creating such environments, where operational excellence and adoption of skill-multiplying technology flourishes, Australia will be able to profit from Advanced Manufacturing well into the 21st century.

5.2 Impact of COVID-19

COVID-19 exposed many weaknesses in critical supply chains for Australia and shone a spotlight on the importance of sovereign agile manufacturing capability to quickly secure essential items.

In response the Australian Government released a Modern Manufacturing Strategy[12] backed by $1.3b in funding, to support the growth of the manufacturing sector in six key areas considered to be of comparative advantage and strategic importance to the nation, with roadmaps for the next ten years released:

1 Resources Technology and Critical Minerals processing (see Resources Chapter)
2 Food and Beverage (see Agriculture and Services Chapters)
3 Medical Products (see Healthcare Chapter)
4 Recycling and Clean Energy (see Services Chapter)
5 Defence (see Defence Chapter)
6 Space (see Space Chapter).

There are concerns that while Australia's manufacturing sector is adopting technology, particularly automation, it is lagging in fundamental operational excellence in the SMEs that make up the majority of the sector, hindering their ability to make best use of technology.[13] Improving the operation of manufacturing businesses is a core pillar of the Australian government's modern manufacturing strategy. Once that has been achieved then manufacturer's can leverage technology to become more resilient and to be more successful participants in global supply chains. The main technologies being deployed include analytics and artificial intelligence, IoT, advanced robotics and digital platforms with companies now able to access new solutions for running scenarios, assessing trade-offs, improving transparency, accelerating responses and changing the economics of production. These advances can help manufacturers become more agile and innovative and ultimately resilient to crises such as the COVID-19 pandemic.[14]

According to AiGroup's June 2021 Performance of Manufacturing Index, the sector has experienced nine straight months of recovery following the disruptions of the COVID-19 pandemic in 2020.[15] Recovery was attributed to: strong demand from the construction and agricultural industries; improved exports; local customers seeking local suppliers; low interest rates; and end of financial year sales.[15] Despite these positive signals, the overall maturity of Australian supply chains fell from 2018 to 2019 despite increased investment in automation. The sector's output has quadrupled over the past six decades but labour productivity is decreasing.[13] The sector is also unusually volatile with businesses swelling to more than 20% their average size in upcycles and 20% below average during downturns, largely due to transport costs associated with our geographic isolation and swings in terms of trade.[3]

5.3 Robotics and the manufacturing sector today

Manufacturing was the first sector to embrace robotics, with prototype industrial robots introduced to the factory floor of automotive manufacturer General Motors in 1961.

Since then, robots have become more sophisticated, but until recently, were too expensive for use by SME manufacturing plants and were unsafe to work collaboratively with humans in unstructured environments. Technological developments mean that robots are now cheaper, safer, more flexible, and can be used in mass customisation or even bespoke applications in ways that were impossible even ten years ago. However, it is not clear that Australia is benefitting from many of these advances, or that it will be able to harness the benefits of Industry 4.0.

Australia does not manufacture its own industrial robots, defined by ISO 8373:2012 as "an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications." Similarly our manufacturing sector is heavily reliant on importing technologies for Industry 4.0 rather than producing them in Australia, making it unlike other sectors such as healthcare, resources, agriculture and environment. The lack of sovereign technology creation in Australia for our manufacturing sector is a critical risk as it is intimately linked to the necessary increases in productivity that will help Australia maintain and grow standards of living. Automation will combat relatively high national costs (living and energy costs combined with weak productivity growth) against strong emerging competition in low cost and/or technology- or cash-rich countries and regions.

> Australia has a need for robots to act as a skilled human force

Not only is Australia reliant on importing Industry 4.0 technologies, our manufacturing sector is not taking up these technologies at the same rate as other nations. Numbers of installed industrial robots have declined since 2014 by 14%, compared to an increase of 60% worldwide, dropping Australia from a ranking of 18th to 35th (of 37) in the world in robot density in the manufacturing industry.[16] A key driver of Australia's demise in world rankings was the closure of Australia's last car manufacturing plant in 2017.[17] The automotive industry is the largest deployer of industrial robots (28%), followed by electronics (24%), metal and machinery (12%), plastics and chemical products (5%), food and beverages (3%) with a further 20% not attributable to a particular manufacturing sector.[16]

Another contributing factor to Australia's low robot population density is the continuing reduced role of large enterprises in manufacturing, such that 87% of Australian manufacturing companies that employ people are small (1-19 employees), 12% are medium-sized (20-199 employees) and only 1% are large (200-plus) (note 44% of active manufacturing businesses are non-employing).[18] Traditional robotic technologies have been designed for large-scale automation, making it more challenging for adoption by SMEs. Automation in Australia must evolve to support small manufacturers with a diverse range of needs and capital constraints.

The benefits of adding a robot to a production system is that it yields improved quality, safety, and productivity. However, SMEs typically lack the resources to have dedicated automation engineers on staff, which is where the advent of smart robots that use AI and computer vision can allow robots to be added to Australian factories at low cost and without requiring highly skilled programmers on staff. SMEs may not be able to easily quantify the impact of adding robotics to their manufacturing lines. This is where high fidelity simulation becomes important, enabling virtual prototyping, design, and commissioning of automation to reduce risk by allowing manufacturers to assess the benefits of robots before investing in hardware.

Robotics in large manufacturing companies has been widely deployed across a variety of tasks. This includes handling operations (46%), welding (20%), dispensing (3.3%), assembly – drilling, fastening, fitting, riveting (10%), processing – gluing, painting, polishing, routing (1.5%), and inspection – including clean room (8.6%).[16] However, take-up of robotics by Australian SME organisations, which tend to produce low volumes and customised or complex products, has been limited due to high barriers of entry of existing robot systems and lack of programming staff. The main areas of uptake are in handling operations (69%) and the food industry (20%), with 567 new robots installed in Australia and New Zealand in 2019, giving Australia a robot population density of 75 robots per 10,000 employees.[16]

Australia has a specific need for robots to act as a skilled human force multiplier, augmenting and extending world-class capability while reducing human exposure to dirty, dull, and dangerous processes. The specific trend towards this worker-enhancing opportunity is reflected in data showing that half of the world's forklifts will be autonomous by 2030, and the growth in service robotics (that is, robots that work with humans) was 32% in 2019,[19] compared to -12% in industrial robotics (after six years of double-digit growth).[16] Another considerable opportunity is the blurring boundary between manufacturing and other industry sectors, which were once considered discrete. For example: construction is moving towards prefabrication while embracing design for manufacture. Assembly principles are being applied to the construction of building elements, in a plant with a mass-customisation mindset, and the assembling of these elements is taking place onsite. This is an opportunity for two discrete and non-competitive sectors who have a shared driving need in the core capabilities that robotics offers.

COVID-19 has intensified pressure on Australian manufacturers to adopt new technologies. With the impact of COVID-19 on the world economy, disruption to the global supply chain, logistics and distribution, Australia needs to rethink and encourage sovereign capability on a number of fronts. Intelligent robotic systems that can easily and rapidly adapt to new product lines based on demands and real time needs, may pave our way out of being isolated and being at the mercy of global supply chains. The pandemic has also provided the opportunity for companies to rethink their logistics with suppliers. 'The Micro-factory', by Haddington Dynamics, has been developed to set-up small scale factories using open source 3D-printed robotic arms. In deploying robotics in all parts of the process, with cobot capabilities, the micro-factory allows for just-in-time (JIT) logistics to be realised and for tool-changing to be faster and less costly than the traditional large-scale manufacturing practises seen today.

5.4 The future of robotics in the manufacturing sector

There are several technologies that will influence the future of manufacturing in Australia, including 3D printing for rapid prototyping of new or improved products, the development of more capable collaborative robots (cobots – a type of service robot) through related technologies like computer vision, and enhanced simulation capabilities, including by the application of synthetic data.

The opportunity to apply new robotic technology in the manufacturing sector is two-fold: to enable seamless, skill-multiplying, and safe co-operation between robots and people; and to allow rapid adaptability of robots to new tasks without requiring a deep automation skill-set on behalf of the manufacturer. Put simply, enabling a new class of robots to think and see has the potential to drive a step change in Australia's manufacturing competitiveness and productivity. The use of cobots is also not fully accounted for in Australia's robot population density statistics, which does not include the use of service robots in manufacturing. However, even if cobots were included in measures of robot density, Australia does not manufacture these robots and we remain at the mercy of foreign imports.

CHALLENGES OF TECHNOLOGY ADOPTION

BENEFITS TO AUSTRALIAN COMPANIES INCLUDE:

- Rapidly adding a new production line to a factory, without manual programming of process steps, logistics, layout, and without explicit expertise
- Enabling a future where assistant robots routinely work cooperatively with people in semi-structured manufacturing environments, communicating using natural language, and explaining decisions
- Building sensor networks to provide live data as a service to enable holistic quality, logistics, safety, and robotic function while integrating into manufacturing systems
- Decision-making tools to continuously self-improve operations
- High fidelity simulation allowing virtual prototyping, design and commissioning of automation, to reduce risk and validate benefits before significant money is invested in hardware
- Having solutions that can be quickly and easily adapted to different tasks and industries.

5.5 Main findings for robotics in the manufacturing sector

Despite the loss of car manufacturing capability, niche manufacturing in high-value industries and production related to food and beverage, machinery and equipment, and metal has increased significantly in Australia.

Australia has a specific need for robotics to act as a force multiplier, augmenting and extending world-class, skilled human capability while reducing human exposure to dirty, dull, and dangerous processes. Safety is a key priority for the sector, which is dominated by SMEs who need skilled workers to take advantage of Industry 4.0. Ongoing training is required to allow the workforce to continually evolve to stay ahead of the latest technological developments. However, the sector has an ageing workforce with a lack of gender diversity, while struggling to attract young people. This can create skills shortages and impact other sectors that source workers from the manufacturing industry. If Australia invests wisely, and shares people, data and solutions across sectors, it can grow a national capability to support and expand niche manufacturing expertise, and remain globally competitive. Importantly for investment impact, Australia can profit internally and then turn this capability into an export opportunity, as the same needs are now global.

Adopting these new technologies is not a technology challenge alone. The Australian robotics supply chain, supporting imported robots and cobots, must be equipped to integrate and supply these next-generation solutions to manufacturers. A parallel effort to develop shared libraries and tools to enable and encourage IP leverage, across industry sectors, will allow capability to be used by Australian manufacturers and be shared with other Australian companies.

BENEFITS TO AUSTRALIA, AS A WHOLE, INCLUDE:

- Higher-tech manufacturing to improve profit margins and differentiate with low-wage, low-skill manufacturing countries
- Productivity advancements to enable our society to be self-supporting, competitive, and continue to improve living standards
- Higher-tech suppliers and workforce to become self-fueling in the creation of new industries stemming from new technology advancements
- Future attraction and retention of talent, enabling self-sustainment in capturing and exploiting new technology for national benefit
- Skill ripple effect to benefit wider Australian society
- Export profit, if and when we can harness the full strength of Australian industry and talent.

Case studies

Advanced manufacturing of the Boeing Airpower Teaming System

The Boeing Airpower Teaming System is Boeing's first uncrewed system to be designed, developed and manufactured in Australia. Designed to provide a transformational capability for global defense customers, it is the company's largest investment in a new uncrewed aircraft program outside the United States.

This purpose-built aircraft can be missionised to suit country-specific needs. It provides fighter-like performance, measures 38 feet long (11.7m) and is able to fly more than 2,000 nautical miles. Together with the Royal Australian Air Force, the company is developing six aircraft prototypes, called the Loyal Wingman, which will inform the global Airpower Teaming System product.

In October 2020, Boeing Australia signed a partnership with the Queensland Government to develop an advanced manufacturing capability in the state, including introducing technologies such as advanced robotics as well as creating global export opportunities for Australia's supply chain. Queensland will become the primary final assembly location for future Airpower Teaming System aircraft by the middle of the decade, pending production orders. The aircraft completed its first flight in February 2021, with flight testing ongoing.

Top: First engine test of the Loyal Wingman. Image courtesy of Boeing.

Bottom: The Boeing Australia, Airpower Teaming System – 'Loyal Wingman' conducts its first flight at Woomera Range Complex, South Australia. Image courtesy of the Department of Defence.

ARM Hub accelerating innovation potential

Helping manufacturers since early 2020, the Advanced Robotics for Manufacturing (ARM) Hub has a mission to take 'Australian Made' to the world. As a not-for-profit company, the ARM Hub is a trusted service bringing together the expert teams needed to accelerate industry's adoption of advanced manufacturing. Through their partnerships, the Hub bridges the gap between industry and research, effectively lowering the technical, operational, and economic barriers experienced by companies seeking to innovate.

Among the businesses using ARM Hub's services is Australian Droid + Robot (ADR), who manufacture remotely operated vehicles. ADR have deftly entered the space of robotics and established themselves as problem solvers and innovators, offering a range of products and services from deploying remote inspection vehicles to designing and constructing specialised Uncrewed Aerial Systems (UAS).

ARM Hub has provided ADR with access to the learning factory for testing and prototyping their innovations, helping them to scale up. This Hub helped ADR secure national grant funding in order to leverage more R&D activities, in turn supporting their endeavours into new supply chains including defence. ADR's automation solution, optimised for aerial search and rescue missions, will stimulate new global markets for UAS'.

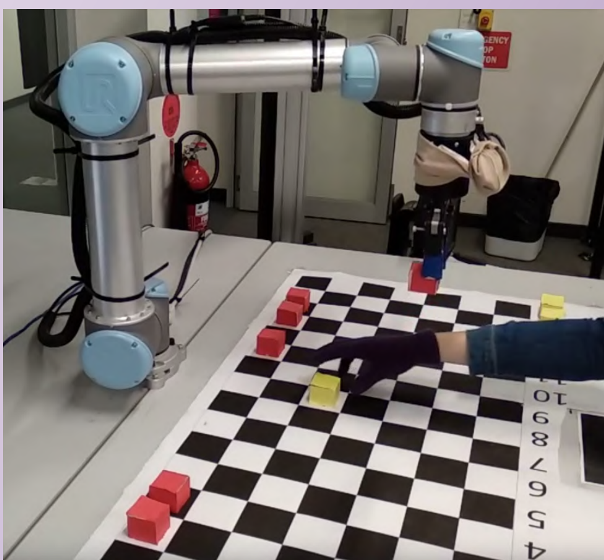
Australian Droid + Robot's testing space at the ARM Hub Learning Factory. Image courtesy of ARM Hub.

Robots that seamlessly interact with people

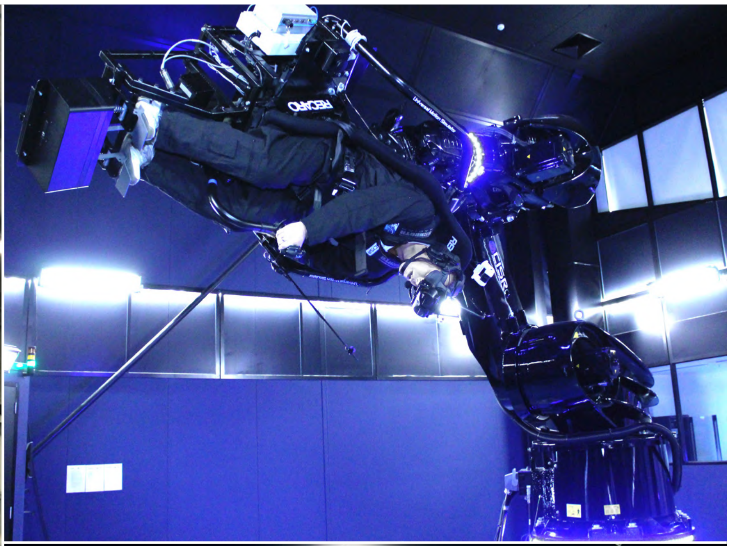
Most robot manipulators in manufacturing are confined to cages to keep them away from people. The newly established Robotics Precinct at Monash University is leading the research to enable natural interaction between humans and robots along with academic collaborators.

A useful capability for interactive robots is the ability to pass objects from, and to people. Researchers at QUT and Monash implemented a system that allowed a robot to pick up many everyday objects from a human with ease. The approach integrates deep learning to automatically identify stable and safe grasp configurations to allow the robot to take the object without colliding with the human's hand or fingers.

A second scenario of interest is where humans and robots work together in close proximity to access objects in a shared workspace. Robots can support their human co-workers by taking action to reduce interference and assist the human worker with their task. Such supportive actions are perceived more favourably by coworkers and reduce interference in cluttered environments.



A human and robot manipulator can work together in the same workspace without interfering with each other's task. Image courtesy of Monash University.



Virtual manufacturing

Using motion simulators for automotive research and development and prototyping can significantly improve road safety and reduce the number of fatalities. In addition, simulators are the safest and most cost-effective tools to test, evaluate, optimise and analyse driver-based and driver-less vehicle designs, their ride and handling, human perception of comfort/discomfort, and trust in autonomous vehicles. The same parallels apply to other domains such as trains, aeroplanes and ships. At present, the low motion fidelity of the existing motion simulators fails to deliver a realistic driving/flying experience to the user.

The world-first hapticaly-enabled motion platform, namely, the family of Universal Motion Simulators (UMSs), has been developed to address this challenge. Consisting of a fixed-base UMS, mobile UMS and UMS-Infinity, this family of UMSs has unique high-fidelity, highly realistic motion generation capabilities. Artificial intelligence-based motion cueing and control algorithms will realise cross-cutting technologies to de-risk, scale up and add value to Australian manufactured products. The UMS family will be able to enhance Australian technologies by providing a world-class platform for virtual prototyping and testing. These advanced robotic systems will also facilitate innovations and enable Australian industries to gain a competitive edge over their international competitors.

Left: Universal Motion Simulator on a rail for complex manoeuvre and vehicle testings. Image courtesy of Deakin University.

Upper-right: Universal Motion Simulator is configured as an air vehicle performing an acrobatic manoeuvre. Image courtesy of Deakin University.

Upper-left: Universal Motion Simulator is configured as a car simulator for virtual prototyping and testing. Image courtesy of Deakin University.

Universal Robots takes REDARC Electronics from 'Manual to Automated'

South Australia's REDARC Electronics invested $22m into a recent facility expansion project and prides itself in continuously investing in R&D and the upskilling of its more than 200 employees. REDARC also has their sights set on becoming a smart factory by 2025.

REDARC looked to expand its footprint and increase its competitiveness in the export market. Central to this was the need to automate manual processes – more specifically the assembly of their PCB boards. Answering this automation need was Universal Robots. Two UR5's and one UR10 collaborative robots (cobots) were selected. The cobots are used in the assembly, labelling and transport of PCB boards. One of the UR5's is fitted with Cognex 2D camera for PCB recognition and location, whilst the UR10 is fitted with a 3D Pickit Camera which allows for picking of the plastic components for assembly.

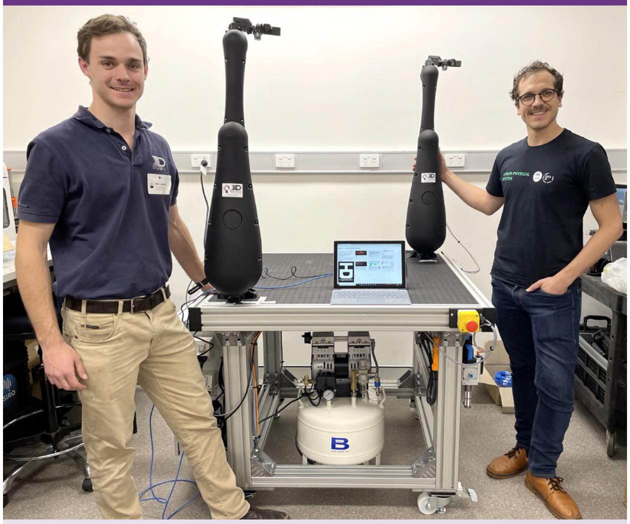
The robotic cell has increased productivity by 52%. Workers can now focus on value-added tasks and REDARC can rest assured that every PCB board is good to go. The cobots ensure safety, collaboration, quality, improved production efficiency and were easily integrated into the production facility.

Top: Collaborative robots (cobots) in action. Image courtesy of Universal Robots.

Right: Automated PCB board assembly made possible by collaborative robots (cobots). Image courtesy of Universal Robots.

Automated PCB board assembly made possible by collaborative robots (cobots)

DCISIV Technologies manufactures general purpose articulated robots



DCISIV Technologies, based in Toowoomba QLD, launched in March 2020 to manufacture under license the Dexter HDI — a 7-axis robot designed by Haddington Dynamics based in Las Vegas. Since then, DCISIV Technologies has been exporting robots to the U.S. and positioning themselves as local Assembly Line Automation Experts. With the acquisition of Haddington Dynamics by Ocado in 2021, the opportunity for DCISIV Technologies is to supply local and international markets with the support and backing of a global company.

The company is excited for the future, with many product improvements scheduled by Ocado's central R&D hub in 2021 and 2022. DCISIV Technologies complements their manufacturing activities with mechanical, pneumatic, and electrical expertise. They are capable of designing, prototyping, building, and integrating general automated equipment and machinery – and offer ongoing training and support for their systems.

As the Dexter HDI is best suited for lightweight pick and place applications, DCISIV Technologies chooses to specialise in Assembly Line Automation. Their vision is to help Australian manufacturing remain competitive and sustainable in a Global Economy, by providing reliable and cost-effective automation solutions to both local and global enterprises.

Ben Leamon (DCISIV – Left) and Josh Pinskier (CSIRO – Right) after installation of CSIRO's new DexCell – a stand-alone robotic platform for research and development. Image courtesy of DCISIV Technologies.

OnRobot — Boosting productivity for Australian manufacturers

OnRobot delivers innovative plug-and-produce solutions for collaborative applications which integrate seamlessly with leading collaborative and light industrial robot brands. Its tools – electric grippers, force/torque sensors, vision system, screwdriver, sander and tool changers – facilitate quicker and simpler automation of tasks such as packaging, quality control, materials handling, machine tending, palletising, assembly and surface finishing.

The company helped Australian injection moulding specialist Designed Mouldings implement a collaborative application to cope with a surge in orders due to COVID-19. Combining the OnRobot VGC10 electric vacuum gripper with a Techman Robot cobot, Designed Mouldings automated the sealing of wads on plastic caps, boosting productivity and decreasing cycle time significantly. The VGC10 offers unlimited customisation to fit various needs and can easily be redeployed to other tasks. The gripper and the robot work as a stand-alone system and does not require extra cabling, piping or air, enabling it to be moved easily and stationed anywhere. More importantly, the collaborative application works safely with employees.

The manufacturer can now complete a 20,000-product run in 24 hours, three time faster than when done manually. Employees no longer need to be stationed at the machine for hours and can focus on higher-value tasks. With a constant stream of jobs, Designed Mouldings is expected to achieve ROI in six months or less.

The OnRobot VGC10 inserting wads into the bottom of individual plastic caps, before dropping the assembled cap into a hole in the table under which finished goods are stored. Image courtesy of OnRobot.

ABB robots enable 3D printing of antimicrobial copper on metal surfaces

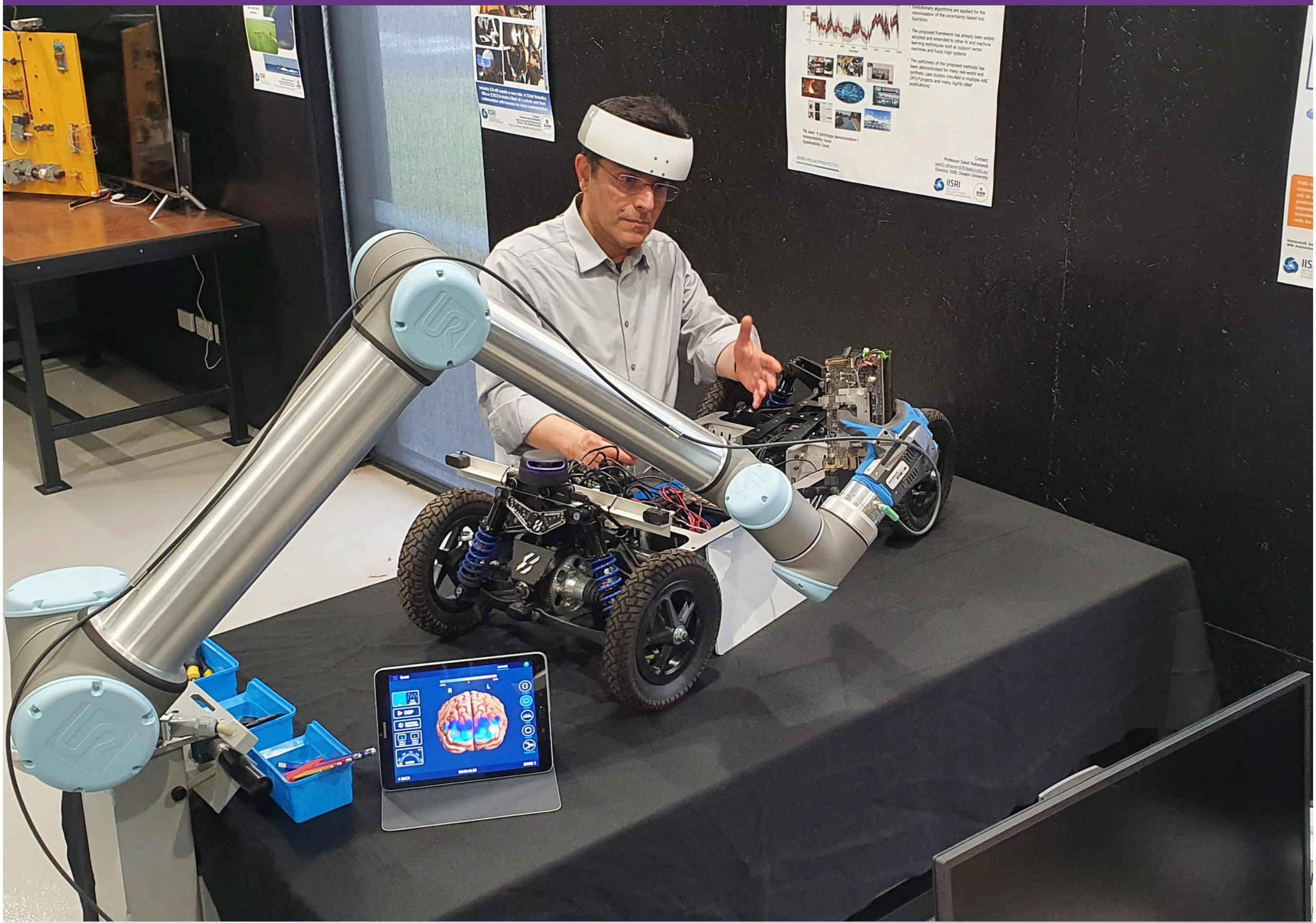
As the world vaccinates against COVID-19, finding ways to safely live with the coronavirus is paramount, especially as more of us return to workplaces and other public areas. SPEE3D has developed a high-speed additive manufacturing process that coats existing hardware — such as door handles, push plates and handrails — with a thin layer of copper, which is proven to 'contact kill' 96% of the SARS-CoV-2 virus within two hours. CSIRO research shows that the COVID-19 virus can otherwise remain infectious on glass and steel surfaces for at least 28 days.

The cost effective, scalable, portable solution involves placing the hardware to be sprayed such that a six-axis robotic arm can move around it directing copper powder, injected into an airstream propelled at up to three times the speed of sound by SPEE3D's 'rocket nozzle'. In a patented process called Supersonic 3D Deposition, kinetic energy binds the powders and forms a copper coating within five minutes.

The ACTIVAT3D Copper project, as it is known, is a global collaboration. Test sites in the US, Japan and Australia have copper-coated parts using SPEE3D's technology, enabled by ABB IRB1200 and IRB4600 robots, and installed them within days.

WarpSPEE3D Large Format metal 3D printer. Image courtesy of SPEE3D.

Industry 5.0



Many organisations and factories are implementing Industry 4.0 strategies to improve productivity and process efficiency through the use of existing interconnected advanced technologies, edge computing, in a distributed and intelligent manner. Meanwhile, the arrival of the next wave of industrial revolution, Industry 5.0, is brewing in the background.

One important factor currently being overlooked is humans being able to work harmoniously and collaboratively alongside robots. Current systems lack capabilities to predict the intentions of their human counterparts, and fail to satisfy their needs and demands in a truly flexible and agile manner, operating under partial or full autonomy. We are yet to see a change in the definition of robots where human touch and human problem solving capabilities will be a 'traits' role of any robot, where they can notice, understand and feel, not only the human being but also the goals and expectations of a human operator.

The Directorate-General for Research and Innovation, European Commission is already putting emphasis on Emerging Enabling Technologies for Industry 5.0 through a white paper. At Deakin University, researchers are exploring the use of AI and Machine learning to process human physiological signals, such as fNIRIS and EEG, for robots to be able to predict what task should be executed to achieve a true human cobot collaboration.

Cobot assists engineer in an assembly task. Image courtesy of Deakin University.

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Footnotes

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6

Healthcare and wellness

Robotic technologies that can be applied to clinical healthcare and quality of life are benefitting patients and staff in the healthcare sector

6.1 Healthcare and wellness in Australia

Australia has an ageing population and enjoys one of the highest life expectancies in the world (80.7 years for men and 84.9 years for women in 2018).[1] Yet, almost half of Australians (47% or 11 million people) suffer from a chronic condition,[2] making wellness an important consideration.

Good health is not shared evenly across the Australian population. First Nations Australians (3.3% of the population), those living in rural and remote locations (28%), those with a disability (18%), and those located in low socioeconomic areas, do not benefit from many medical advances to the same extent as other people in the nation. People living in regions such as the Torres Strait, Northern Territory, and remote areas of Victoria and South Australia have higher rates of hospitalisations, deaths, injury and also have poorer access to, and use of, primary health care services, than people living in major cities.[3] Patients outside metropolitan areas have difficulty seeking clinical services and specialised treatments from clinicians who may not work in areas close to them. In areas of high socioeconomic disadvantage, more frequent visits to a general practitioner (GP) are reported with these patients more likely to require complex care – for example, for higher rates of mental health, and multiple chronic conditions.[4]

Snapshot

Healthcare and wellness: What's changed since 2018?

Strengths

- Combinations of AI and data analysis allow for more accurate and faster diagnosis; specifically targeted treatment plans; remote monitoring; and unique medical device development
- Healthcare has become more consumer, outcome and data driven. It is also digitised, AI assisted and value-based
- The use of robotics and AI technology is transforming healthcare with safer, more effective cost-saving technology, treatments, products, clinical services and facilities
- Greater use of telehealth delivery models deliver a consumer-driven value-based approach to healthcare
- Advent of new bionic devices and treatments allowing for remote programming of devices, and access to the cloud and other digital systems
- Changes in healthcare mean a greater variety and quantity of jobs are available

Wins

- Bionic innovations
- Social and logistics robots working together to underpin health and wellness services
- Robotics used for diagnostics, surgery, and automated jobs in healthcare allowing for focus on critical interpersonal relationships with consumers
- Care for our planet through increasing focus on impact, environment, sustainability, waste and recycling of robotic devices

New opportunities

- More reimbursement packages for telepractice
- Increase in focus on sanitation + control of biological threats
- Expansion of remote healthcare, wellness and education training through telepractice
- Societal changes such as flexible working models and work-from-home
- Increase in telepractice acceptance by professionals and consumers

Challenges

- Medico-legal, ethical and professional responsibilities arising from access to personal health records + data
- Equality of access to devices/treatments
- Different healthcare service models not yet developed
- Defining the critical human elements of a particular treatment path which may be automated through robotics and AI
- Education of professionals to accept automation/robotics for back-of-house operations at hospitals with professionals freed up for tasks requiring human skills, empathy and compassion

Realistic 5—year goals

- Infection control measures to be monitored by robotic vision scanning for risks
- Artificial/bionic pancreas and other replacement body parts becoming available
- Improved clinical simulation approaches to training for health and wellness education workers
- Robotic and AI assisted minimally invasive surgery and remote telesurgery. Medical staff understanding how to become competent in the operation and performance of automated robotic surgery
- Affordable physical assistance for aged care workers. Social and logistical assistance for the aged and people with physical or intellectual disabilities including robotic lifters for all patients
- Biofabrication on demand at the point of use for biofabricated body parts, organs, and soft, sensing bionic arms

> The COVID-19 pandemic has seen rapid expansion and/or adoption of telehealth services in Australia to help patients access care from the safety of their home

Health dominates public expenditure and employment. We spent 10% of our GDP ($195.7b) in 2018-19 on health,[5] making it a prime candidate for innovation to both reduce costs and improve outcomes. The healthcare (and social assistance) industry is Australia's largest employer, accounting for 13.9 percent of the working population, or 1.83 million people.[6] It also accounted for 17% of serious workers' compensation claims in 2018-19, totalling 19,505 claims.[7] Healthcare and social assistance workers are a key risk group for injury due to the nature of their daily work. Workers may be exposed to a range of hazards including highly toxic drug and chemical agents, workplace stress, and violence. They also perform physically demanding and repetitive tasks such as lifting patients, and have one of the highest rates of work-related injuries and illnesses.

The COVID-19 pandemic has seen rapid expansion and/or adoption of telehealth services in Australia to help patients access care from the safety of their home, and has also contributed to low rates of infection among staff at GPs.[8] In response to COVID-19, the Australian government fast-tracked the implementation of paperless electronic prescribing, allowing pharmacists to dispense medication on receipt of e-prescriptions from May 2020.[9] They also expanded access to mental health services in the 2020-21 budget, with 20% of these services delivered via telehealth in early 2021.[10] There are concerns that, in the future, there will be a significant increase in patients presenting with mental health issues as well as the downstream effects of people delaying or avoiding seeking care during the pandemic.[11] The pandemic has also had a disproportionate impact on healthcare workers, who face nearly three times the risk of infection than the general community.[12] Healthcare workers are also at greater risk of mental illness, particularly sleep disturbances, post-trauma stress syndromes, depression and anxiety.[13] Residential aged care around the world has faced significant challenges during the pandemic. In Australia there have been 262 outbreaks in aged care facilities with 2,134 patient cases and 2,315 staff cases, with the government responding by increasing funding, providing training to bolster infection prevention and control and providing significant surge workforce assistance.[14]

6.2 Robotics, healthcare and wellness today

Today there are a range of robotic technologies that can be broadly applied to clinical healthcare or to quality of life, with benefits to both patients and healthcare and social assistance workers. Additional general purpose robotic technologies for logistics, material handling, cleaning and monitoring are also increasingly being used in hospitals, aged care facilities or in people's homes in Australia.

The growth of new robot products and services in healthcare and wellness sees service robots applied to:

- Facilitating medical processes by precisely guiding instruments, diagnostic equipment and tools for diagnosis and therapy
- Improving safety and overall quality of medical treatment, reducing patient recovery time and number of subsequent treatments
- Collecting data
- Enhancing the cost-effectiveness of patient care
- Enabling the delivery of services to remote areas (telehealth)
- Assisting the elderly or people with a disability with necessary activities (feeding, lifting, mobility, toileting, bathing and monitoring)
- Rehabilitation, including physical (e.g. powered exoskeletons) and social (emotional) therapy
- Bionics, including robotic limbs
- Improving the training and education of medical personnel by using simulators
- Promoting the use of information in diagnosis and therapy
- Fetch, carry and cleaning tasks to assist healthcare workers in hospitals and aged care facilities.[15]

Medical robotics is one of the most lucrative areas of service robotics with an increase in turnover of 28% in 2019 to US$5.3b, representing 47% of the total turnover of professional service robots. Revenue is mainly driven by expensive robotic surgery systems, like the Da Vinci robot from Intuitive Surgical Solutions, which has performed more than seven million procedures worldwide.[15] Medical robots typically include: surgical, diagnostic, rehabilitation/therapy and telepresence robots. There are many more robots actively deployed in healthcare than those defined as "medical" robots, including: bionics, logistics, cleaning, companion/caring/social, and research/education/training robots.

Surgical robots

Robotic surgery allows doctors to perform complex procedures with more precision, flexibility and control than is possible with conventional techniques, while also being associated with fewer complications, less pain and blood loss, quicker recovery and smaller, less noticeable scars for the patient.[16] In Australia, surgery may be performed at a public hospital (funded by the government) or a private hospital (operated by a private organisation but licensed and regulated by the government). Robotics-Assisted Surgery (RAS) has mainly been applied to minimally-invasive procedures in urology, arthroscopy, gynaecology, colorectal, cardiothoracic, orthopaedic and some general surgery. RAS tends to be restricted to the private hospital sector in Australia and is often used in hospital marketing or by individual medical practitioners to raise the profile of their practice. Australia is a net importer of these types of robots.

Robotic systems used for surgery may be passive, semi-active, or active systems. Passive systems must be directed by the surgeon to perform a task. Semi-active systems, constrain surgical manipulation through feedback to restrict what can be done surgically, while active systems are capable of independently performing tasks without human manipulation through algorithms and other mechanisms.[17] The regulatory, ethical, and legal barriers imposed on medical robots necessitate careful consideration of different levels of autonomy, as well as the context for use.

The use of robotics as assistive technology in surgery was first documented in 1985 with the use of the PUMA 560 system. This was an assistive surgical arm to help perform neurosurgical biopsy. By 1987, the system had developed to be used in laparoscopic surgery and transurethral surgery.

While other operating systems have been developed, it is the Da Vinci surgical platform that has revolutionised robotic surgery. Da Vinci was a research project supported in part by NASA with some interest from the US military. It was approved for use in the USA in 2000. In 2003 the companies behind ZEUS (Computer Motion) and Da Vinci (Intuitive Surgical) merged. The Da Vinci system provides a four-area surgical platform with one camera and three surgical arms, of which two can be in active use at any time. The instruments attached to the arms are introduced into the abdomen or chest via laparoscopic ports. The system allows a minimal access approach to surgery with three dimensional vision (standard laparoscopy is two dimensional). The instruments can move with seven degrees of freedom (movement) around the "wrist" of the instruments, similar to the movement of a human hand rather than being rigid as with laparoscopy. In other words the system is intuitive in many ways, closer to the 3D world of open surgery.

There are now over 5,900 Da Vinci units installed with over 50% being in the USA. More than 8.5 million Da Vinci procedures have been performed worldwide with 55,000 surgeons trained on the system. There are approximately 80 Da Vinci units in Australia, mainly situated in private hospitals.

Advantages of the Da Vinci system include; better precision with seven degrees of freedom, an excellent close-up 3D view of the operating field, ability to dissect and suture using small movements in a confined space, and ergonomically better for the surgeon. Disadvantages include the size of the unit, high costs and training requirements. In Australia the full costs of a Da Vinci Xi can be over $3m with instrument costs at over $3,000 per case and service costs of almost $200,000 per annum. Training can be costly requiring animal lab and simulation training, on site proctoring and subsequent mentoring.

So, what drives Da Vinci and other robotic usage? The evidence base in soft tissue surgery is poor. The probability is that increased precision improves outcomes but there are few level one studies to confirm this. Radical Prostatectomy (RALP) has been the most common procedure performed on this platform as the precision of the system is inferred to produce less damage to nerves and structures that control potency and continence in men, and potentially better cancer clearance with less collateral damage. Despite over 24,000 scientific articles written around the Da Vinci, only one large randomised trial of outcomes against standard open surgery has been published.[18] Although early outcomes, blood loss, time in hospital, were superior for the robotic approach, outcomes at six months were similar between the two groups. There are other trials which suggest that robotic surgery can decrease morbidity from surgery, and may improve cancer outcomes.

Surgical robotics systems hold promise for many more evolutionary steps in years to come. Already single port systems are available to allow operations to be performed through one access point rather than four to six. Remote surgery has already occurred and may become an option, and indeed was considered (and rejected), for battlefield or space exploration surgery. The use of technology to bring in imaging to the operative field or fluorescent dye to identify anatomy or pathology are already feasible. Machine learning and AI may allow the system to recognise potential errors and guide the surgeons' hand. Eventually, parts of procedures, which are repeated in identical fashion, could become truly robotic and the machine could perform operations under supervision and eventually teach new surgeons how to operate. In the end we must evaluate if these surgical systems give benefit to patients, surgeons and our health system.

> There are over 5,900 Da Vinci units installed world wide.

One barrier to the uptake of robotic surgery in public hospitals is the perceived high cost. A study of the actual costs of RAS in Australia suggests it contributes to between 17%-60% of the overall costs of a patient's surgical treatment depending on the volume of RAS surgeries and the surgery type.[19] However, Australia does not have a consistent approach to determining the value of new health technologies, and a values-based approach should look beyond costs to also consider equity of access,[20] which is arguably not being achieved in robotic surgery in Australia. This could be addressed through greater use of remote surgery and telepresence robots. Using 5G networks the first remote RAS was conducted in 2019 with the operating surgeons located kilometers away from the patient on the operating table (back-up surgeons were present for the trial).[15] New communication and network technologies provide the necessary bandwidth and have low enough latencies for surgical procedures, which could allow greater access to healthcare in rural and remote areas of Australia.

One of the newest developments in RAS is super microsurgery, where the surgeon's hand movements are converted into smaller, more precise movements, and performed on the patient by a set of 'robot hands'. This technique stabilises any tremor in the surgeon's movements, which makes the procedure more controlled and thus easier to perform.[15] For instance, in a surgical technique for some types of localised brain surgery, a human expert determines the area to be addressed, the process and the path, all unique to the individual and their disorder. A fully automated system then performs the delicate process of navigating through veins to perform the task. Since 2018, micro and nanotechnology has enhanced and extended this general method. Recent advances in miniaturisation methodologies have contributed to the application of robots in ear, nose, and throat micro-surgical procedures. This robotic surgical area is growing in importance as major providers of equipment issue new capability and a new cohort of trained surgeons and nurses enter practice.

Diagnostic robots

Diagnostic robotics is possibly the best candidate for growth in intelligent robotic systems. Indeed, many of our current diagnostic technologies depend on complex technologies and devices. The extent of knowledge required, and its dynamism, greatly exceeds a human's capability to process. This may result in rare disorders being missed. Precision is essential. Often, hazardous or potentially hazardous material is being transported. In many cases, information from several tests must be fused. As we enter a possible period of serial epidemics and novel pathogens, the requirement for contactless diagnoses, fusing information across tests and patients must be coupled with national reporting, tracking and alert systems.

This area is therefore likely to be driven by device-centric technological innovation rather than function-driven demands. We can expect a number of innovative startups to enter this area, if conditions are suitable. Another area of relevance for robotic technologies will be precision health, where non-intrusive sensing technologies – AI, machine learning and computer/machine vision – will play a significant role.

Capsule-based mini robots can revolutionise current diagnostic techniques, drug delivery, and surgical treatment. Micro-robots are currently being developed that are inserted into the body (capsule endoscopy) to help determine the cause of gastrointestinal symptoms, such as abdominal pain, diarrhea, bleeding, or anemia. A tiny camera contained in the capsule captures images of the gastrointestinal tract as it travels through the body and transmits the images to a computer. A doctor can view the images and then make a diagnosis.[15]

Soon, these immersive robots will be equipped with actuators and be able to navigate inside the human body. The next step will be the development of cell-sized nanobots, even smaller than the capsule robots. These could be introduced into the human body in greater numbers, fulfilling a variety of medical procedures or tasks necessary for health maintenance, such as cleaning arteries, taking biopsies, or fighting cancer cells.[15]

Rehabilitation/therapy/ care robots

More than four million people in Australia have a disability (18% of the population)[21] and there are more than 9,000 lower limb amputations performed in Australia each year.[22] These figures are strong drivers for the development and adoption of rehabilitation robots for therapeutic and rehabilitative procedures to achieve the best – and better – motor or cognitive functional recovery in daily life, for disabled individuals with various conditions. Robotic-assisted therapy can significantly improve controlled motions for everyday function and quality of life.

Similarly, robotic devices can help rehabilitate people injured in car accidents or disabled from arthritis, heart disease, and other conditions. Such devices include exoskeletons – electromechanical structures that patients wear to benefit from "motorised muscles." These powered suits help patients, who have limited or no muscle control, to walk, lift and generally be mobile. Exoskeletons are promising innovations that are expected to make a huge impact in the rehabilitation and enablement of patients who have suffered strokes or spinal injuries, and those who suffer from degenerative neuromuscular diseases such as amyotrophic lateral sclerosis. Challenges are seen in the long-term safety of rehabilitation robots, clinical effect, and cost-benefit of many of these interventions on functional recovery.

Great potential exists in the creation of wearable technologies for rehabilitation. It is now possible to create a unique, personalised digital twin of a patient who has a structural problem, and to use robots to create a personalised robotic prosthesis with intuitive control as well as touch feedback to the wearer. Soft exoskeletons can analyse the wearer's posture, gait, or movement when performing a task, giving important feedback for physiotherapy to ensure strenuous movements are performed in an ergonomic way. Exoskeletons can increasingly provide limited force support or be used to correct walking gait.

Social robots are starting to be used in the treatment of mental/cognitive/

behavioural disorders where therapies are aided by constant presence, human-like qualities or conversational interaction.

Telepresence robots

Most telepresence robots are mobile platforms equipped with screen, video cameras, and user interfaces. They may allow direct connection with medical devices, such as electronic stethoscopes, like the Australian innovation Stethee Pro, otoscopes and ultrasound to transmit data to the remote clinician. These robots enable a healthcare provider to instantly connect with a patient and give real-time attention, assessment, diagnosis, and patient management. In addition, the risk of infection is eliminated.[15] Australians have a strong appetite for remote services with more than 10% of Australians regularly accessing telehealth services in 2021.[23] In the future, these services will also allow virtual medicine connected to a patients' wearable devices, as well as to their connected home. Telehealth will open new, and possibly unexpected, uses for tele-robotics and robot companions designed to help people with cognitive and physical challenges.

Bionics

Bionic implants refer to electronic or mechatronic parts that augment or restore physical functionality to a differently-abled person. Human bionic interfaces bring the prospect of fuller participation for millions of people with untreatable medical conditions. The bionic ear (cochlear implant), invented in Australia, was the world's first moon-shot discovery in human bionics and opened the gate to a wave of potential life changing bionic devices, implants and treatments. The interface between humans and bionic devices has recently expanded to cover not only the ear, but also many other areas of the body, vastly increasing the potential for bionic devices to treat previously untreatable medical conditions. Human bionics now has the potential to not only transform the lives of people with organ problems, brain disease, blindness, limb amputation, paralysis or other disorders, but also to become a high-growth, science-based industry for Australia.

The bionics industry in Australia has grown along four major application areas: vision, hearing, orthopedics, and implants that augment cardiac and neurological functions. The bionic eye consists of bioelectronic implants that restore functional vision to people suffering from partial or total blindness. Auditory bionics create an artificial link between the source of sound and the brain – in this case, with a microelectronic array implanted either in the cochlea or the brain stem. Orthopedic bionics are designed to restore motor functionality (not necessarily sensory functionality) to the physically challenged. Bionic limbs are replacing prosthetic limbs, and are interfaced with a patient's neuromuscular system for limb control – flexing, bending and grasping – using the brain. The damaged peripheral

nerves are bypassed and a new electronic pathway connects the mechatronic limb with the brain. Bionics also covers the class of robots known as "exoskeletons", also covered under "rehabilitation robots".

Logistics robots

In terms of the overall medical sector, this is the largest, most diverse, and most complex in terms of steps. Those steps, for example, may start with a manufactured pharmaceutical, medical device, or sundry supplies and equipment, all of which tend to be created with strong robotic involvement. The supply chain that supports this enterprise and delivery to clinicians is large. The use of robotics in warehousing and delivery has grown as just-in-time delivery lowers carrying costs. Because these back room and supply chain functions are largely unseen and the benefits of robotics are hidden, it is hard to evaluate the growing influence of robotics on current models of care. But to judge from similar sectors the benefits are significant.

Another relatively hidden area is the management of documents, records, and payments. Most of the progress here is with processes that are fully digital – that is, without a robotic element. But much does involve the *physical* management of records, and that is increasingly handled by robots. The increased digitisation of information allows for introduction of robotic services. This continues to be a known problem with guaranteed savings through investment.

In some hospitals robotic porters are programmed to deliver laundry or other goods between departments. Such systems are most often deployed in specially designed facilities with wide corridors and robot specific lifts between floors which allow robo-porter trolleys to move autonomously delivering to the non-patient facing side of the facility. The Sunshine Coast University Hospital, opened in 2017, was designed to include extensive underground tunnels so that automated ground vehicles can be used to transport food, linen and waste underground to service the 165,000 square metre facility.

Pharmacies have also embraced robot technology. Robots are largely used for dispensing and tend to replace menial tasks. There is some evidence that, if used appropriately for managing and dispensing medications, they may reduce medication errors. Such a system was introduced in the Perth Children's hospital incorporating a fully closed loop automated drug management system, administering medication direct to the patient.[24]

Companion/caring/social robots

Companion robots support the infirm, the aged or disabled to stay at home longer rather than become institutionalised. Monitoring patients or residents and taking measurements to assess their status is also a function of care robots. Such robots also fill a critical care gap, which sees an insufficient number of people working in the sector to take on these functions. As interactions between machine and human become more sophisticated, the range of tasks the robots can perform will increase.

Social robots are finding increased use in care environments. The main function of these robots is to increase user interaction, which is why many of them simulate a pet or a toy. Impressive results have been collected from using robots as part of specific therapies towards autism, Alzheimer's disease, and mood or learning disorders. A major product in socially assistive robotics is PARO, an advanced interactive robot developed by the AIST (Japan's National Institute of Advanced Industrial Science and Technology). This robot, resembling a baby seal, allows the documented benefits of animal therapy to be administered to patients in environments such as hospitals and extended care facilities, where real animals present treatment or logistical difficulties. Robot dolls are used to encourage social interaction and communication in children on the autism spectrum.[15]

Research/education/training robots

Funding for medical research often overlaps clinical operations, but the functions are quite different. Robotics and other automated systems are widely used in research because they remove human influence, deal with hazardous material, or require massive numbers of identical operations. In this role, they support operations but not analyses. Separately, a vital sector provides bioinformatic support for all phases of research and often diagnosis. In the past, epidemiological bioinformatics was an independent domain. Since 2018, COVID-19 has completely changed this equation. Clinical and epidemiological information now directly feeds research models, which in turn inform both research and treatment. The evolution has been rapid, and in most cases effective. As with other significant intelligent systems, this makes the area 'robotic ready' for a number of novel applications.

Health professionals will increasingly become clinical data analysts with digital literacy and basic training in AI and data science to support clinical skills. Data visualisation and clinical decision-making support tools will be more available – helping health professionals to better diagnose, develop treatment plans and prescribe the appropriate drugs, exercises or lifestyle – as well as a choice of automated digital tools/apps that can assist professionals in communication, treatment planning, sharing information and education, gaining feedback and making decisions. The use of simulation in health care education has become relevant in order to improve patient safety and quality of care. The adoption of more realistic simulation-based teaching methodologies, which serves as a bridge between the acquisition and application of clinical skills, knowledge, and attributes, increasingly includes robotic simulators for particular medical scenarios.

The human elements for a healthcare and wellness practice remain critical and are complemented – rather than replaced – by digital and robotic tools. These human elements include developing rapport and empathy with the client, necessary physical examinations, and assisting clients to change their behaviour through forms of communication not replicable with a robot.

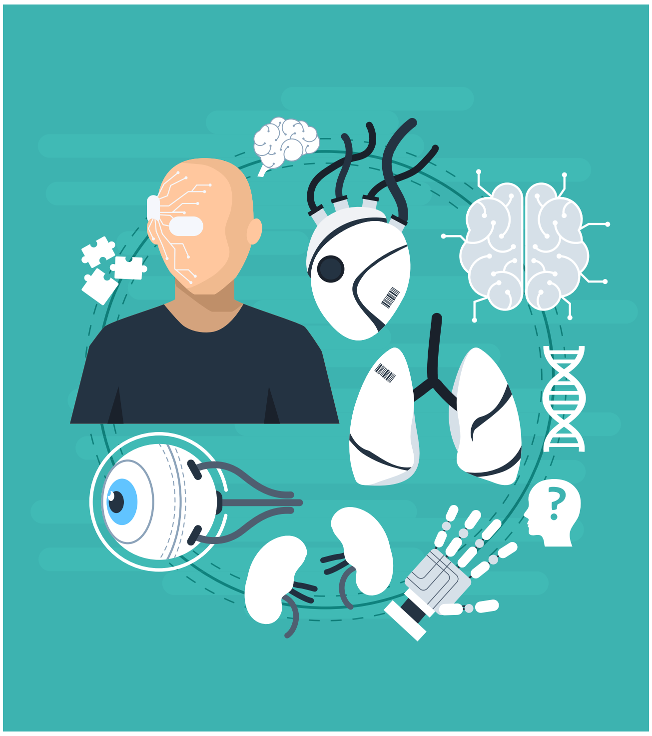
6.3 Impact of COVID-19

In response to the pandemic, existing robots have been adapted and new robots have emerged to assist medical staff in routine testing for COVID-19, caring for patients, and to assist with physical distancing and removing healthcare workers from harm's way – for example, by facilitating telehealth consultations, and through the use of UV disinfection robots for cleaning hospital rooms and common areas.

Robots applied in pathology laboratories can automate testing, allowing for faster processing of samples, increased volumes, and the rapid return of answers to people.[25] Lifeline Robotics developed a prototype system that can take throat swabs for virus testing, reducing the number of personnel required for the testing process and hence the risk of infection for medical staff.[15] Telepresence robots increasingly enable doctors to examine patients from a distance, acquiring basic information such as temperature, blood pressure, etc.[25] InTouch Vita, developed a mobile robotic platform that hosts a panoramic visualisation system, intuitive interfaces, and allows direct connection of medical devices such as electronic stethoscopes, otoscopes, and ultrasound for transmitting data to the remote doctor.[15] As long as direct bedside care providers are available, remote-controlled, robotic tele-medicine technology is increasingly being used, which will have clear benefits after the pandemic for those living in rural and remote parts of Australia.

6.4 The future of robotics in healthcare and wellness

Future developments will enhance the results of robotic technology applied in healthcare. Haptic feedback will tell practitioners what they feel as well as what they see. AI will help the machine correct a surgeon's defects and may eventually train the machine to perform operations.



Melding imaging technology with human vision will improve accuracy of surgery, while 3D printing and imaging will improve planning of procedures. Eventually, heads up and virtual technology will help us deliver care in an environment which allows an entire surgical team, not just the surgeon, to be part of the operation.

Application of robots in healthcare settings is likely to increase as the technologies mature and become more capable, reliable, trustworthy and cost effective. However socio-technical barriers to implementation remain, associated with the disruptive nature of these technologies. These include: no clear pull from healthcare workers and patients and societal distrust of robots; the appearance of robots, either too "robotic" or too human-like; required changes to existing roles and workflows; and lack of existing ethical and legal frameworks.[26]

If we had a crystal ball to consider what the future of robotics applied to healthcare and wellness might look like, it would involve:

- Liberating the elderly to live at home longer with assistance from a range of capable mobile, lifting and social robots
- Community robot hubs located in parks and libraries to engage with people, provide community support to encourage health consciousness, and promote basic living skills
- Direct real-time 3D mapping and printing of human materials at the point of surgery to replace damaged or diseased material
- Continuing development of bionics for both prosthetics and implants
- Full range of healthcare diagnostics able to be conducted remotely with the assistance of telepresence robots and digital health tools
- All back-of-house functions in hospitals and care facilities, such as cleaning, waste removal, laundry, meal preparation and delivery etc., conducted by robots, freeing up staff to spend time with patients
- Ingestible micro-robots that will detect, diagnose and treat medical conditions
- Social robots used to help understand meaning and intent, to make healthcare more accessible to people who may have English as a second language or who have communication challenges

- Robots as disability aids, e.g. robotic guide dogs
- Increased use of exoskeletons in both rehabilitation, and to support frontline healthcare workers
- Medicines and medical services delivered and dispensed in people's own homes, or directly to emergency services to enable care to be provided at accident sites without the need to transport patients.

The realisation of this future requires fusion between the medical and engineering professions, to ensure robots are infused with critical domain knowledge. This may involve bootstrapping of medical knowledge for physical perception, e.g. understanding what medical professionals learn at university that make them safe and competent professionals, that can be transferred to medical robotics and AI. There are also some fundamental advances required in physical perception of shape, movement, material properties and mechanical structure to realise the future of robotics in healthcare. This is the critical grounding required for semantic and causal comprehension for robotic technologies, especially those that must physically interact with people. Effective physical interaction will require the development of humanoid robotic hands that have the sensitivity, dexterity and robustness to perform the tangible tasks of patient care. This will best be achieved by functional emulation of human musculoskeletal and dermal anatomy. Such hands will need to be integrated into the tactile/proprioceptive side of the physical perception system.

6.5 Main findings for robotics in healthcare and wellness

Advances in robotics (including AI) can assist with the provision of medical, pharmaceutical and imaging services to rural, remote and disadvantaged communities and can aid in the detection, diagnosis, treatment, and management of diseases.

Australia is well placed to take advantage of telepresence robots to provide specialist services to these communities.

Such remote services may also help with the anticipated rise of mental health issues for all Australians post the COVID-19 pandemic. Australia is a wealthy nation where health dominates public expenditure, yet challenges to adoption of new disruptive technologies could stifle innovation. Although healthcare and social assistance are Australia's largest employers, working in the sector can be hazardous. It may involve physically demanding and repetitive tasks, high levels of workplace stress, and violence. The sector has one of the highest rates of work-related injuries and illnesses, predominantly due to regular people handling. Robotics can help to address these workplace issues by reducing manual handling and repetition, and reducing stress through the deployment of social robots. This will minimise some of the physical demands placed on our healthcare professionals and enable them to undertake alternate value-adding activities.

Case studies

ROBERT® — Pushing the limits of true recovery

ROBERT® is a rehabilitation robot offering passive and active mobilisation for the lower extremities, able to treat patients up to 160kg. Exercises can be tailored to the individual patient's needs and the operator 'shows' the exercise once to the robot, which can then be repeated precisely and as many times as requested.

Exercises can be done in various positions, supine, prone or lateral position. Resistance levels can be adjusted according to the functional ability of the patient. These benefits relieve staff from heavy and repetitive lifting tasks whilst being able to obtain a greater number of repetitions in the same amount of time.

Australian studies from, among others, Prof. Dr. Louise Ada have proven that stroke patients and others with incomplete spinal cord injuries experience faster recovery when receiving early intensive care with high amounts of repetitions. The ability to self-train at their own pace with ROBERT® enhances motivation and improves patient outcomes. Training data from the session enables process tracking and physical contact with the patient can be reduced to a minimum. The goal is to improve work environments, reduce work-related injuries and hence reduce sick leave, enabling practitioners to stay on the job market for longer while giving patients the training they need on a daily basis.

ROBERT®: combining the physiotherapist's expertise with innovative technology, planning treatment is easy and fast. Image courtesy of Stable Orthopaedics.

Socially-assistive robots in therapy and education

For many people living with autism spectrum disorder and/or an intellectual disability, developing academic skills as well as communication and social interaction skills can be a significant challenge. Often, these individuals need additional support to improve their competence in these areas.

CSIRO's Australian e-Health Research Centre, led by Dr David Silvera-Tawil in collaboration with the University of New South Wales, Autism Spectrum Australia and the Murray Bridge High School in South Australia, has developed novel interventions, a software platform and artificial intelligence (AI) algorithms to facilitate the integration of social robots into therapy and education for young people with intellectual disability and autism.

A number of robots were trialled: NAO and PARO were evaluated in a longitudinal (24-month) study in a public secondary school to support students across a range of disciplines, from science and exercise to social skills and emotion regulation; and the humanoid robot Kaspar was trialled in a clinical setting, where a therapist facilitated the robot's interaction one-on-one with children, specifically focussing on developing children's social and communication skills. These studies show that social robots have the potential to enrich the learning experiences of students. Importantly, some of the benefits observed in participants when they interacted with robots were also transferring to their interactions with other people.

Kaspar Robot (University of Hertfordshire), interacting with a student. Image courtesy of Australian e-Health Research Centre.

RoboUV

The RoboUV is an autonomous mobile robot solution designed specifically to kill and disinfect virus. It is used for disinfecting rooms and high-touch points surfaces automatically in hospitals, clinics, hotels, offices, retail, and shopping centres. The RoboUV's UVC light breaks down the DBA and RNA chains of the cells of micro-organisms beyond recovery. This disables the function of the cell and eventually kills it.

It autonomously navigates to all the high touch points in a facility and then safely disinfects them using UV light. The RobotUV calculates the proper disinfection exposure and then scans the immediate area for any humans while the process is occurring. Autonomous disinfection helps ensure that the process is tracked and recorded and will send an alert if any step in the process fails.

Lamson RoboUV. Image courtesy of Lamson.

Low profile, flexible exoskeleton for 'assist as needed' walking

University of Queensland-based Dr Alejandro Melendez-Calderon is leading the development of a low profile, flexible, economical and lightweight wearable device for 'assist-as-needed' walking. The goal of his international research team is to deliver a wearable robot that is functionally valuable, safe and intuitive; automatically adjusting its level of assistance according to the user's residual neuromuscular activity at any given time.

Stroke and musculoskeletal disorders are among Australia's leading causes of physical disability, and related health-care delivery has traditionally absorbed significant government expenditure. Walking aids and passive orthoses are commonly prescribed solutions for people with partial mobility loss. Ankle-foot-orthoses (AFOs) are typically used for stroke, cerebral palsy, spinal cord injury, and for nervous or vascular issues of the foot (e.g. consequent to diabetes).

One major drawback of AFOs is that they are passive devices that alter the biomechanics of walking and inhibit active neuromuscular contributions from the user. In contrast, a wearable robot (i.e. exoskeletons or powered orthoses) that are unobtrusive, assist with daily living activities and work for long periods of time, can revolutionise the management of mobility impairments. Dr Alejandro Melendez-Calderon and his team (Bionics Queensland Challenge 2020 finalists) are working on a lightweight robotic ankle exoskeleton for patients with foot drop, a solution that will be personalised to user-specific parameters.

Dr Alejandro Melendez-Calderon. Image courtesy of Bionics Queensland.

Pepper robot trials at the Townsville University Hospital

In late 2018, nurses Anne Elvin and Chris McIntosh of the Townsville University Hospital collaborated with the Social Robotics Team (led by project manager Belinda Ward) of the ARC Centre of Excellence for Robotic Vision at the Queensland University of Technology. Together they developed demonstration applications for the Pepper robot of SoftBank Robotics. The robot applications were the foundation for research conducted by nursing researchers from the Townsville University Hospital and James Cook University. The Pepper Study Team included Dr Wendy Smyth, Anne Elvin, Chris McIntosh, Professor Cate Nagle and Professor Melanie Birks.

The projects were the first Australian hospital trials to investigate the acceptability and usability of a humanoid social robot in health information delivery in an acute care setting and to explore potential for social robots to influence health literacy. The researchers examined the robot's appeal while collecting information about people's knowledge and attitudes towards social robots, influenza and vaccination. In two separate studies, human reactions to the robot were observed and the robot collected survey data in the Emergency Short Stay Unit and the main lobby of the hospital.

During the trials the robot proved very popular amongst staff, patients and visitors. These trials highlighted the real-world potential for this emerging technology to be made available in a variety of clinical settings and as a valuable tool to assist Australian healthcare providers in information delivery and patient education.

Like this family, Pepper interactions were enjoyed by a broad range of people of all ages. Image courtesy of Townsville Hospital.

New Children Hospital Perth — Automated Guided Vehicle System (AGVS)

Following a successful deployment of an Automated Guided Vehicle System (AGVS) in another hospital, WA Health decided to implement a sophisticated transport robot solution for the new Children Hospital. The New Perth Children Hospital was built to replace the old Princess Margaret Hospital for Children and was officially opened in May 2018. WA Health engaged consultants from Germany to design a world-first closed cycle waste solution in a hospital. Lamson was engaged to provide a turnkey system for the transport of meals, linen and waste.

The unique design feature is a no-touch solution for waste. After placing the waste bin for disposal, the AGVS automatically returns an empty and disinfected bin. This process reduces bio-hazard risk to staff and improves logistics in the hospital. The system includes a fleet of AGVs, conveyor buffers, robotic arms, automated waste tippers, industrial trolley washer and an automated vision and weighing system. The system is designed to transport up to 500 trolleys a day and to empty and disinfect waste bins.

AGV handing over trolley to automated waste tipper with a weighing scale for accounting purpose. Image courtesy of Lamson.

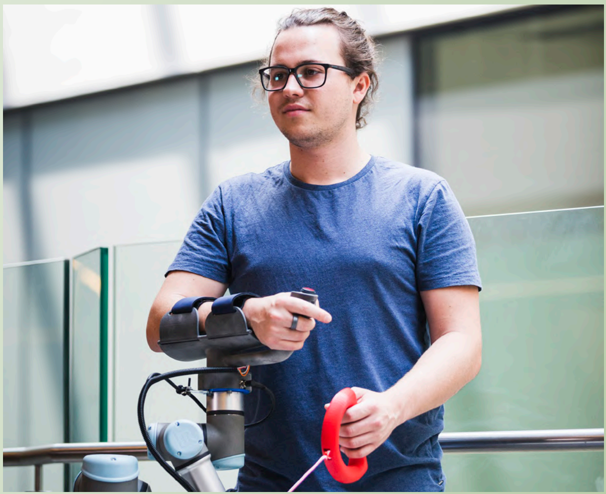
Universal robots' automation to provide more patient access to therapy in Australia

Rowan Smith is the CEO of Tech Gym, a University of Technology Sydney (UTS) startup. In 2017, Rowan's grandma suffered a stroke and had to undergo extensive rehabilitation. It was during this time that he recognised a need to provide easier access to physical therapy through technology. Putting his bachelor's degree in Mechanical and Mechatronics to good use, Rowan developed Tech Gym which makes use of Universal Robots collaborative robot (cobot) technology and intelligent programming to provide therapy to patients by mimicking human movements.

In the product development phase, Tech Gym worked closely with a team of physio, clinical and occupational therapists. Astoundingly, the B1 prototype did all the rehabilitation work. Soon thereafter they added sensors. In this way cobots can be set up in-line with where the patient is in their rehabilitation journey. For instance, if a patient requires more resistance in the various movements, this can be achieved. Beyond the physical capabilities, Tech Gym truly instils confidence in patients.

Tech Gym has received their clinical trial after two years of R&D and their prototype is now ready to be trialled at South West Sydney Hospital.

CEO of Tech Gym, Rowan Smith works with a collaborative robot to automate rehabilitation. Image courtesy of UTS - TechGym.



Soft robotic glove to deliver 'intuitive grasp'

UQ Research Fellow in Bio-Medical Engineering, Dr Antonio Padilha Lanari Bo and his team are seeking to restore hand function via a hybrid wearable that includes a soft robotic glove and functional electrical stimulation (FES). The loss of hand function in any individual significantly impacts their quality of life and ability to perform daily activities. Potential contributors to the loss of hand function are conditions such as arthritis, polio, Traumatic Brain Injury (TBI), cerebral palsy, stroke and Spinal Cord Injury (SCI).

For more than 50% of people with SCI, paralysis of upper limbs gives rise to tetraplegia. Physiotherapy and occupational therapies are used to improve hand function, but benefits can be limited. Bionic innovations are an emerging option e.g. robotic orthoses or exoskeletons mounted on upper limbs that use actuators to produce body motion. However, the need to customise solutions to users has impeded commercialisation so far.

Dr Bo's team has found that wearable sensors coupled with advanced machine learning can deliver a reliable and flexible control interface. They have compared the use of inertial and electromyography sensors to control a robotic hand in clinical tests, delivering an intuitive and predictable control interface. Clinical investigations also evaluate separately different aspect of both robotics and FES-based control of hand grasping. Pending further development and clinical testing, a soft robotics glove integrating electrodes, sensors, and AI-enabled algorithms could give intuitive hand movement to millions of people living with tetraplegia.

Dr Bochkezanian in early clinical testing of the technology at Central Queensland University (CQU). Dr Vanesa Bochkezanian, CQU.

Contributors

This chapter was based on a workshop held on 10 March 2020 in Brisbane, QLD with contributions from the individuals listed below:

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Ajay Pandey (QUT)
Robyn Stokes (Bionics Queensland)
Denny Oetomo (Univ. Melbourne)
Olivier Salvado (CSIRO's Data61)
Paul Carboon (MicroBio)

Footnotes

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7

Services

Robotics capabilities have improved by necessity during the pandemic. Demand for robotics has increased as people have been forced to work from home

The term 'services' applies to all activity in the economy not directed at the production of 'goods', and ranges from online retail to medical services and tourism operations. It covers a diverse range in the nature of its outputs and methods of production, and is increasingly important for our future wellbeing.

Knowledge intensity is an important characteristic that differentiates services from other sectors of the economy, and reflects the degree of independence and freedom of planning and organising tasks that need to be performed on the job.

Different services have a varying level of impact on the Australian economy. The next sections look at how robotic technologies have already infiltrated Australia's services sector and what might be expected in the future. Note the distinction between the services sector of the economy and the term 'service robots', which describes a relatively new class of non-industrial robots that perform useful tasks for humans or equipment. Service robots have a key role to play in addressing societal challenges such as demographic change, health and well-being, transport and security.

What industries are service industries?

Distribution services
wholesale and retail trade, transport and storage, IT and communications

Social (non-market) services
health and community services, education, emergency services (police, ambulance, firefighters and state emergency services), government administration and defence

Business services
property and business services, finance and insurance

Personal services
tourism, accommodation, hospitality, cafes and restaurants, cleaning, security, personal and other services, entertainment, cultural and recreational services

Utilities
electricity, gas and water

Construction
building and demolition (see the Construction Chapter)

Snapshot

Services: What's changed since 2018?

Strengths

- Services now accounts for 80% of Australia's GDP (compared to 70% in 2017)
- Demand for robotics has increased as people have pivoted to 'work-from-home'
- Robotics capabilities have improved by necessity during the pandemic

Wins

- Large-scale automation projects are moving beyond Resources and into the Services sector (e.g. supermarket chains)
- Australian accents are recognised and correctly interpreted due to rapid improvements in Natural Language Processing
- Investment in robotics has increased

New opportunities

- Increased appetite for robotics to support critical supply chain operations
- SMEs can participate in robotic deployments thanks to 3D printing and open source design
- Increased talent supply into robotics, mechatronics graduate numbers are increasing

Challenges

- The Services sector exports are down by 14% due to the pandemic
- Growth in the sector
- Reduced size of working population (if no changes to immigration policy)
- Ageing population
- Adaptation of more highly skilled workforce
- Competition from emerging knowledge economies

Realistic 5—year goals

- Autonomous vehicles (for transport of people and goods)
- Inspection robots (construction, utilities, retail)
- Visual verification technologies
- Social/service robots helping in aged care, healthcare and retail
- Telepresence robots, shared autonomy robotics, chatbots and virtual assistants
- Integration between robotic technologies and built environment technologies (e.g. elevators, doors, dock levellers)

WHAT IS A SERVICE ROBOT?

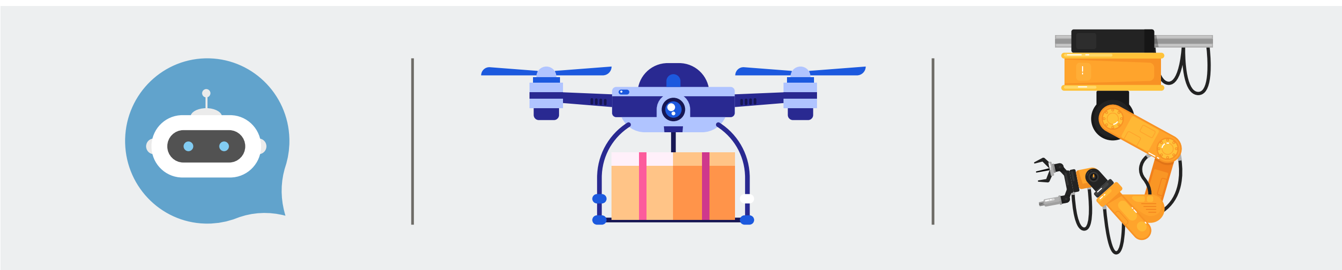
Robots are often broadly termed either 'industrial' or 'service' robots, with the former typically in industrial settings and the latter in service settings. The first robots deployed in manufacturing in 1961 were industrial robots. They are highly specialised, automatically controlled machines that can be reprogrammed, and can be classified according to the number of axes – three, four, five, six, or more. Service robots are a recent phenomenon, apparent only since the 2000s, yet their numbers are now outstripping those of industrial robots.[1] Service robots may be distinguished according to the scale at which they are used. Service robots that help individuals or households are called 'domestic', 'personal' or sometimes 'consumer' robots, while robots that operate on a larger scale, e.g. helping in a warehouse, are called 'industrial', 'commercial' or 'professional' service robots.

7.1 Australia's services sector

Australia's services sector is critical to our overall economy. Services employ 88% of Australian workers and accounts for around 79% of our GDP.[2] Services have become an increasingly important component of Australia's export revenue, with education-related and personal travel, professional, ICT, financial and technical services all in the top 15 export categories.[3] If the value of intermediate services is captured, the services sector contributes over 45% of our value-added export earnings.

As with most mature economies over the last 70 years, Australia has seen a shift away from primary production and manufacturing (which used to employ 50% of Australians in the 1950s) and towards service provision. This makes improvements to productivity in the Services sector very important to the Australian economy, and these are best achieved by digitisation and adoption of emerging technologies, such as robotics. While some parts of the Services sector such as finance, ICT and transport have seen significant productivity growth compared to the goods sector, more labour intensive services have seen persistently low productivity gains.

While high-skilled workers predominate, the absolute size of the services sector means that it is also a major employer of low-skilled workers. Such workers earn higher wages in the Services sector than in other industries, possibly due to access to on-the-job training. 24% of Australian workers are casual, reflecting a growing trend towards casualisation of the workforce since the early 1980s.[2] Although service jobs are clustered around Australia's coastline, particularly in capital cities, service workers also dominate (75%) employment in non-metropolitan regions. Any impact on services jobs has a widespread impact on the Australian community.



7.2 Impact of COVID-19

Australia is experiencing its first recession in nearly 30 years due to COVID-19 and parts of the Services sector, such as hospitality, accommodation, recreation and retail, have been hit hard.

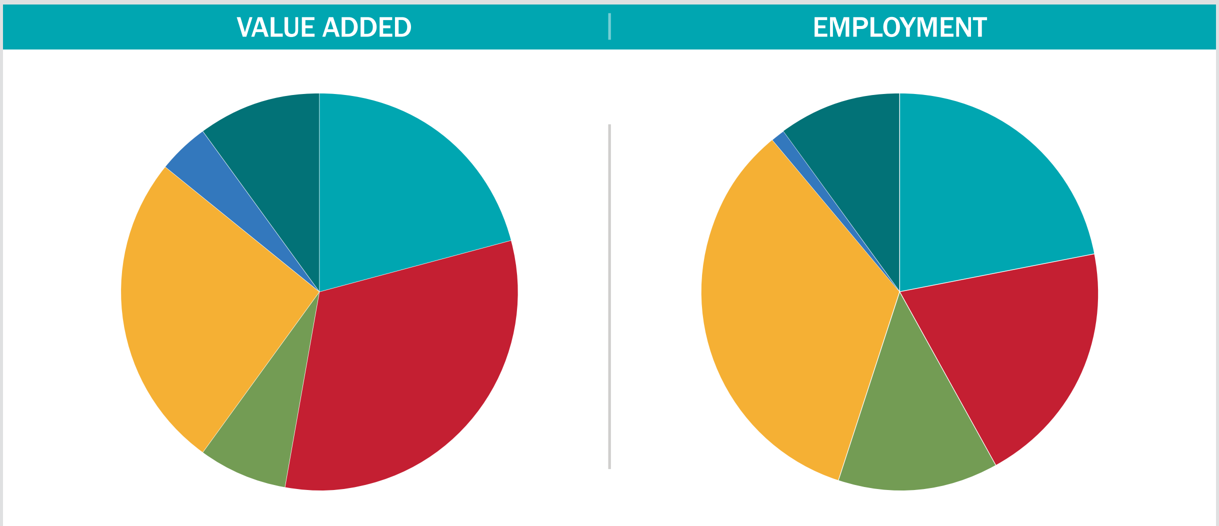
In the first few months of the pandemic, the food and accommodation industry laid off a third of its employees, and the recreation industry shed nearly 30% of its workforce.[2] While employment has since improved, the impact of COVID-19 continues to impact on this sector disproportionately compared to other sectors of the Australian economy.

The closure of Australia's borders has also seen a dramatic drop in some services exports. There are four modes of supply for the services we export:

- *cross-border supply* – where services are transferred digitally or by post and do not require movement of consumer or supplier
- *consumption abroad* – where the consumer moves to Australia to get the service (e.g. tourism or tertiary education)
- *commercial presence* – where the supplier sets up operations in another country to supply services
- *movement of natural persons* – where the supplier moves across borders to deliver services (e.g. an expert travelling overseas to consult).

International travel restrictions have severely impacted *consumption abroad* (Tourism and International Student numbers) and *movement of natural persons* where Australian providers travel abroad to deliver services. However, there is a rise in cross-border supply, particularly via digital technology and this is expected to increase as businesses innovate and adapt their service delivery models to digital platforms.[3] In general, the COVID-19 pandemic has accelerated the use of technology to allow many services to be delivered remotely to support working from home requirements, conform with travel restrictions and reduce the risk of human-to-human contact.

Value of the different services sectors to the Australian economy[4]



Distribution
Transport, postal and warehousing
Information, media and telecommunications*
Retail trade
Wholesale trade

Business
Professional, scientific and technical services*
Financial and insurance services*
Rental, hiring and real estate services
Administrative and support services

Personal
Accommodation and food services
Arts and recreation services*
Other

Social (non-market)
Education and training*
Public administration and safety
Healthcare and social assistance*

Utilities
Electricity, gas, water and waste services*

Construction

**Services considered "knowledge-intensive"[5]*

7.3 Robotics and the services sector today

There are multiple reasons that the Services sector in Australia will be impacted by robotics. In general, knowledge-intensive services show more possibilities to scale-up and automate routine tasks because they exhibit relatively lower routine content, higher capital intensity, higher R&D intensity and higher allocative efficiency.

For this reason, knowledge intensive services have higher productivity levels than less knowledge intensive ones, with the exception of the trade sector. Retail and wholesale trade has experienced relatively high productivity growth despite being strongly localised and generally less knowledge intensive. The trade sector has benefited from the use of technology to transform supply chains and improve managerial and operational processes to improve productivity.[5]

The accelerating rate of technological change, and increasing penetration of mobile devices, combined with shifting customer preferences will have dramatic implications for the ways in which services are structured, delivered and consumed. Digital platforms and rating systems offer new possibilities to enhance competition between service providers by reducing information asymmetries and barriers to entry. Advances in communication technologies increase service tradability by enabling a growing range of traditional and digital services to be delivered at a distance. Artificial intelligence and advanced robotics are good at automating the cognitive tasks that are typical of service activities such as driving a car, which may transform certain localised lower-skilled industries into non-localised higher-skilled ones.

This type of automation requires an increase in demand for people with skills to deal with machines (e.g. programming) or that are complementary to machines (e.g. "soft" interpersonal skills).[6] However, the demand for these skills is likely to be concentrated in the cities where knowledge intensive service activities, such as ICT, are concentrated, resulting in job losses in the regions (where localised services predominate).[5]

> The trade sector has benefited from the use of technology to improve and transform supply chains.

There is a strong correlation between firms that adopt advanced technologies such as robotics, and those that have also adopted digitisation and cloud services, suggesting some interdependency and the potential need for staged adoption of different technologies.[7] The adoption of robotics in different parts of the services sector is also interrelated with worldwide trends related to the maturity of robotics technology for different applications. In general these include:

- An ageing workforce, unable to sustain current practices and also leading to under-resourcing in some sectors, such as aged care
- Expectation of our younger workforce, who are less likely to want to do direct manual labour, but view working with robots as more normalised
- Increased online purchasing and consumer choice increases the pressure for mass customisation, adding complexity to current warehouse, fulfilment, and transport infrastructure
- Australia's long distances between major centres, mainly serviced by road transport, which puts human drivers at risk
- Smaller regional centres are often serviced less than major centres. Robotics could make more frequent servicing of these towns viable, as well as a range of other benefits supporting online education and healthcare delivery.

Logistics

There are many ways in which robotics are being applied in the Services sector today. Logistics is an area where automated ground vehicles (AGVs) are increasingly playing a role transporting goods in warehouses and storage facilities and also for back-of-house functions in many large-scale operations, such as hospitals and aged care facilities. AGVs are equipped with containers to store goods, or as towing trailers or as automated forklifts, or may have mobile manipulation capabilities (article transfer belts, slides or arms for loading and unloading, and manipulators for handling material). Australia led the development of autonomous stevedoring with the invention of autonomous straddle carriers to transport shipping containers around ports. A special class of logistics robot (also used in rehabilitation) are exoskeletons. Exoskeletons are active mechanical devices worn by an operator to reduce load on the spine, hips and/or shoulder when lifting heavy weights.

The main advantages of these systems is workplace safety (eliminating lifting injuries), reduced need for manual labour, increased productivity and increased inventory accuracy. Logistics robots are experiencing the greatest growth of any service robots with a projected compound annual growth rate (CAGR) for 2020-2023 of 42%.[1]

Cleaning

Robots used for industrial cleaning (as opposed to home robotic vacuum cleaners) is a growing corporate service area. The adoption of robotics is driven by labour costs, which comprise 70% to 80% of costs, with floor cleaning representing 60% of the cleaning task. Cleaning robots eliminate certain types of cleaning work, which frees employees to do more skilled tasks. The demand for cleaning robots has exploded due to COVID-19 with the need for robots to perform disinfection tasks both indoors and outdoors to protect the human workforce from exposure to coronavirus. Specialised disinfection robots that either spray chemicals such as hydrogen peroxide, filter air, or emit high frequency ultraviolet light (UV-C) have been in demand while existing robot platforms were also modified to serve disinfection tasks. There is high potential to combine facilities management services, for example, cleaning robots that double as surveillance robots for security rounds, and also for logistics services. Cleaning robots are increasingly being developed for more challenging applications, such as cleaning of building facades, windows and solar panels. They are also being developed to clean tanks, tubes and pipes, which is closely related to the development of inspection robots, particularly useful for the Utilities sector.[1]

Inspection

Inspection tasks are usually manually conducted and are extremely hazardous as they may involve working in confined spaces. In Australia, fifty-nine confined space related deaths were identified over the period 2000-2012, an average rate of 0.05 deaths per 100,000 workers.[8] Australia has a vast network of critical infrastructure assets, required to deliver water and energy to homes and workplaces, and to remove waste. Australia's electricity grid spans more than 5,000 kilometres and is one of the largest interconnected power systems in the world. Australia has more than 37,000 kilometres of natural gas transmission pipelines. Sydney alone maintains more than 21,000 kilometres of water pipes, with 243 reservoirs and 150 water pumping stations. For wastewater there are more than 25,000 kilometres of pipes, 16 treatment plants, 14 recycling plants, and 677 wastewater pumping stations. Inspection robots must be mobile and may need to operate on the ground, in the air or underwater. They need to be outfitted with sensors to collect information as well as communication units for teleoperation or sensor signal transmission, and may link into an operations centre. The main goal of inspection robots is to lower the health risks to workers associated with radiation, toxic gases and high temperatures, often combined with confined spaces.[1]

Rescue and security

Another area of robotics important to the Services sector is in the area of rescue and security. There is some overlap in the robotic platforms used for rescue and security and those used for inspection, cleaning and defence. Such robots may be used for fire-fighting, bomb disposal, disaster response and relief, and are mainly applied by emergency services. Interestingly, the robots are typically only deployed if the responding agency owns the robot, rather than if they have to borrow one.[9]

Intelligent security robots are more widely deployed, patrolling autonomously, building models of their environment and flagging suspicious activities and providing real-time response, either autonomously or via remote pilots. Surveillance robots are being trialled in a range of settings and could be used in challenging operations, like prison security or to monitor occupational health and safety in workplaces. The relatively high cost of these robots has restricted their use to areas that justify the high costs, where surveillance by people is tedious, costly or hazardous.[1]

Social robots

Social robots are a class of robots mainly restricted to use in the Services sector where they can be applied to social services, education, retail, banking, hospitality, tourism and other customer-facing roles. Social robots are designed to interact with humans and can have a range of applications, from concierge robots working on hotel front desks, to public health education, where robots are used to reduce the workload on healthcare professionals by tackling repetitive tasks. The main benefit of these technologies is their ability to act as a force multiplier in areas traditionally under-resourced, such as education. Robots are being trialled and adopted for behavioural and therapeutic interventions that can benefit social workers, teachers and police.

The organisation Missing Schools[10] assists schools in providing telepresence solutions for students that have ongoing issues that mean they can't attend school. Australians have not yet been exposed to social robots designed to manipulate or 'nudge' their responses. The introduction of these technologies may fundamentally shift the relationship the Australian public has with, and the feelings they experience towards, robots.

Other robots

There are many other types of robots applied in the Services sector and new use cases are being explored all the time for example restaurant robots free personnel from routine tasks such as food preparation, serving and customer-service. Melbourne has its own robotic ice cream shop by Niska, and robotic coffee kiosks are found in San Francisco. Robots can reduce labour costs in the delivery of personal services by assisting or replacing human workers, and many are available in the consumer market, such as vacuum-cleaning, pool-cleaning, lawn-mowing, home security, education, aged care, disability and toy/hobby robots. The application of robots to aged care and disability is mainly around manipulation and mobility assistance, e.g. autonomous wheelchairs and robots that help with tasks such as feeding. The use of robots is known to stimulate users and can improve coordination and physical condition.[1]

COVID-19 has seen an increase in demand for robotics as people reduce face-to-face interactions and many goods and services are delivered directly to people's homes for safety and security. The pandemic has posed a significant threat to people working in the Services sector where working in close-proximity is required, particularly in healthcare, retail and hospitality services. This has opened up several new opportunities for the application of robotic technologies. There has been increased interest in the use of telepresence robots and the need to reduce human-contact for point-of-contact services and essential services, such as food preparation, opens the opportunity for further automation, using technologies such as cobots. Whereas telepresence robots and plant automation either distance and reduce the presence of people, cobots fill in the roles where human-presence is still required but enables physical distancing to be maintained.

Where does Australia rank?

Data on sales of service robots to different countries is currently unavailable. Australia does not rank in the top ten countries that manufacture service robots but is recognised for developing mobile guidance robots, education robots and field robots that can be applied to defence, resources, construction, and infrastructure inspection and maintenance.[11]

Global Trends in robotics in industries related to the Services sector[1, 12]

Service sector	Relevant service robot category	Units sold 2019	CAGR
Distribution • Transport, postal, warehousing • Information, media and telecommunications • Retail trade • Wholesale trade	Logistics	74,647	+53%
Business • Professional, scientific and technical services • Financial and insurance services • Rental, hiring and real estate Services • Administrative and support services	Logistics	3,837	+25%
	Other cleaning	1,185	+274%
Personal • Accommodation and food services • Arts and recreation services • Other	Robots for public environments	20,043	+40%
	Robots for domestic tasks	18,593,928	+27%
	Toy and hobby	4,132,894	+10%
Social (non-market) • Accommodation and food services • Arts and recreation services • Other	Education and research	487,743	+8%
	Medical	8,900	+34%
	Elderly and handicap assistance	12,218	+46%
	Defense	18,914	+14%
	Mobile platforms	495	+41%
Utilities • Electricity, gas, water and waste services	Solar panel cleaning	7,498	+25%
	Pipe cleaning	497	+16%
	Inspection and Maintenance Robots	14,858	+22%
Construction	Construction and demolition	1,198	+17%

7.4 The future of robotics in the services sector

Over the next five years, the continued impacts of the global pandemic will act as a catalyst for the market pull towards robotics adoption and use. The transformation of numerous service sectors to automate processes in response to health concerns will further embed the need for robotics in various applications.

With a market shift from a push strategy, whereby robotic manufacturers have focused on selling the benefits of enhanced robotic adoption, to a pull strategy aligned with new sector practices – and automation at the core of business practice – we can anticipate a growth in not only the adoption of robotics, but a reduction in the perceived risks and barriers to adoption the sector has experienced over the past few years.

Some of the robotic technologies we are likely to see in the future in the Services sector include:

- Autonomous on-road vehicles for logistics and passenger transport
- Self-serve retail with robot shop assistants, shelf stackers and inventory management
- Expanded capabilities on warehousing robots leading to people-free warehouses
- PR robots to guide people and improve customer experience
- Ubiquitous use of robot ballistic shields to protect emergency service workers
- Response robots that are truly autonomous (not remote-controlled)
- Customised exoskeletons and bionics
- Affordable companion robots.

7.5 Main findings for robotics in the services sector

Service robots have a key role to play in addressing societal challenges, such as demographic change, health and well-being, transport, and security – or more specifically, safeguarding human lives, protecting people from injury, and completing dangerous tasks such as lifting heavy objects.

Like most developed countries, Australia's population is ageing due to sustained low fertility and increasing life expectancy. This has resulted in proportionally fewer children (under 15 years of age) in the population and a proportionately greater increase in those aged 65 and over. This means that there will be fewer workers available in the future to take on many roles in the economy and robotics will become an imperative.

Case studies

SPYDER — Autonomous facade cleaning and condition reporting solution

There are long existing pain-points for managers of building facades in a CBD and similar assets in suburban and remote locations. Present technology only allows humans to access these structures using Building Maintenance Units (BMUs), cherry pickers or scaffolds.

The cost and time components are substantial, and the safety performance using these means leaves a lot to be desired. YellowFIN Robotic Solutions' SPYDER prototype is being developed to provide a one-stop solution for asset managers to wash, clean, inspect, evaluate and report on their industrial assets and determine corrective maintenance.

The SPYDER will use cable-robotics to autonomously manoeuvre itself along the face of the asset using proprietary software after mapping a building or an asset's facade. It will work contact-less along the facade, washing and drying the facade substrate whilst on-board payload array can closely inspect the condition of the asset using multi-spectrum cameras. The asset condition can be monitored real time and live-streamed to the client. AI will be used to identify, collect and sort the data showing generic condition and problem areas of the asset. The SPYDER will be designed to work 24/7 and sustain weather such as precipitation and wind and is a smart combination of cable robotics, AI and machine learning.

Cleaning and inspection can be achieved autonomously without sending humans over the side of buildings. Image courtesy of YellowFIN Robotic Solutions.

Auto loader for the maritime industry

Maritime freight or cargo accounts for more than 80% of world trade by volume. Break- bulk freight needs handling with a crane hooking it on, swinging it over and hooking it off, with 2-3 qualified crew at each end. This is one of the leading causes for accidents and fatalities on those sites, and requires a significant amount of human and capital resources.

YellowFIN Robotic's ROBO-LOADER is designed to circumvent the human interface in manual-handling of break-bulk-freight to make it autonomous and safe. Robo-loader is very different to container loading straddles, as it deals with single-point suspended loads. The technology is being developed for the proprietary hooking arrangement to work in conjunction with a simple array of transponders which can be used in a marine terminal or a floating maritime asset or a ship.

Use of AI enables real-time mapping of freight handling area; optimising space use, auto-locate and positioning of freight; handsfree auto hooking, turning and un-hooking of freight; real-time detection of ship dynamic motion to determine sea-state cut-off; continuous scanning of physical attributes of containers for weak-points and corrosion; and real-time freight plan status on the terminal and floating asset. The cost saving by this substitution is substantial and the scaling possibilities are exponential. But the real win is in saving human life-and-limb by using the Robo-loader.

Offshore boat and crane. Image courtesy of YellowFIN Robotic Solutions

Online tank inspection deployment

Intero successfully deployed its OTIS500 to undertake tank bottom inspection of an in-service Naphta storage tank (10,000 cbm naphta, 25.4m diameter, fixed roof, 24 inch manway entrance). The primary objectives were to: demonstrate the ability to safely deploy an Online Tank Inspection (OTIS) Robot in a tank with a low flashpoint product; and perform an online inspection of the tank bottom in a limited time-frame. This inspection was Asia's first online/no man entry inspection of a low flashpoint (ATEX zone 0) product tank.

The benefits of this technology include: no downtime; no need for temporary storage; cost savings of cleaning the tank; minimized waste disposal costs; ATEX approved robot for safe zone 0 deployment; reduced environmental risks such as spills and VOC release; improved safety by eliminating confined space entry and personnel exposure to hazardous chemicals.

Lowering the tool into the tank. Image courtesy of Wouter Keuris Fotografie.

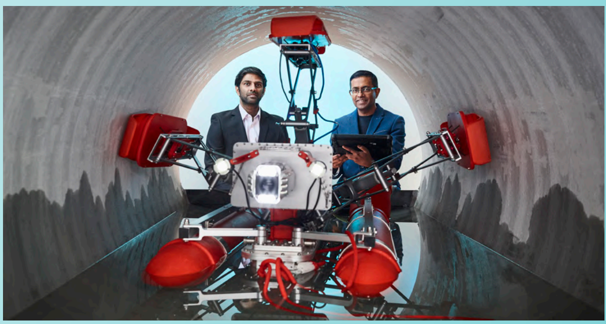
Intelligent robots that crawl inside sewers

Australia has over 110,000 kilometres of sewage pipelines worth more than $100b. Every year, water utilities spend over $100m on pipe renewals and rehabilitation programs. The microbial activities that take place on the surface of the concrete sewer pipes are responsible for much of the corrosion of the sewer pipes.

Current non-traversable sewer pipe inspections rely heavily on CCTV cameras, which can provide only visual information, but fail to measure sub-surface corrosion conditions. To address this multi-million dollar problem, Sydney Water collaborated with the iPipes Lab at University of Technology Sydney to design the CRAFT (Corrosion and Reinforcement bar Assessment Floating Tool) robot which can be deployed in non-traversable circular concrete sewer pipes ranging from 900mm to 1500mm diameters.

The CRAFT uses multi-modal sensor fusion approach for non-destructively estimating the thickness of the sub-surface corroded concrete layer and remaining thickness of intact concrete cover to reinforcement bars. This floatable robotic system can enter concrete sewers through a 600mm diameter manhole and extend its arm to a maximum diameter of 1.5m for safer remote inspection in confined spaces. The CRAFT builds a true colour three-dimensional reconstruction of the internal sewer structure in real-time, which can serve as a screening tool to focus on suspicious areas rather than along the pipe full inspection. This innovative technology offers key data for asset managers to make timely decisions to reduce the cost of pipe renewals, adverse environmental impact, and public health issues.

UTS researchers with the remote sensing maintenance robot CRAFT. Photo Toby Burrows. Image courtesy of UTS.



An update on Blindsight by Presien (formerly Toolbox Spotter) AI computer vision for heavy industries

There are roughly 200 workplace deaths and 100,000 serious workplace injuries per year in Australia, costing the nation an estimated $62b every year. Being struck by an object is by far the leading cause of serious accidents (roughly 65%), and the heavy industries disproportionately contribute to these statistics. Data suggests around 84% are attributable to lapses of attention, distraction, and failure to see the potential hazard.

Blindsight, a technology by Presien, a spin-out from Laing O'Rourke's Technology & Innovation Group, is a frontedge hand tool suitable for on-the-dirt immediate integration into complex works. It is equipped with a spotter's proactive intelligence and sees and understands without special tags, markers or processes. It is an advanced ecosystem of extra sets of never tiring, always alert, always diligent, intelligent eyes that has its mind on the team and its focus on the job. Blindsight reduces fatalities, traumatic injuries and property incidents, enables otherwise non-possible works, and decreases resource requirements, workers' compensation and insurance.

For instance, the image here depicts a real scenario in which the operator clearly saw the entire group of people behind him leave the area, but Blindsight saw a person in the blind spot and the operator was alerted. The operator believed the area was clear and was under pressure to return to work. But instead he voiced concern, at which point an unseen person in the blind spot responded. The operator asserts that Blinsight saved a life!

Laing O'Rourke developed and extensively tested and honed Blindsight, game changing technology on the basis of which the venture capital funded spinoff company Presien was formed. Image courtesy of Presien.

Australian built robots making it safer for first responders

BIA5 is an OEM with a history designing, manufacturing and supporting uncrewed ground vehicles, UGV's serving Australia' first responders. Robotic platforms such as BIA5's original Ozbot and ATR Fire are able to operate in rough terrain and under conditions that can often render other machinery inoperable.

With the use of multiple cameras and 'human in the loop' operation, the platforms are able to act as the eyes and ears of First Responders. Enabling firefighting and law enforcement personnel to use their training and expertise to combat critical incidences, whilst limiting the risk to human life. Multilayered redundancy is one of the additional key features that enhances BIA5's robot's durability to operate in these often dangerous and harsh environments.

The addition of the Warfighter ATR for military applications, showcases the platform's adaptability and stability which includes class leading stair climbing and integration of a variety of payloads. This versatility offers the opportunity for the mobility of weapon systems above its class and carriage of patients and support medics and logistics payloads comparable to larger UGVs.

Development of these platforms is accelerating our growth to Industry 4.0 systems to reduce the cost whilst maintaining high end performance. BIA5's willingness to collaborate with customers, academia and industry partners is opening up opportunities in industries such as mining, agriculture, construction and even extending to space both here in Australia and overseas.

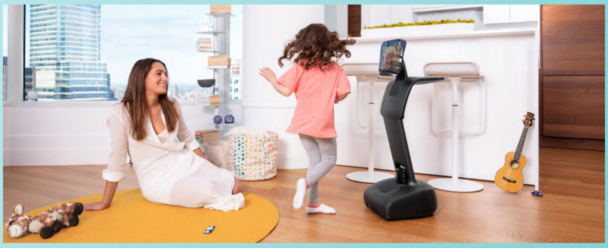
BIA5 ATR Fire undergoing live fire testing with Rio Tinto, Perth WA. Manufactured by BIA5 in Brisbane Australia. Integrated into market by BIA5.

Telepresence, social and educational robots

Exaptec is a robotics company based in Melbourne specialising in telepresence, social and educational robots. Exaptec's clients include universities, government departments, schools, retail businesses, aged care and hospitals. Some examples of deployments include:

- A private school in Melbourne bought a telepresence robot to assist a student that had an immune compromising disease and couldn't attend school. The student could dial in from either hospital or home to attend school.
- A disability organisation in Western Australia invested in a telepresence robot which enabled one of their housebound clients to attend a conference, virtually, for the first time few years.
- As part of a settlement, an insurance company bought a telepresence robot for an accident victim who became a paraplegic as the result of a motor car accident. The client owned his own business and used the telepresence robot to "go to work" while rehabilitating and adjusting to his new circumstances.
- Telepresence robots are deployed in aged care centres in Brisbane and hospitals in Adelaide and Brisbane. Doctors and medical practises are also experimenting with telepresence to teleconsult with patients and other medical specialists.
- Social robots are used frequently at conferences to educate audiences and explain new technology.
- The QTrobot specialises in assisting children with autism and comes with a syllabus designed by autism specialists and physiotherapists. This robot is also deployed in a Tafe in Victoria and has potential for use in homes which care for people with acquired brain injuries.

Grandparents connecting through temi with family. Image courtesy of Robotemi.



Devising a Universal Signage System for Human Robotic Interaction (HRISS)

As robots continue to move beyond factory locations into shared public spaces, we will increasingly find ourselves working alongside robotic devices to undertake everyday tasks and services. The growing number of interactions between people and robots in the public domain point to the real need for a standardised communication signage system that will help individuals and communities engage with, understand, and trust ways of working with robots.

A universal Human Robotic Interaction Signage System (HRISS) is being developed to visually help people to comprehend how a robot might act or perform, and importantly how they should behave around it. HRISS will use best practice from established national and international signage systems, and will reference International Organization for Standardization (ISO) and Standards Australia (SA) guidelines. HRISS is modular, allowing for a flexible application to familiar and emergent robot typologies (delivery bots, drones, robotic arms, humanoid robots, a range of assistive devices, swarm robotics etc.) and will communicate specific functionality and actions to people within the operational zone of the robotic device. HRISS signs will employ a three-tier communication strategy, developing comprehensive design guidelines for signs that convey: instruction, advisory or cautionary messages, and detailed information.

Work on this project was undertaken by an interdisciplinary team of researchers including roboticists, designers, psychologists, and programmers from Sheffield Robotics UK. This work was initially funded by the EPSRC Centre in Innovative Manufacturing in Intelligent Automation as a feasibility study for assessing graphical robot aids for interactive co-working in industry. This work is being continued at the Australian Research Centre for Interactive and Virtual Environments, University of South Australia.

Left: Co-botic working concept sign. Image courtesy of Ian Gwilt (UNISA) and Joe Rolph.

Right: Prototype instructional signage for collaborative human-robot co-working. Image courtesy of Ian Gwilt, Joe Rolph, Iveta Eimontaite, David Cameron, Jonathan M. Aitken, Saeid Mokaram, and James Law, Sheffield Robotics.

Roboticisation of commodity products

For Australia to benefit from our homegrown talent, we need to apply robotics skills and experience to general product development. Adding robotic capability to enhance existing products reduces the product development cycle, compared to developing new robotic platforms from scratch, and also expands the range of products that benefit, hence increasing the demand for robotics capability.

For Australia to develop a sustainable robotic industry, we need to take advantage of the wider markets available through "roboticisation" of commodity products, which will increase market share across many sectors and also increase the demand for talent, providing increase job opportunities for graduates with robotics-related skills.

COLETEK has been involved in a number of projects that demonstrate how robotics expertise can be applied to commodity products: localisation algorithms, typically deployed by robotics, can be applied to location-aware based devices such as indoor high asset tracking; sensors for detection can enable a product to avoid children wetting the bed; object classification algorithms, which may be trained from data using machine learning, can analyse the wild dog population; and security products might require computer vision algorithms such as predestined detection, face recognition and licence plate recognition, which have origins in robotics vision.

Electronics, software and mechanical product development - COLETEK is a Multi-Award-Winning high-tech innovative company providing key R&D services for entrepreneurs, inventors, startups and companies. Image courtesy of COLETEK.

Contributors

This chapter was based on several virtual workshops held between April 2020 - November 2020 with contributions from the individuals listed below:

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Nicole Hartley (UQ)
Mary M. McGeoch (Lendlease)

Footnotes

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12 Global robot sales figures copyright Müller, Christopher; Graf, Birgit; Pfeiffer, Kai; Bieller, Susanne; Kutzbach, Nina; Röhricht, Karin: World Robotics 2020 – Service Robots, IFR Statistical Department, VDMA Services GmbH, Frankfurt am Main, Germany, 2020.

8

Transport and mobility

Experts believe that four aspects of the future mobility ecosystem (incremental change; a world of carsharing; the driverless revolution; and a new age of accessible autonomy) are likely to exist simultaneously moving forward

8.1 Australia's transport sector

The transportation sector is a key component of Australia's infrastructure, with almost every person relying on some form of transportation to go about their daily lives. Its significance is reflected in its estimated worth ($125.3b) and it employs 8.6% of all employed persons in 2015-16[1].

Like other sectors, transportation in Australia is shaped by the large size of the country and relatively small population. Australia's road network is over 877,000 kilometres long[2], which means that, when factoring in our population, Australia has one of the world's largest road networks per capita. Transport as a sector is increasingly being shaped by technological advances that are either core to robotics or relevant to the field. Mobile internet, big data, AI, autonomous vehicles and cloud computing are providing conditions for change[3] in the transportation and mobility sectors. Technology is driving the transformation and reconstruction of the sectors, but significant challenges and a rescaling of expectation with respect to the timelines of major technology rollouts, like highly autonomous vehicles, are providing a highly dynamic environment.

8.2 Setting the scene: Visions of a future transport sector

Social and technological trends are changing the way people and goods get from A to B[4]. These changes bring both new challenges and new business models, providers, and opportunities enabled in significant part by new and emerging technologies.

On the social side, concepts like "Liveability" are driving the agenda, promoting connectivity, fewer emissions, and equitable transport access as cities become larger with corresponding increased pressure on infrastructure and services like transport[3].

How people and goods move around is also changing, driven by technology mega-trends[5] and shared mobility models[3]. Vehicles themselves are being powered by new, increasingly efficient and cost effective energy sources including lithium ion batteries[3].

There are four versions of the future mobility ecosystem which emerge from the intersection of two critical trends: vehicle control (driver vs autonomous) and vehicle ownership (private vs shared).

FUTURE MOBILITY ECOSYSTEM

(1) Incremental change	**(3) The driverless revolution**
(2) A world of carsharing	**(4) A new age of accessible autonomy**

Experts believe that these four versions are likely to exist simultaneously across different metropolitan areas, driven by the specific needs of each area which determine the pace of which new technology is adopted[3]. These four versions draw heavily on two divergent visions for the future: the *insider view and the disrupter view*, as illustrated by the figure below.

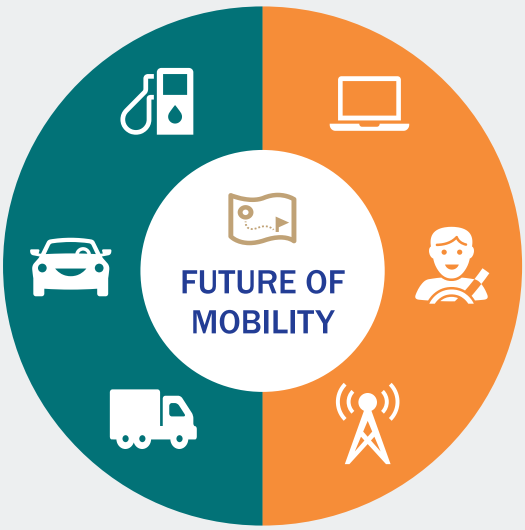
Different perspectives on the future of mobility

Insider view

The industry will **evolve naturally** and **incrementally** toward a future mobility system that **retains its roots** in what exists today.

The key players, major assets, and overall structure of the **current ecosystem can remain intact** while change progresses in an **orderly, linear fashion.**

The incumbent mindset appears **dually focused** on sustaining the current model while **testing change in small ways.**



Insider view

A **whole new age** is dawning featuring **fully autonomous** cars accessible on demand.

Before long, a **tipping point** will occur, after which the **momentum of change will become unstoppable.**

New entrants, notably Google, Uber, and Apple, **are catalysts** for transformation.

Unlike the stakeholders in today's system, they **do not have vested stakes** to protect.

Source: Deloitte University Press

> The impacts of lower cost per kilometre, improved safety, and dramatically lower overall environmental impact will require the automotive sector and its supply chains to rethink "where to play and how to win"

The most conservative end of the spectrum is thought to be *incremental change*, assuming that private ownership remains pervasive and uptake of autonomous vehicles is limited in the near future[5]. The next version is *a world of carsharing*, where private ownership is forgone in favour of on-demand car sharing[5]. Further along the spectrum is the *driverless revolution*, in which autonomous-drive technology is the norm and private ownership prevails[5]. The most advanced version of the mobility ecosystem is known as *a new age of accessible autonomy*; this envisions the converging of autonomous and vehicle sharing trends[5].

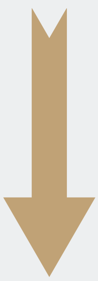
The *disrupter view* of future mobility promises accessibility, affordability and safety with seamless multimodal transportation featuring electric and autonomous vehicles, the objective of which aligns most closely with version 4 on the spectrum: *a new age of accessible autonomy*[5]. The beginnings of this are already gaining traction; ridesharing accessibility through smartphones are in use globally, and there is incremental adoption and trialing of intelligent driving and connected-car technology[5].

These changes come even as many governments grapple with growing congestion, rising populations, urbanisation, and aging transportation infrastructure[4]. Digital innovation is enabling the rapid entry of many new transport operators into the market, catching regulators and transit operators unprepared[4].

The impacts of lower cost per kilometre, improved safety, and dramatically lower overall environmental impact will require the automotive sector and its supply chains to rethink "where to play and how to win"[5]. The graphics (featured below and on the following page) illustrate the potential effects of the shift to today's mobility ecosystem, as well as potential societal benefits expected as a result of autonomous drive, shared mobility and technological advances[5]. Simultaneous management and regulation of disruption is required, with an emphasis on thinking of new ways of doing business[5].

SOCIAL BENEFITS

40% TO 90%



decrease in emissions from automobiles[a]

32k+

lives saved[b]

100B

hours of productivity recovered[c]

[a]Deloitte analysis; annual percentage decrease is calculated prior to any changes in fuel mix and is equivalent to a decrease of 10% to 35% of overall US emissions.
[b]2013 figure for US only; global figure is 1.24 million annually (WHO)
[c]Deloitte analysis based on miles driven in the US in 2014 (DOT) and average travel speed in miles per hour (Columbia University)

FUTURE MOBILITY ECOSYSTEM FLOW ON EFFECTS

AUTOMOTIVE

- **Decrease in personally owned vehicle sales and increase in fleet vehicle sales** due to shift toward shared mobility
- **Wider range of vehicle designs** could emerge
- **Value shifts from asset ownership and driving performance** to software and passenger experience
- **Lighter vehicles** could enable OEMs to more easily meet CAFE and ZEV requirements

FINANCE

- **Growth in fleet financing**
- **Shifts away from personal vehicles** could lead to a decrease in auto loans and leasing

INSURANCE

- Potential opportunities for **experience-based insurance products**
- **Shifts from personal liability to catastrophic system-failure insurance** could lead to a decrease in insurance sales

ENERGY

- Potential opportunities for **increase in miles driven**
- **Improved vehicle efficiency** could lead to lower energy consumption
- **Autonomous technology** could further enable a transition to alternative fuels

PUBLIC SECTOR

- **Reduced number of automobiles** could decrease current revenues (e.g. licensing fees, fuel taxes, etc.)
- New **consumption-based, dynamic taxation** models could offset tax revenue decline
- Potential change in **mix and usage of public transportation**

MEDICAL & LEGAL

- **Reduced number of automobiles** could decrease current revenues (e.g. licensing fees, fuel taxes, etc.)

MEDIA

- **Greater time available through autonomous drive and shared mobility** increases consumption of multimedia and information
- **Increases in advertising and subscription revenues and data monetisation** opportunities

TELECOM

- **Increased demand for connectivity and reliability** could result in additional bandwidth requirements

TECHNOLOGY

- **Emergence of autonomous drive operating system players**
- **Autonomous cars and shared mobility** would likely lead to the rise of mobility management providers

RETAIL

- Increased mobility of underserved segments (e.g. seniors) could increase retail sales
- Expands home delivery options
- Changes retail landscape in response to city demographics shift

TRANSPORTATION

- **Shared fleet vehicles** could substitute demand for traditional taxis, limos and rental vehicles
- Increased automation creates **new business models** for long-haul tucking, movement of goods

KEY ● Value creating effect ● Value diminishing effect ● Mixed impact

Source: Deloitte University Press

Government and private sector roles

The emerging mobility ecosystem brings with it complex public policy implications, often placing traditional mechanisms for government decision-making at odds with the disruptive landscape that policymakers must look to shape[4]. Government is faced with a challenging balancing act; shifting expectations of citizens, constrained infrastructure funding, and increased uncertainty in planning horizons, all of which are amplified by emerging mobility trends[4]. To assist in this process, Deloitte's *The Future of Mobility Maturity Curve for Government* (see the graphic below) identifies the various stages.

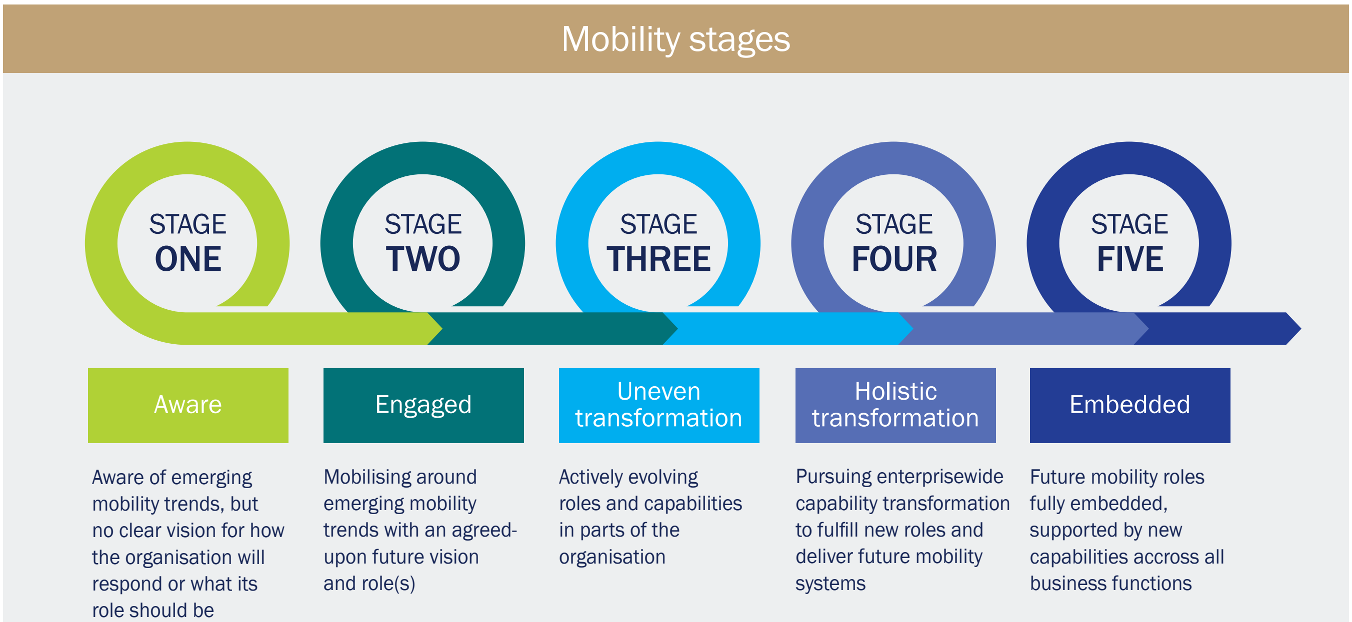
The ability of government organisations to make relevant, timely decisions and create meaningful impact in the face of disruption is tied to progression through the curve, and requires change in both external policy and internal operations[4]. Currently, State and Commonwealth agencies typically sit between *Stage 2 – Engaged* and *Stage 3 – Uneven Transformation* on the *Future of Mobility Maturity Curve*.

At these stages, agencies may be engaged in mobility trials, but lack an overarching vision necessary to guide internal transformation and confidence when faced with impending disruption[4]. Progression through the *Future of Mobility Maturity Curve* relies on data-centricity, agility and customer focus as crucial elements allowing agencies to embrace disruption while maintaining influence over key decisions[4].

Change towards a new mobility ecosystem is predicted to occur unevenly around the world, as business leaders and governments respond to the differing requirements of different populations[5]. As seen in graphic below, there are a range of inertial forces in play in the realm of mobility, either acting as accelerants or delaying the adoption of new technologies[5]. This means that businesses and governments should be prepared to operate across the spectrum of futures, each which have a distinct set of customers with distinct customer needs[5, 3].

> Change towards a new mobility ecosystem is predicted to occur unevenly around the world, as business leaders and governments respond to the differing requirements of different populations

The enabling influence of the private sector in capturing and monetising data, and in the ability to provide vehicle-operating and traffic network information systems, is significant, but faces challenges with new market entrants



Source: Deloitte University Press

and emerging business models[5]. The consensus is that movement towards a new mobility ecosystem will be systematic, with the slow approach to a tipping point driven by companies inspired by the *disrupter view*. Finding ways of balancing the accelerants and forces of delay towards any variant of the new mobility ecosystem poses a challenge to maximising benefits and relies on defined roles and clear outcomes.

Australian government agencies are embracing data-centricity, agile thinking and customer-focussed views of the transport system, all of which are capabilities required in the future of mobility[4]. However, a fundamental shift in thinking is required to embed these foundational processes into decision-making[4]. The public sector needs to diversify its role of regulator and operator of mobility services in urban markets, further incorporating new capabilities to plan and deliver transport solutions. This can be achieved by providing platforms that facilitate collaboration between public and private mobility operators[4].

Progression along the Future of Mobility Maturity Curve has the potential to provide a more integrated, transparent, and efficient transportation system that enables economic growth and equitable access[4]. Realising these benefits for government, industry and community will require different, tailored approaches suitable to the roles of various agencies[4].

In the future mobility system, it is expected that the government will fulfil several roles:

- Strategist; setting strategic policy direction
- Convenor and catalyst; managing or enabling the behaviour of other players
- Regulator; intervening in the event of market failure or adverse social impacts
- Operator; delivering mobility services.[4]

These roles are not new to government, but the rapid pace of change in the transportation industry provides a new opportunity to rethink the capabilities of these roles, and incorporate fresh thinking to maximise benefits[4].

8.3 Technical challenges in autonomous vehicles

A recent review of the key technical challenges remaining for autonomous vehicles focused on several key issues[6]. In particular, interaction with vulnerable road users (VRUs) is rapidly becoming one of the key, if not the key, technical challenges, and the subject of increasing scrutiny given recent fatalities involving autonomous vehicles (ABC/Reuters/AP, 2018).

Vehicles share the road with bicyclists, pedestrians, motorcyclists and scooter riders, to name just a few, and ensuring AVs will interact safely and effectively with them is incredibly difficult. Pedestrians and cyclists for example are not always predictable, yet prediction is critical if autonomous vehicles are to continue to operate safely around them, rather than becoming paralysed when in the vicinity of them. Interaction with other vehicles driven by humans is also challenging, as evidenced by the increase in rear-endings or sideswipings between autonomous and non-autonomous vehicles in areas like California[7]. These challenges are equally relevant in Australia, and perhaps even more so than in countries like the United States where car culture is generally more dominant.

Detecting and predicting the intent of VRUs, such as cyclists and pedestrians, is a critical challenge for AVs (Source: Perceptive Automata).

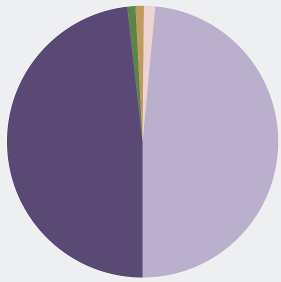
8.4 Conclusions

The reality of changing mobility is already evident in mega cities around the world (Hannon, 2016). Reinforcing mobility trends will encourage further shifts in the mobility landscape, allowing the movement of people and goods to be more efficient, more affordable, and more frequent.

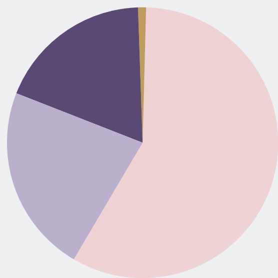
Regulatory cues can be taken from previous consumer-friendly technological developments that also promote public goals such as clean air and reduced congestion[3]. Strong partnerships that blend public-private mobility solutions will most likely provide the most positive outcomes[3]. "Getting mobility right" will be a significant competitive advantage for cities, and will improve the quality of life for all Australians[3].

Predicting the future of autonomous mobility

Proportion of 2025 new car and SUV SALES with automation features



Proportion of 2025 new car and SUV FLEET with automation features



While predictions for the uptake and roll out of highly autonomous vehicles were optimistic in the middle of the decade, recent years have seen a drastic softening of the predictions and timelines for when this might occur. Reflecting this trend, an Austroads report "Future Vehicles 2030" presented a range of predictions for the expected roll outs and composition of various automated vehicle technologies[8].

Notable in the 2020 timeline is the fact that the majority of vehicles do not have automated emergency braking (AEB), and almost none have high levels of automation. This distribution only changes slightly in the 2030 timeframe. The story is the same albeit not as drastic in terms of connected vehicles (the C in CAV), with increasing levels of connectivity expected to occur over this timeframe.

Infrastructure and autonomous vehicles

In 2019, a collaborative project between iMOVE, Queensland Department of Transport and Main Roads (TMR) and QUT was completed which investigated the current capabilities of autonomous vehicle technology on Australian road infrastructure[9]. The objectives of the project were manifold, and included questions like; how capable is existing computer vision and artificial intelligence (AI) technology, with respect to recognising and obeying Australian road signage and markings? A follow-up question was then: how can infrastructure be improved to address the limitations of the existing technology, to enable the safe deployment of autonomous vehicles?

To answer these questions, the research team utilised a data collection vehicle, called ZOE1, equipped with cameras, LiDAR (Light Detection and Ranging) and GPS (Global Positioning System) sensors. Data was collected from numerous driving routes throughout south-east Queensland, in a variety of weather, lighting (day, night) and traffic conditions, with a total driven length of 1200km. A variety of open-source computer vision and AI software systems were evaluated on the collected data, with the choice of software based on the sub-tasks that are performed by an autonomous vehicle. For example, traffic sign detection and recognition are critical components in any autonomous vehicle, therefore one section of the project was dedicated to evaluating the performance of existing state-of-the-art traffic sign detection systems on Australian roads and conditions.

The project resulted in a number of findings, which indicated that further technological and infrastructure work is required before autonomous vehicles can be safely deployed in Australia. One of the key findings from the project was that existing traffic sign detection systems operated poorly on Australian roads. Re-training the AI to better understand Australian road signs improved performance, however, it was discovered that the largest improvement to the sign detection rate occurred by using prior maps of the road environment. In terms of infrastructure improvements, the project concluded that the creation of high-definition maps of the road network would provide the greatest improvement to the reliability of autonomous vehicles. This project has demonstrated that, with a future investment in digital and physical infrastructure for autonomous vehicles, the deployment of automated vehicles in Australia can be realised.

ZOE1 Research Vehicle. Image courtesy of QUT.

Autonomous shuttles

Autonomous shuttle technology has the potential to enable mobility for vulnerable people in our community, particularly in locations where existing public transportation infrastructure is lacking. In a first for Queensland, RACQ deployed a Smart Shuttle on the streets of Karragarra Island from November 2019 to May 2020. As explained by Redland City Mayor Karen Williams "the bus is the first-ever form of public transport for the Karragarra Island community which has some incredibly unique transport challenges that present a need for innovative solutions like this".

The shuttle is the EasyMile EZ10 model which, globally, has transported over 320,000 passengers without serious incident. It is classed as a Level 4 autonomous vehicle, which means that there is no requirement for a driver of the vehicle. The shuttle seats six people, and has a maximum speed of 20km/hr. Karragarra Island was an ideal testing environment, as it had no prior public transport service and is a low traffic and low speed environment. A second trial by RACQ was conducted in the Raby Bay area. 1,339 passengers took a free ride between November 2020 to June 2021, and the EasyMile vehicle travelled more than 3,000 kilometres. RACQ is now looking closely at the learnings and feedback from the trials at both Raby Bay and Karragarra Island to better understand and develop how driverless transport options could help serve communities in the future.

In another example, Transport for NSW deployed an automated shuttle bus in Sydney Olympic Park in 2017. The trial, the first of its kind in Australia at the time, enabled the study of how automated vehicle technology can improve the mobility of people in the community and what infrastructure is required to support this technology. The shuttle, a Level 4 autonomous vehicle from Navya, can carry up to 15 passengers and travels at approximately 20km/hr. The shuttle uses cameras, LiDAR, Radar and a 3-D map of the road network to navigate safely. The trial is partnered with HMI Technologies, who is a provider of custom Intelligent Transport Systems headquartered in New Zealand. HMI Technologies has also backed autonomous shuttle trial at La Trobe University in Melbourne. The shuttle was used to carry students and University staff around the campus.

RACQ autonomous shuttle trial at Karragarra Island with an EasyMile model EZ10. Image courtesy of RACQ.

The campus shuttle trial was a joint effort between Keolis Downer, VicRoads, La Trobe University, RACV, HMI Technologies and ARRB, which began in 2017. Like the Sydney trial, the Navya vehicle was used. In the autonobus pilot project report, key recommendations were that the shuttle is a safe and valuable service for customers, however, further testing is required at speeds greater than 20km/hr. Increasing the shuttle speed, without compromising safety, would increase the commercial value of the system. The report notes that the shuttle was operating without fault in a challenging environment, managing pedestrians, other road users and dynamic weather conditions over an extended period. More recently, another autonomous shuttle trial has begun in Newcastle, Australia this year. Due to COVID-19, the number of passengers is limited to three at a time, however, in a post-pandemic world, it can be expected that autonomous shuttles will add a valuable contribution to our public transportation infrastructure.

Contributors

This chapter was based on a virtual workshop held on 24 June 2020 with contributions from the individuals listed below:

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Stephen Hausler (QUT)
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Ian Christensen (iMOVE CRC)

Footnotes

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9 Michael Milford, S. G. (2020). How automated vehicles will interact with road infrastructure. iMOVE CRC.

9

Defence

The market for defence robots is growing with an expectation that in 2022 there will be more than 28,000 defence robots deployed worldwide. These will mainly in the form of demining robots, uncrewed naval vessels, uncrewed aerial vehicles and uncrewed ground vehicles

9.1 Background

It has been forecast that in 2022 there will be more than 28,000 (known) robots deployed worldwide for defence, mainly in the form of demining robots, uncrewed naval vessels, uncrewed aerial vehicles and uncrewed ground vehicles. The market for Defence robots is steadily growing with a compound annual growth rate (CAGR) of 15% and a sales value exceeding US$2.6b in 2022.

In Australia, the defence sector generates $38.6b in revenue and employs 106,000 people, with annual revenue growth expected to be 3.5% over the next five years to 2026 to reach $45.9b. The ADF is involved in combat, deterrence, peacekeeping missions and humanitarian disaster relief efforts, all of which were activated through multiple global deployments, the 2019-20 Australian bushfires and in support of state and territory governments during the COVID-19 pandemic. Increased defence funding has also been driven by naval expenditure for border protection though Operation Sovereign Borders.

In Australia, the defence sector generates $38.6b in revenue and employs 106,000 people, with annual revenue growth expected to be 3.5% to 2026.

The Australian defence sector is an essential part of the Australian economy, engaging thousands of Australian businesses and generating both direct and indirect employment. A study by AlphaBeta commissioned by Defence contractor Thales, showed that spending by that one contractor resulted in the creation of 1,765 direct jobs and more than $522m of spending in 2019 with 1,362 Australian companies, with more than 60% going to small- and medium-sized enterprises (SMEs). While Defence's supply chain is heavily reliant on industry clusters located in urban centres, the government is encouraging regional participation and sovereign capability development in the national defence supply chain. Initiatives such as the Centre for Defence Industry Capability (CDIC) helps regional small businesses connect with Defence and provide training for businesses on how to enter and work in the defence market. The Sovereign Industrial Capability Priority (SICP) grant program has awarded more than $47m to small Australian businesses, while the Defence Innovation Hub has also invested more than $38m with regional Australian businesses and universities.

Snapshot › Defence: What's changed since 2018?

Strengths

- Government recognises need for sovereign capability in this sector
- Establishment of a Defence AI Centre to support development of AI in robotic systems
- Industry of robotics, autonomous systems and AI (RASAI) included in Sovereign Industrial Capability priorities announcement by Minister for Defence
- Establishment of Defence conceptual foundations and roadmaps for Robotic and Autonomous Systems (RAS)
- Funding initiatives through Defence Strategic Update (DSU) and Force Structure Plan (FSP) July 2020

Wins

AIR DOMAIN:	First Loyal Wingman aircraft developed. Early 2021 - Flight tests undertaken
LAND DOMAIN:	Army fleet of operational roboticised M113s increasing to 20 vehicles
MARITIME DOMAIN:	Ocius Bluebottles - AMSA approves autonomous patrol in the Australian Economic Exclusion Zone (EEZ)

New opportunities

- New Defence funding initiatives announced (DSU/FSP 2020)
- Equip ADF "red teams" with RAS = acceleration of feedback regarding research, development, tactics and operational concept effectiveness
- Development of sovereign Common Control for all RAS operating across all domains
- End-of-life crewed platforms repurposed into robotic and autonomous fleets (Ghost Fleet)
- Defence to offer funded, ongoing opportunities to accelerate innovations such as challenge competitions, demonstrations and exercises with RAS

Challenges

- The scale of effort, focus and funding of RAS by near-peer competitors
- Staff with STEM capabilities / interests are under-utilised and lost from the defence "ecosystem" (ADF, industry, academia, DST)
- Lack of empowerment, training and cultural barriers to rapid adoption and continuous innovation in defence
- SMEs lack access to secure shared infrastructure for sovereign RAS development
- Easing the transfer of development-oriented academics to Australian industry

Realistic 5—year goals

- Significant increase in SME participation with Defence in the development and fielding of many smart, small sovereign robots
- Significant increase in autonomous capabilities of robotic systems (within ethical and legal bounds)
- Operational deployment of RAS to transition from permissive environments to denied environments
- A flexible STEM career circuit with the Five Eyes (FVEY) nations, supporting a seamless flow of security-cleared talent through industry, ADF, DST and academia
- Risk reduction in achievement of sovereign, interoperable Common Control across all vendor robotic solutions, achieving adaptable mission solutions for Defence operations

Recent developments in robotics and autonomous systems will disrupt current methods of warfare. While Australia's Defence forces have used robotics for decades, new developments in platforms, payloads, controls systems, artificial intelligence and other technologies are converging to create more advanced, smaller and more capable systems that will enhance, augment, replace or revolutionise current capabilities.

Such emerging, disruptive technologies can only generate advantage if they are employed in a way that disrupts the future operating environment. Defence is looking to deploy robotics in human commanded teams to increase efficiency, generate mass and decision superiority while decreasing risk to personnel. To maintain advantage, Defence must also counter adversary robotics and autonomous systems through perception and control system attacks, information warfare and platform destruction. Achieving these goals allows robotics to be the force multiplier needed to augment Australia's highly valued human workforce and to enable persistent, wide-area operations in air, land, sea, subsurface, space and cyber domains.

The economic challenges for the industry include building capability, fostering research and innovation, developing global supply chains and export, improving the efficiency of every dollar spent, and coping with opportunities and challenges of technological and digital disruptions. Such solutions could be applied in Australia, for national and international supply chains in defence, in other markets, and even in other sectors. Challenges for defence operations in wide-area and extreme environments are mirrored in other sectors of economic significance for Australia, such as agriculture, resources, healthcare, remote services, assets, and the environment.

9.2 Impact of COVID-19

Despite the COVID-19 pandemic the Australian Government expected to meet its defence spending target of 2.0% of national GDP in 2020-21, continuing support to the defence industry. In future, Australia's defence spending has been decoupled from GDP to prevent fluctuations in expenditure resulting from 'black swan' events such as the pandemic.

9.3 Context 2020

POTENTIAL ROLE AND FUNCTIONS OF RAS IN DEFENCE

- Intelligence, surveillance and reconnaissance
- Decision support
- Decision making in limited contexts
- Cognitive load reduction on operators
- Communications
- Management of electromagnetic spectrum
- Enterprise level management including human resources, training, simulation
- Logistics, health-care and preventative maintenance
- Mine and obstacle clearance
- Force protection, security monitoring
- Counter-measures to adversary use of RAS

Strategic update

The government released the Defence Strategic Update (DSU) and Force Structure Plan (FSP) in July 2020 due to the rate of change in geopolitical circumstances since the 2016 Defence White Paper. This calls for a credible deterrent and sovereign capability that can hold adversary forces at risk further from Australia, supported by a resilient national support base. The DSU and the FSP arising from it signal a significant investment in high-tech and especially robotic and autonomous systems. The 2016 defence white paper committed $195b in defence spending over ten years, the new strategic plan will boost that to $270b over the decade to 2029.

> The 2016 defence white paper committed $195b in defence spending over ten years, the new strategic plan will boost that to $270b over the decade to 2029.

The DSU highlights three technological factors that are changing the strategic environment: accelerating military modernisation; emerging and disruptive technologies (including sophisticated sensors, autonomous systems and high-speed weapons); and expanding cyber capabilities. The deepening relationship between artificial intelligence (as an enabler with its own roadmap) and robotics will also continue to blur distinctions.

International perspectives

Internationally, RAS are gaining significant research investment internationally with the promise of new technologies across all defence domains including space and unembodied electronic/cyber, from demonstration through to operational deployments in conflict zones.

Australia's key ally the United States (US) have created a Joint Artificial Intelligence Centre (JAIC) to integrate AI across the US Department of Defence and are considering escalating leadership from the Lieutenant General (three-star) to a Deputy Secretary of Defence oversight, a demonstration of the importance of these technological possibilities.

The US and United Kingdom (UK) are both developing their own Loyal Wingman air-power teaming equivalents, Skyborg and Tempest. Future systems may also have runway-independence and be containerised systems with the ability to be emplaced in strategic locations ready to team with inhabited aircraft. In August 2020, a US Defence Advanced Research Projects Agency (DARPA) competition pitted a human pilot against an AI, which won 5:0 in their simulated AlphaDogfight trials event.

The US and UK have also invested in eXtra-Large UUVs systems in the Boeing Orca with potential for an offensive role and the UK Manta respectively. US trials of the ocean-going Sea Hunter USV, with platooning and optionally crewed models continues. Autonomous Mine Counter-Measures (MCM) systems also

> Smaller-scale attritable systems are becoming ubiquitous in Intelligence, Surveillance and Reconnaissance (ISR) roles with the potential for organic fire support in small sections of dismounted troops only limited due to finances, culture, policy or imagination.

continue to gain popularity. The newest US service arm, Space Force, is likely to utilise significant RAS in roles including autonomous station keeping and robotic maintenance, as it will in Australia's emergent space industry.

RAS are also gaining traction in defence logistics, training and predictive maintenance functions to assure military capability.

Smaller-scale attritable systems are becoming ubiquitous in Intelligence, Surveillance and Reconnaissance (ISR) roles with the potential for organic fire support in small sections of dismounted troops only limited due to finances, culture, policy or imagination. The US DARPA research and competitions including the Subterranean Challenge (Sub-T) and AlphaDogFight continue to fuel innovation and the growth of RAS investment, as do UK DSTL equivalent competitions for military problem sets.

Key US strategic competitors China and Russia are investing in AI technologies at a state-sponsored level, rather than the industry and research-led approach in Western nations. China is seeking to close the military gap with the US. The parade marking the 70th anniversary of communist rule in October 2019 included a display of numerous robotic technologies in advanced demonstrator or operational form (including the UUV HSU001 and UAVs GJ-11 and DR-8). China is developing and deploying RAS for persistent surveillance and communications near disputed maritime zones including the South China Sea.

Russia has demonstrated a Su-57 Sukhoi fighter teaming with a Su-35 Hunter-B UAV, has deployed UGVs operationally in the Syrian theatre, and is reportedly making design changes and strategic planning for deploying RAS based on these experiences. There are speculative but continuous reports that Russia is now fielding an Autonomous Nuclear (powered and warhead) UUV weapon, the Poseidon/ Status-6 system. The protection of allied intellectual property in RAS will be key to maintaining a military advantage.

There is a proxy-war in Libya, described as 'drone war', where an 'instant air force' has been provided to combatants through UAVs. Increased reporting of UAVs lost in conflict zones further demonstrates their increased use. In 2019, there was a high-profile loss of a US RQ-4A Global Hawk over the Strait of Hormuz, the lack of a lost life contributing to a de-escalation. Importantly, there will be a requirement to focus almost equally on counter-RAS of varying sophistication and capacity to ensure the safety of defence force personnel and platforms. The September 2019 attack on Saudi Arabian oil refineries clearly demonstrated the strategic effect of a small number of RAS and need for effective defences. The late 2020 conflict between Armenia-Azerbaijan also demonstrated the decisive role low-cost drones can play against conventional "modern" forces, decimating opposing armoured forces in the early stages of the conflict.

Fuelled by commercial research, advances in size, weight, power and cost (SWaP-C) of RAS will continue to accelerate the accessibility of systems for military use. In the future, the potential for RAS to be combined with other emerging technologies in hypersonic (either offensive or defensive use of AI), additive manufacturing (in-

Defence Science and Technology Group (DTSG) personnel prepare to launch an Autonomous Underwater Vehicle (AUV) for a training exercise as part of AUV Summerfest at HMAS Creswell, Jervis Bay, ACT. Image courtesy of the Department of Defence.

field creation of systems on demand) or neural interfaces provide further potential to accelerate advances in their military application.

Sovereign capability need

The DSU states "A Defence enterprise that is resilient to shocks and outside interference is critical to the Government's defence strategy. The ADF must increase its self-reliance... including the development of sovereign manufacturing capabilities". This positioning is reinforced in the wake of the COVID-19 pandemic. The Government remains committed to developing a strong, sustainable and secure defence industry and supporting leading-edge national innovation.

Robotics and Autonomous Systems have been identified as a Sovereign Industrial Capability Priority (SICP), affording Defence additional resources, beyond other sovereign capability development, to support small, medium and large Australian enterprises (industrial and academic) working in robotics.

Defence is increasingly looking to fill a spectrum of sovereign robotic capabilities varying in size, endurance, range, and payload capacity across all domains of air, land, sea surface, underwater, space, electro-magnetic and cyberspace. Robots for defence must be capable of operating in extreme environmental and contested physical, electromagnetic and cyber conditions.

STEM for defence

The second Australia's STEM Workforce[1] report provides a comprehensive analysis of Australia's science, technology, engineering and mathematics (STEM) trained workforce. It includes a specific section on STEM in Defence. According to the report, "the proportion of people working in the Defence industry who were STEM qualified has not increased substantially over the last decade". Further it appears that the public service holds the majority of STEM qualified persons, and at this stage the STEM capabilities in industry that support Defence as part of a mature sovereign military-industrial complex remains unknown.

An overview of people with STEM qualifications working in the ANZSIC industry class of Defence is shown in Table 3.5. The vast majority (97%) of these people worked in the public sector, suggesting they were employed by the Australian Defence Force or the Australian Government Department of Defence. Using Census data, it was not possible to explore the STEM capabilities of the broader private sector who support the work of the Defence force.

Benefits of RAS for Defence

Increased safety for human operators

Operations in areas denied to or dangerous for humans
(termed "Anti-Access/Area Denial" or A2/AD)

Force multiplication
(creating mass)

Increased manoeuvre options
through low cost and large numbers (attritable RAS – expendable)

Persistent presence

Speed of action and response

9.4 Navy robotics

The force structure plan outlines changes related to maritime capability. The Australian Navy has been working with robotic and autonomous systems for over 30 years, with this area receiving a high percentage of Navy's R&D resources due to Australia's leading academic capabilities in the field.

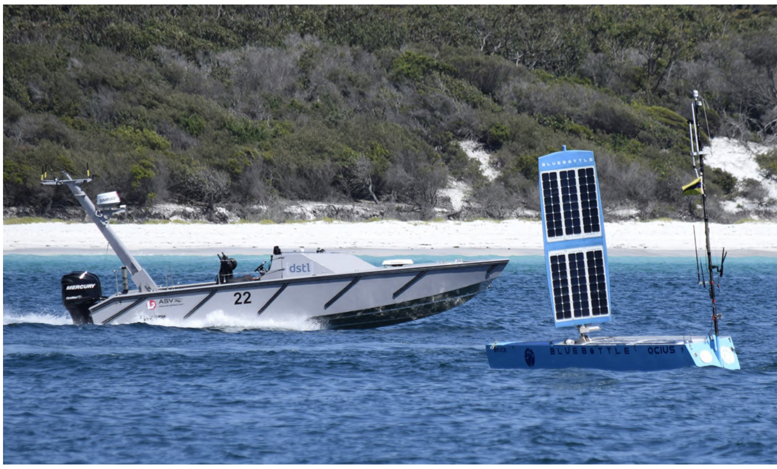
To support further enhancement of operations throughout the ADF's strategic operating environment, the Government will improve its capability options using robotics and autonomous systems in all its major projects, including future submarines, future frigates, new aviation capabilities and significantly its littoral and undersea warfare capabilities.

In the immediate future this includes:

- Mine warfare capabilities to secure Australia's maritime approaches, focused on modern, smart sea mine systems and enhancements to mine countermeasures and hydrographic capabilities (Force Structure Plan 2020, S4.12)
- Navy's SEA1905 project to address mine countermeasures capability is also a pathfinder for the future of naval RASAI, and means of Common Control
- Anti-Submarine Warfare (ASW) capabilities using RAS in air, surface, subsurface and cyber domains
- To further safeguard Australia's undersea capability, the Government will also invest in an integrated undersea surveillance system, including exploration of optionally crewed and/or uncrewed surface systems and autonomous undersea systems (Force Structure Plan 2020, S4.9)
- Maritime Uncrewed Systems (MUS) are an international priority with the FVEY community and NATO, to which Australia is recognised as a leader, following its conduct of still the largest operational experimentation in the field (Autonomous Warrior 2018). Navy has developed a comprehensive Roadmap and Program Execution Strategy of its own (Royal Australian Navy RAS-AI Strategy 2040), with a particular focus on the need for a Common Control System (CCS), supporting AI applications and a rolling Autonomous Warrior program to drive spiral development.

Example

An example of Naval investment in robotic and autonomous systems is the recent announcement of the Ocius Bluebottle receiving approval to autonomous patrol in the Australian Economic Exclusion Zone (EEZ). These trials are part of the journey to enable RAS systems to provide the Royal Australian Navy (RAN) a patrol capability to protect sovereign borders. The RAN have also established 822X Squadron to test and evaluate uncrewed (particularly air) systems and their integration into the fleet.



Left: The Maritime Autonomy Surface Testbed from the Defence Science and Technology Laboratory (UK), and Bluebottle from OCIUS (right), at Exercise Autonomous Warrior 2018 held at HMAS Creswell, Jervis Bay. Image courtesy of the Department of Defence.

Right: Australian Mine Warfare Team 16, MCDGRP and DSTG staff operating the Bluefin 9 Autonomous Underwater Vehicle (AUV) from a Mine Countermeasure Support Boat (MCMSB) during a Project Sea 1778 equipment application course at Pittwater, NSW. Image courtesy of the Department of Defence.

9.5 Army robotics

Army is continuing its exploration of robotic systems and inherently sees the value of robotics, as articulated in its Robotic and Autonomous Systems Strategy, and realising this through Army's Robotic and Autonomous Systems Implementation and Coordination Office (RICO) launched in March 2020 to explore, coordinate and develop concepts for disruptive technology.

Army seeks to leverage robotics, with variable levels of autonomy, depending on their role in the following ways:

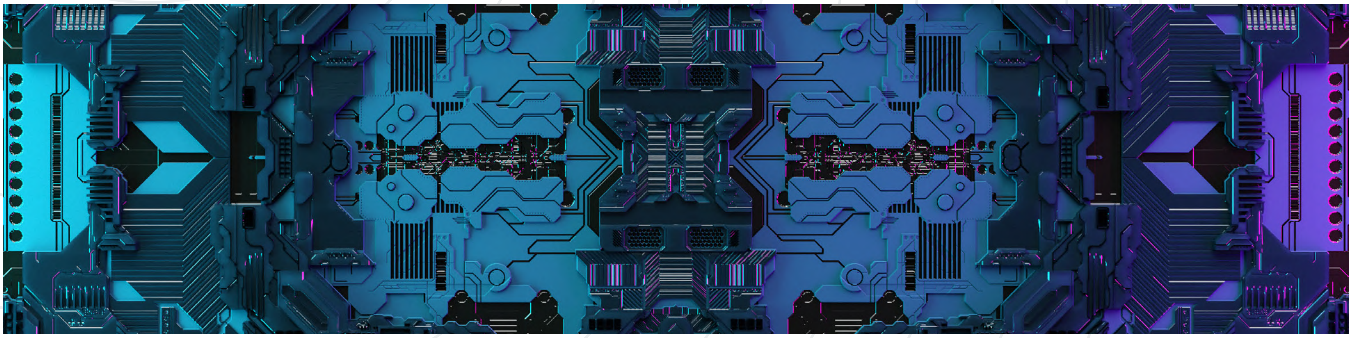
1. Maximising soldier performance through reducing their physical and cognitive loads – Army will seek to reduce the physical and cognitive burden on the soldier through the use of robotic load carriage, smart materials, automated situational awareness tools, and improving power management

2. Improving decision-making at all levels – Automated decision-making tools have the ability to create greater clarity and can sense and respond faster than humans. This speed, coupled with reliability and accuracy, creating periods of 'decision advantage', will enable commanders at all levels to make faster, better decisions underpinned by comprehensive analysis

3. Generating mass and scalable effects through human-machine teaming – Robotic systems can significantly increase combat effect and mass without the need to grow the human workforce. Robotic systems can improve firepower, force protection, and manoeuvre and enable sustained missions. This is anticipated to be through greater human-machine teaming and heterogenous swarming capabilities

4. Protecting the force – This will be achieved by using robotic technology to conduct highly dangerous activities and is the traditional role of robotics, removing the human from the immediate danger and hence increasing force protection

5. Efficiency – Robotic systems will allow Army to streamline sustainment, medical and maintenance efforts. Coupled with autonomy, Army will be able to reduce what it moves around the battlefield and be more directed with its logistic effect both in terms of cured logistic effect but also with direct logistic delivery autonomously.



Example

As part of the investment in developing robotic, optionally crewed and autonomous systems, the Australian Army held a 'battlefield concept simulation' in late 2019, showcasing two M113 Armoured Personnel Carriers roboticised by BAE Systems Australia alongside numerous other robotic systems including various sized UAS and quadruped systems. These types of demonstrations and exercises also advance Human-Machine Teaming, familiarity and design and functionality improvements.

> Automated decision-making tools have the ability to create greater clarity and can sense and respond faster than humans. enabling commanders to make faster and better decisions.

The promise of these technologies has led to the Australian Government investing an additional $7.7m into increasing the fleet of roboticised M113s to 20 among a suite of $1.2m of roboticised investments as, according to Minister for Defence Industry, Melissa Price, these "...systems are central to meeting Australia's future operational challenges, including humanitarian assistance and disaster relief, and combat operations".

The recent Force Structure outlined that Army will continue to invest in robotic systems in both the short term and in the longer term, with up to $11b highlighted for up to a Brigade's worth of future autonomous systems.

Top: A Ghost Robotics legged robot stands ready with Australian Army soldiers during an autonomous systems showcase at the Majura Training Area, Canberra. Image courtesy of the Department of Defence.

Middle: An Australian Army M113AS4 Crew Commander positions his vehicle behind an autonomous M113 AS4 optionally crewed combat vehicle (OCCV) before a mounted assault demonstration at the Majura Training Area, Canberra. Image courtesy of the Department of Defence.

Bottom: Australian Army soldier Trooper Chris Jack from B Squadron 3rd/4th Cavalry Regiment , School of Armour, remotely controls an autonomous M113 AS4 optionally crewed combat vehicle (OCCV) at the Majura Training Area, Canberra. Image courtesy of the Department of Defence.

9.6 Air force robotics

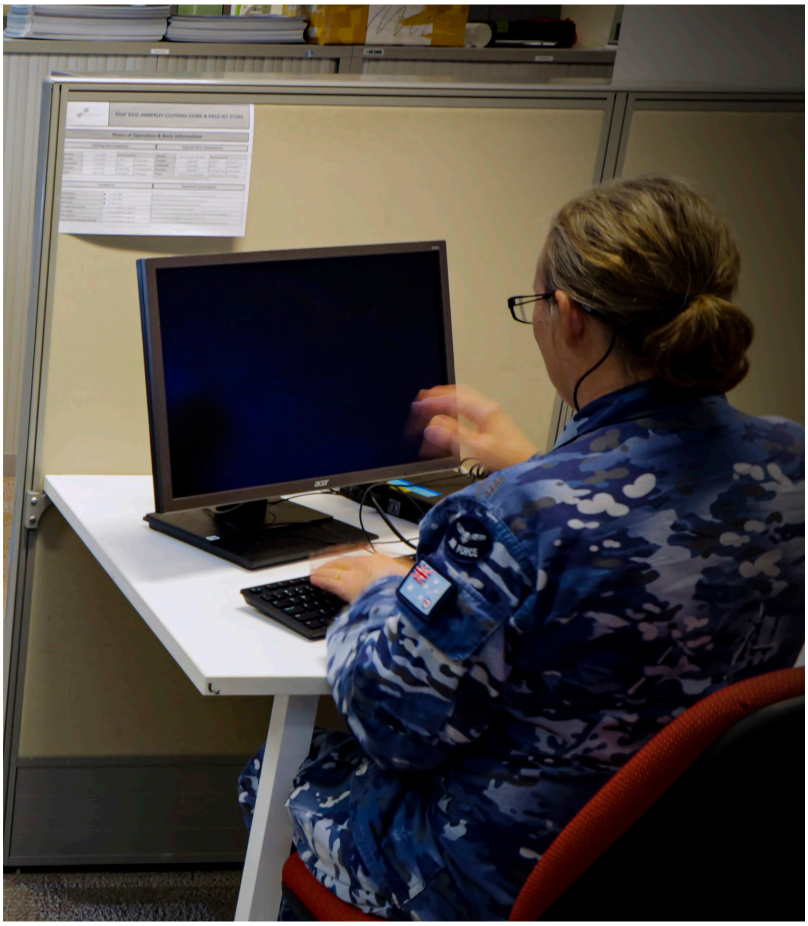
The 2020 Defence Strategic Update and Force Structure Plan noted the planned Government investment aimed at enhancing existing Air Force capabilities, as well as the acquisition of new systems including remotely piloted and autonomous aerial systems. Remotely piloted and/or autonomous systems will be developed and acquired for all air power roles, including air combat, intelligence, surveillance, reconnaissance, electronic warfare and maritime patrol and response. As with the other domains, the Air Force intends to team existing and new aircraft and ground systems with remotely piloted and autonomous systems to provide increased lethality, survivability and capacity.

Deputy Director of Artificial Intelligence, Wing Commander Michael Gan on board a C-27J Spartan during an artificial intelligence search and rescue training mission conducted off the coast of Stradbroke Island, Brisbane. Image courtesy of the Department of Defence.

Examples of remotely piloted aerial systems being acquired include the MQ-9B Sky Guardian armed Medium Altitude Long Endurance (MALE) remotely piloted aerial system, as well as the High-Altitude Long Endurance (HALE) MQ-4C Triton. The MQ-4C will operate alongside Air Force crewed P-8 Poseidon aircraft to provide Australia with an advanced maritime patrol and surveillance capability, replacing the AP-3C Orion aircraft. In addition to these remotely piloted systems, Government announced in February 2019 that is was investing in the Boeing Loyal Wingman – Advanced Development Program to examine how autonomous uncrewed aircraft can support existing crewed aircraft, such as Air Force F-35 Lightning II Joint Strike Fighters, F/A-18F Super Hornets and EA-18G Growlers. The Loyal Wingman is the first military aircraft to be designed and built in Australia in more than 50 years and has been rolled out as part of a partnership between the Royal Australian Air Force and Boeing Australia. As noted earlier, the Loyal Wingman completed first flight tests in early 2021.

In addition to aerial systems, the Air Force will be exploring robotic applications in the ground environment, where the technology has the potential to conduct a wide range of operational and air base tasks. This may include the use of smaller Uncrewed Aerial Systems and Uncrewed Ground vehicles for logistics, maintenance inspections and air base surveillance. Air Force Plan Jericho has been exploring the utility of these systems in close collaboration with the Australian Army. Australian industry is well placed to support these ground systems, as well as for the through-life sustainment and development and integration of Australian-specific capabilities on the larger remotely piloted and autonomous aerial systems operated by the Air Force.

The Air Force is also exploring lower-cost novel platforms. Autonomous systems are being utilised to reduce the physical demands on staff, making significant cost savings by introducing a Supply Assistance Robot – Autonomous Hardware (SARAH) to automate movement of aircraft parts. Air Force, through Plan Jericho, are partnered with companies on a project for self-organising, low-cost, high-altitude balloon constellation (pseudo-satellite) for persistent surveillance and communications. This project aims to deliver an initial prototype stratospheric self-organising balloon constellation for persistent ISR and communications, specifically to test key control algorithms and sensing capabilities for a full-scale project. It is a proof of concept for low-cost constellation to support persistent ISR and communications in military operations over land and sea – replacing high-cost, low-persistence space-based solutions – deployable from anywhere. The Air Force has also demonstrated with the Navy the potential for a rapidly deployable AI capability to augment human operators in at-sea Search and Rescue (SAR) Tasks. This 2019 demonstration was able to identify vessel hulls in the water in order to rapidly improve the quality and speed of a SAR task where time can save lives.



Left: Plan Jericho is undertaking a number of advanced sensing activities , including high altitude balloon launches and sub-orbital rocket launches. Air Force's Jasper hitched a ride on this launch to accompany the high altitude balloon into the stratosphere. Image courtesy of the Department of Defence.

Right: SARAH (Supply Autonomous Robotic - Assistant Hardware) delivers parts from the Logistics Section to Flight Line whilst No. 36 Squadron members go about their daily routine. Image courtesy of the Department of Defence.

The Boeing Australia, Airpower Teaming System – 'Loyal Wingman' conducts its first flight at Woomera Range Complex, South Australia. Image courtesy of the Department of Defence.

Example

The Royal Australian Air Force (RAAF) is partnered with Boeing on the Air Power Teaming Systems, or Loyal Wingman, an uncrewed 'fighter-like' air platform to 'complement and extend' the role of crewed aircraft. The first of three demonstrator models has been built and flown and will provide a lower-cost maximisation of the capability of the crewed advanced aircraft platforms. Aiming for a 30-foot length and 2,000 nautical-mile range, this is also the largest investment in uncrewed aircraft outside the United States and involved numerous sovereign Australia suppliers.

9.7 Science, technology and innovation

The Defence Strategic Update outlines changes related to science, technology and innovation capability.

Effectively shaping and harnessing the national science and technology enterprise is required to achieve a cohesive and agile innovation system that can deliver defence priorities. Defence, through the Defence Science and Technology Group, will play a stronger role in enabling, coordinating and focusing support to Defence from the national science and technology enterprise including universities, other publicly funded research agencies and industry. This more focussed science and technology effort is set out in the More, Together: Defence Science and Technology Strategy 2030. Defence Strategic Update 2020, S4.11, 4.12

More, Together re-imagines the way critical science and technology inputs will be supplied to Defence. It creates eight Science, Research and Technology (STaR) Shots, initiatives that will be led by the Defence Science and Technology Group (DSTG) and that will focus on Defence's strategic priorities, as exemplified by specific missions.

The STaR Shots will achieve scale through collaboration with academia and other publicly funded research agencies, as well as industry and international partners, both regional and global. Mission-driven research outcomes will be translated into impact through demonstrations of military utility and transition of specific technologies to the national defence industry, including primes and SMEs.

As described in an August 2020 announcement, RASAI will support capabilities being delivered by many of the initiatives, including the STaR Shots on "Agile Command and Control", "Disruptive Weapons Effects", "Operating in CBRN Environments", "Remote Undersea Surveillance", and "Resilient Multi-Mission Space" – and it is likely that AI (e.g. machine learning and data analytics in the information and cyber domains) will be exploited in the STaR Shots on "Battle-Ready Platforms" and "Information Warfare", amongst others. The only STaR Shot unlikely to rely heavily on RAS or AI, "Quantum-Assured Position, Navigation and Timing", will instead provide a critical capability edge that will enable Australian RAS to operate in congested and highly contested environments. This investment indicates the importance of

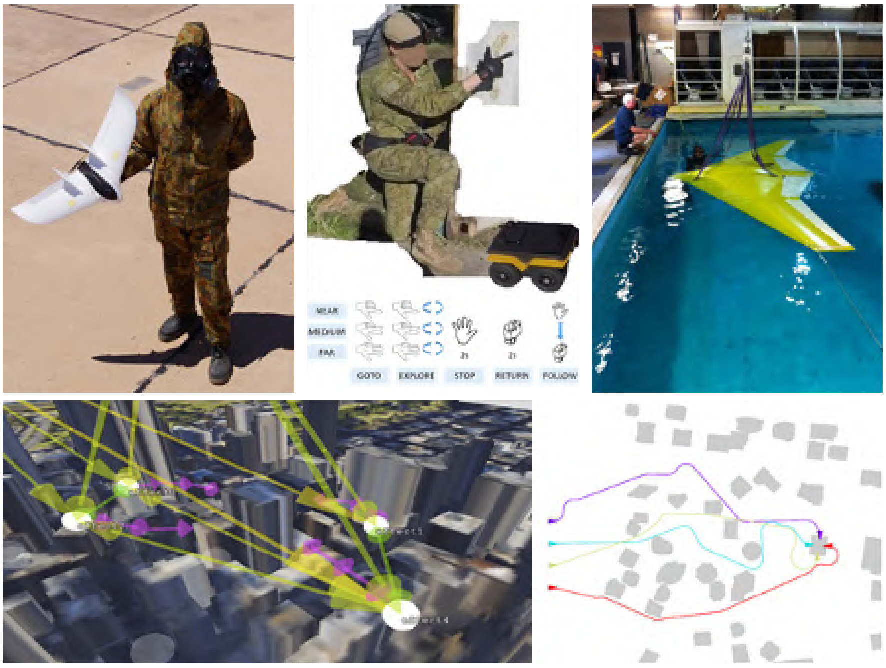
RASAI to future Defence capability and the priority placed on RASAI innovation by Defence.

DSTG brings multi-domain expertise in RAS to the STaR Shots, gained through earlier strategic research. For example, DST's Aerospace Division has demonstrated chemical-sensing missions with a small fixed-winged aircraft and Land Division is experimenting with techniques for soldier-machine teaming in collaboration with international researchers. Both projects will provide background knowledge for the STaR Shot on Operating in CBRN Environments.

DSTG's Weapons and Combat Systems Division has developed techniques for the simultaneous delivery of effects in cluttered (e.g. urban) environments, likely a future part of the Disruptive Weapon Effects STaR Shot; and Maritime Division has developed underwater gliders for long-range, long-endurance surveillance missions, research that will benefit the Remote Undersea Surveillance STaR Shot.

DSTG also has a broad and deep network of domestic and international collaborators, having technology partnership agreements with every Australian university, under which various RASAI projects are conducted, and engagements on RASAI with regional and global partners, including Singapore, Japan, and the other Five Eyes nations (the US, UK, Canada, and New Zealand).

In addition, Defence infrastructure will be brought to bear on STaR Shot projects to enable field trials and demonstrations. The facilities include the Indoor Flight Arena at DSTG–Edinburgh, DSTG–Fishermans Bend's Flight Laboratory, and the RAAF Woomera Test Range, which can be used for large-scale flight tests and contains ground facilities located at Evetts Field.



Upper-left: A small drone carrying a chemical sensor, used to demonstrate airborne chemical detection
Upper-middle: A soldier utilising RAS gesture control for human-machine teaming.Upper-right: The Sun Ray prototype underwater glider being tested in a pool at Holsworthy Barracks
Bottom: A simulation of four drones simultaneously delivering an effect (e.g. a munition or smoke screen) to an urban target.

Top: A swarm robotics experiment being performed in the Indoor Flight Arena at DST-Edinburgh.
Bottom: A view of ground control facilities used for RAS testing at Evetts Field, RAAF Woomera Test Range.

9.8 Defence industry

The Defence Strategic Update and Force Structure Plan outline changes related to industry capability.

Defence requires strong partnerships with Australian industry. This partnership continues to grow, with this Government maximising defence industry opportunity to further build a sovereign industrial base on which the ADF can rely. Force Structure Plan 2020, S9.3

A new focus on independent sovereign industrial capability has emerged. Defence Strategic Update 2020, S1.16.

The technology changes with implications for Defence projected over the following six to ten years will also likely include robotics... Defence Strategic Update 2020, S3.39

RAS capabilities are best considered as comprising physical, electromagnetic and cyber aspects. The physical robotic and cyber global markets are valued at US$103b and US$173b respectively in 2020. The electromagnetic market is dominated by the telecommunications industry with global value in excess of US$1.5 trillion in 2020. The Defence need for strengthening Australian RAS industrial capability and capacity is clear when considered in context of this global investment. Successful strategy must recognise the comparatively small and immature Australian industry capability and investment scale, as well as the inherent complexity of delivering RAS capabilities.

Australian Defence supplier demographics show a market consisting of approximately 90% small and medium enterprises (SMEs), with few medium-sized organisations and the large enterprises being principally foreign owned. The present supply chain immaturity impedes delivery of complex RAS capability to Defence. Given the Australian investment scale in relation to potential adversaries, it is necessary to achieve a high degree of focused growth in the sovereign supply chain. The 2018-19 Defence Industry and Innovation Programs Annual Report shows that Trusted Autonomous Systems are the largest investment area with 45%, and Cyber with 10%, of the Next Generation Technology Fund (NGTF) investment allocation. The same report on page 51 shows that 77% of the investment has gone to SMEs as part of the Defence Innovation Hub (DIH). This shows that whilst RAS investment focus is achieved, it is spread broadly across many organisations. It is not clear how the successful innovation this investment will bear can transition to sustainable operation capability in the absence of suitably scaled sovereign enterprises or consortia.

Whilst significant, the existing Commonwealth investment is insufficient to lead in the global RAS market investment. Unlike many of its peers, Australia lacks adjacent industries (e.g. personal electronics, telecommunications) to fund the maturation of medium and large sovereign RAS-capable enterprises. This limits private co-investment, which other nations leverage to maximise the return on their government-led investment. The investment scale must be addressed to develop Australian sovereign supply chains that are resilient to shocks and outside interference. The capital shortfall could be treated through shaping existing Commonwealth investment to generate enduring sovereign infrastructure to foster SME growth. Significant capital and schedule efficiencies can be achieved through cost reduction of business and technical processes by creating a 'scaffolding' for re-use and leveraging of existing investments.

Example opportunity exists in defence-controlled shared-development environments. For software capabilities, the best practice is for such environments to be implemented to encompass Development, Security and Operations (known as DevSecOps). Defence control of focussed DevSecOps environments to support RAS software development would ensure a high degree of execution efficiency, effective management of technical outcomes across the growing industrial base, as well as appropriate treatment of cyber security risks at a national level. The approach is a key enabler to agile technology project delivery, with the US Defense Intelligence Information Enterprise (DI2E) being a successful exemplar that leverages industry best practice with escalating national benefit. A similar approach can be used to enable efficiencies in physical manufacturing supply chains, through establishment of an enduring national RAS intellectual property repository to facilitate Australian enterprises' re-use of past solutions.

The efficiency dividends obtained from enterprise collaboration outweigh the commercial risks of doing so, as evidenced by successful open business models. The application of open business models in the national security context does not imply that value generated is open for all to access. The critical observation to make is that this approach limits duplication of effort, provides substantial efficiencies and enables capital pooling to deliver outcomes not able to be realised by individual enterprises. This is pertinent in the Australian context which has a broad SME industrial base and a dearth of industries adjacent to RAS to accelerate sovereign industry growth beyond the current Commonwealth investment.

9.9 Think tanks

The Australian Strategic Policy Institute has consistently argued for greater, more-immediate investment in robotic systems for the ADF.

> *[designing] systems that keep their precious cargo of humans alive is difficult and expensive. So, taking humans out of the platform has advantages. You don't need to design the platform to keep them alive in hazardous environments like the undersea domain. You don't need to incorporate space, weight, power or fuel to support them. You can design uncrewed systems for performance that would kill humans, whether it's high-G turns, ocean depths or extended endurance. So uncrewed systems can achieve the same or greater performance (such as speed or range) than bigger crewed platforms. ... Because you don't need to defend the crew, you don't need to design the platform to defeat all potential threats. ... Much of the cost of military platforms is due to the need to keep the crew alive, as is much of the complexity of design. Remove the crew, and the cost, risk and schedule needed to design and build the platforms decreases dramatically. ASPI Cost of Defence, 2019.*

In short, autonomous systems are a way to break out of the vicious spiral of increasing platform cost and decreasing platform numbers created by the need to protect human crews. Only by escaping this cycle will the ADF have the mass necessary to win future conflicts, particularly one in which Australia and its allies may be confronting a major power.

Breaking this cycle would allow implementation of concepts such as mosaic warfare[2] as described by the US think tank Centre for Strategic and Budgetary Assessments. These distributed operational concepts rely on larger numbers of smaller, largely autonomous platforms enabled by artificial intelligence that give commanders more and faster options that present adversaries with decision dilemmas, impeding their ability to react and respond effectively.

Getting to a more autonomous future will take time however it occurs, but ASPI's analysts have argued that Defence could be doing more to accelerate the transition. Granted, Defence is undertaking development and experimentation on autonomous systems (outlined above), but it is largely of an incremental, gradual nature that is potentially out of step with the pace of change and deterioration in Australia's strategic environment outlined in the 2020 Defence Strategic Update.

The new 2020 Force Structure Plan that accompanied the Defence Strategic Update outlines significant new investment in autonomous systems in the air, land and maritime domains. This is certainly welcome, however, these funds are largely programmed in the late 2020s or even the 2030s. For example, the $7.4-11.1b in Future Autonomous Vehicles does not commence until 2032. Until then, R&D activities will have to rely on Defence's much smaller innovation funds which make up less than 0.5% of Defence's overall budget. There is scope for a more ambitious approach (such as those outlined in *Accelerating Autonomy* and *From concentrated vulnerability to distributed lethality*).

We should also note that the new investment plan presented in the Force Structure Plan does not deliver any new combat vessels until 2030. Nor does it accelerate the acquisition of more crewed combat aircraft. Therefore, the step change in capability sought by the government will need to be delivered by weapons or autonomous systems that augment existing crewed platforms. Greater investment in autonomous systems can, then, be seen as a hedging strategy, balancing the risk inherent in over-investment in one future pathway, that of exquisitely expensive crewed platforms. ASPI has also argued that the design of future crewed platforms must be ‘future proofed’ by ensuring that they can function as motherships for future uncrewed and autonomous platforms. Investment in the current strategies is delayed, for example and autonomous land investment does not commence until 2033. The failure to move more rapidly towards RAS from human crewed systems is a ‘missed opportunity’ to accelerate adoption. There is also a potential difficulty for industry in scaling up to meet Defence demand and absorbing the funding now announced as available.

Equally the Williams Foundation (Central Blue) highlight the inevitability of RASAI to the future of the ADF capability.

They note however full-autonomy remains in the future for all but ‘straightforward’ tasks and there will be transitional semi-autonomous human-machine teaming and decision support functions of value as technical capabilities mature.

The advent of robotics and autonomous systems (RAS) has seen the convergence of technologies such as artificial intelligence (AI), swarming, alternative energy, additive manufacturing, and advanced materials. The potential implications for the use of RAS by the Australian Defence Force (ADF) are substantial as they range across autonomous systems themselves (platforms, devices, and agents); human-machine teaming; countermeasures; and autonomous behaviour. As the ADF contemplates these implications, fuelled by our allies adopting RAS, there is both an inevitability of increasing use of RAS and an advantage to be gained from the dogged pursuit of RAS as they will, increasingly, offer high levels of autonomy, stealth, and persistence; and will improve the ADF’s overall military capabilities.

9.10 Trusted autonomous systems

The DSU defines an ADF that fully exploits the use of trusted autonomous systems to enhance future capability in an uncertain geo-political environment. The strategy encourages agile, innovative and asymmetric thinking to accelerate the development of a sovereign industry to develop, design, build and field systems before others do. It seeks to understand the ethical and legal framework under which these systems are conceived and operated to ensure Australia meets its international obligations. It demands that future systems make efficient use of the Defence budget whilst maximizing warfighting capability.

The Trusted Autonomous Systems (Defence Cooperative Research Centre - TAS) is a key contributor to this vision. TAS provides Defence with specialist knowledge in the development and exploitation of new and novel autonomous systems. It promotes collaborative research with Defence Science and Technology and leading universities, building a resilient national intellectual base from which future technologies can be conceived. It develops trusted partnerships with industry to guide future requirements, monitor manufacturing capability, and secure sovereign intellectual property. Importantly, the Centre’s creation as an independent company formally recognises its emphasis on the use of entrepreneurial practices for novel and rapid capital raising, collaborative design and development paths and innovative contracting methods.

A comprehensive external review of the Centre was conducted by Defence in October 2019. The panel of experts, led by ex-Chief Scientist of Australia, Prof Ian Chubb, recommended the centre extend its capacity to “deliver enduring value to Defence and build sovereign capability”. This was further supported by fifteen recommendations. Defence accepted the report and is now working with the Centre on implementation. New strategic industry-led projects continue to be developed through direct ADF funding. Building on successful experience gained in its first years of operation, and on the basis of this report, the Centre is expected to grow in the next ten years. As autonomous systems proliferate, the number of research, development and capability transition programs with Defence will increase.

> **The TAS vision is for:**
>
> *Smart, small and many systems, capable of overmatch of large and exquisite crewed platforms and other robotic systems – enabled by dynamic composition of modular sensor, weapon and human command components from national, allied and regional coalition partners.*

To deliver this new kind of asymmetry, a layered approach is advocated where large crewed and optionally crewed or uncrewed and pre-deployed platforms provide stand-off delivery of "small, many and smart" systems to hold adversaries at risk at long range. This layered approach is illustrated by the graphic on the following page. Given Defence's commitments with multi-national prime industries to deliver "potent crewed platforms" such as JSF, submarines and future frigates; sovereign Australian prime industries might be best placed to develop and deliver the "autonomous, uncrewed and optionally crewed systems"; with the plethora of innovative Australian SMEs best placed to develop and deliver "autonomous smart, small and many" systems. This strategy is enabled by human-machine teaming, a sovereign common control system and spectrum agility.

By 2030, TAS will have built a reputation for good governance, sound financial management, and strong intellectual and research-based collaboration in the field of Trusted Autonomous Systems delivering game-changing technologies to Defence – a trusted partner in technology.

Centre achievements

TAS projects represent potential tipping points for Defence to achieve the Centre's vision.

These projects are guided by broad Defence needs and are industry led, with the support of research providers. Centre activities include common-good initiatives to further support the projects and the vision. The current state of these is summarised as follows:

Trusted scalable search with expendable drones

Led by DefendTex with RMIT University, the University of Melbourne, and the Department of Defence Science and Technology (DST) and utilising the DefendTex Drone-40 platform for research on trusted autonomy. The project is set to place the team in a position to compete in the US on the DARPA Subterranean Challenge.

Distributed aUtonomous Spectrum Management (DUST)

Led by Consunet Pty Ltd with RMIT University, the University of Melbourne, the University of Sydney and DST. DUST aims to research, develop and demonstrate near real-time autonomous spectrum management to deliver orders of magnitude increase in agility and efficiency cost savings for Australian Defence and commerce.

Justified autonomous Uncrewed Aerial System (UAS) effects

Led by Skyborne Technologies and Cyborg Dynamics Engineering with the University of Queensland (UQ) and DST. The project aims to research and develop autonomous live reconnaissance effects assessment using AI and machine vision for day and night UAS operations over land. The system aims to advise operators on the legal and ethical aspects of fire support missions in near-real time. The Athena AI system recently received a national innovation award.

Cognitive intelligence, surveillance, reconnaissance

Led by Boeing Australia this project examines the embedding of machine learning techniques on board an uninhabited system to better understand and react to the threat environment. The project has designed and tested cognitive artificial intelligence algorithms to enable sensing under anti-access conditions and to navigate and conduct enhanced tactics in denied environments.

Trusted autonomous ground vehicles for electronic warfare

BAE Systems, working with researchers at the Universities of Melbourne and Adelaide, will exploit advanced AI techniques to deliver a next-level trusted autonomous platform capable of robust and persistent operation in complex, contested land environments. A series of M113 vehicles have been fitted with robotics to enable optionally crewed operation as a pathway on this project.

Mine counter measures in a day

Thales is partnering with DST, INENI Realtime, Mission Systems, the University of Sydney, Western Sydney University, Flinders University and the University of Technology Sydney to develop new autonomous technologies that will revolutionise mine clearance capability in littoral operations. The five-year project is designing, developing, testing and evaluating various teams of micro Autonomous Underwater Vehicle (AUV) swarms and Autonomous Surface/Subsurface Vessels (ASVs) to deliver autonomous mine clearance capability for zone preparation. The AUV swarms and ASV vessel teams will perform Rapid Environmental Assessment, mine-like object detection and localisation, mine target recognition and simulated neutralisation, enabling zone preparation and clearance in a significantly shorter period of time – 'MCM in a day'. This new capability will provide a significant operational step-change to Navy by removing ADF from harm's way and accelerating the speed of mission execution.

Activity 1 – Ethics and law of Trusted Autonomous Systems

Led the University of Queensland (UQ), TAS with DST. This aims to develop ethical and legal assurance for projects and benefit participants, through advice and policy development, supported by case analysis, education and enculturation. This includes TAS representation as non-government participants in the United Nations (UN) Group of Governmental Experts (GGE) on Lethal Autonomous Systems (LAWS) to ensure the development of RAS accord with ethical principles and the laws of armed conflict (LOAC).

Activity 2 – Assurance of autonomy

Led by TAS and funded by the Queensland Government. This aims to create a trusted environment for test, risk analysis and regulatory certification support of autonomous systems and establish an independent world- class assurance service to global industry based in Queensland. The 2020 announcement by the Queensland Government of developing the Cloncurry UAS Flight Test Range by QinetiQ aligns with this Activity.

Example images are for illustrative purposes only. Concepts derived by Trusted Autonomous Systems.

A Defence Science and Technology Gavia Autonomous Underwater Vehicle is placed back into its cradle after conducting Mine Counter-Measure integration trials during Fleet Certification Period 2020. Image courtesy of the Department of Defence.

Case studies

GaardTech — High-fidelity robotic training

Since 2017, GaardTech have been providing high-fidelity, full scale 2D static and 3D robotic armoured vehicles to Defence. These enable a wide range of training scenarios, to enhance decision-making in a realistic combat setting – from basic gunnery and marksmanship, through to high-level tactics against a moving, thinking threat force. In 2019, GaardTech received an Advance Queensland (Ignite Ideas) grant which supported international marketing and an initial trial with the UK Army.

GaardTech has continued development into 2020, where they are currently incorporating Machine Vision into their systems which will trigger robotic action and combative responses.

Using the GaardTech 3D T-80 Tank replica, the team were able to train a deep neural network on a private data set with an object detection model. The emerging model is able to identify a Tank from drone footage at high elevations and limited exposure due to camouflage, concealment and shadow. Images courtesy of GaardTech.

Sovereign industry capability for uncrewed maritime systems support — BlueZone Group

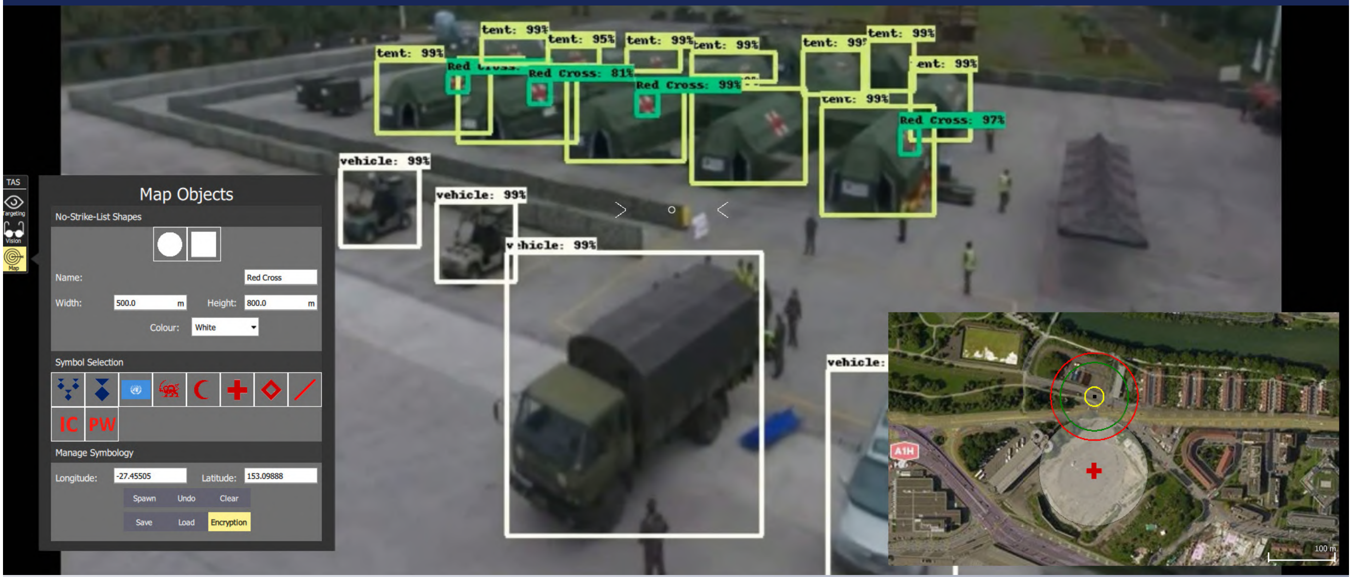
Innovation in robotics is not just confined to design and production of robots. In a local success story, BlueZone Group has supported uncrewed maritime systems operated by the Royal Australian Navy since 2000. BlueZone has grown to provide a capability to maintain, modify and modernise many robotic systems operated by Defence, and has also developed systems for water infrastructure applications and other customers.

As more robotic systems are fielded it is clear that the capability to support the systems in the field, perform workshop overhauls and integrate new sensors and systems will be a key advantage to successful operation. For Defence this provides the "technology edge" that is needed to equip our forces and provide reliable systems in the field. In industry this aligns with Industry 4.0, as robotic innovation will require technical staff with advanced skills and a lifelong commitment to learning as new robotic systems transform many aspects of operations.

Australia's claims over maritime areas are some of the largest in the world, and robotic systems provide the capability to measure, monitor and safeguard these regions. BlueZone Group provides an example of how support for these systems can result in a successful business with bright prospects for the future.

BlueZone Technician maintains the Double Eagle Mine Disposal System . Image courtesy of BlueZone Group Pty Ltd.

The Athena AI project



TAS partners Cyborg Dynamics and Skyborne Technologies have developed Athena AI with the ability to identify protected objects, people and symbols (e.g. red cross or red crescent), on hospitals or ambulances, in near real time for military operations using computer vision at very high probabilities.

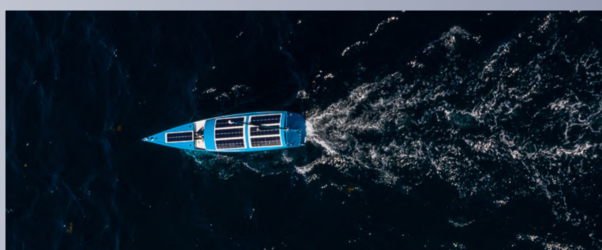
This system will afford military commanders and decision-makers a decision support tool that can scan an environment and identify if there is a change that would require protection of a given piece of infrastructure such as a hospital in a warzone. The system can also process large amounts of information to establish a 'no-strike' list including for example United Nations (UN) and medical or refugee areas in a given location. This system will be ground-breaking in reducing the potential harm to non-combatants and aligning targeting with the Laws of Armed Conflict (LoAC).

AI detection of tents, red crosses and vehicles used for informing locations of 'no strike' areas performed by Athena AI. Image courtesy of TAS.

Persistent ocean presence for uncrewed surveillance and monitoring — Ocius Technology Ltd

OCIUS "Bluebottle" uncrewed surface vessels are perpetual, eco-friendly, ocean-going vessels which are one hundred percent Australian designed and manufactured. Propelled by wind, wave and solar power, and with generous (300kg) payload, continuous live tracking and advanced control centre, the Bluebottle is a multi-utility marine surface robot crucial for the management of remote and vast coastlines.

Bluebottles have been designed to withstand remote and harsh environments, and are currently being put to the test in seas to the north of Australia under a $5.5m defence innovation hub grant. Their implementation will transform Australia's offshore sovereign capabilities in surveillance and monitoring, with applications in customs, fisheries, defence, energy, science and environmental protection.



Bluebottle USV with its solarsail stowed , using propeller and wave power for propulsion directly into the wind. Image courtesy of Ocius Technology Ltd.

Autonomous robotic targets — from university startup to global market leader

Marathon Targets makes autonomous robotic targets for military and law enforcement marksmanship training. The system addresses a problem common to all military and police forces: the first time they engage a realistic moving target is in a firefight - not the right place for on-the-job training.

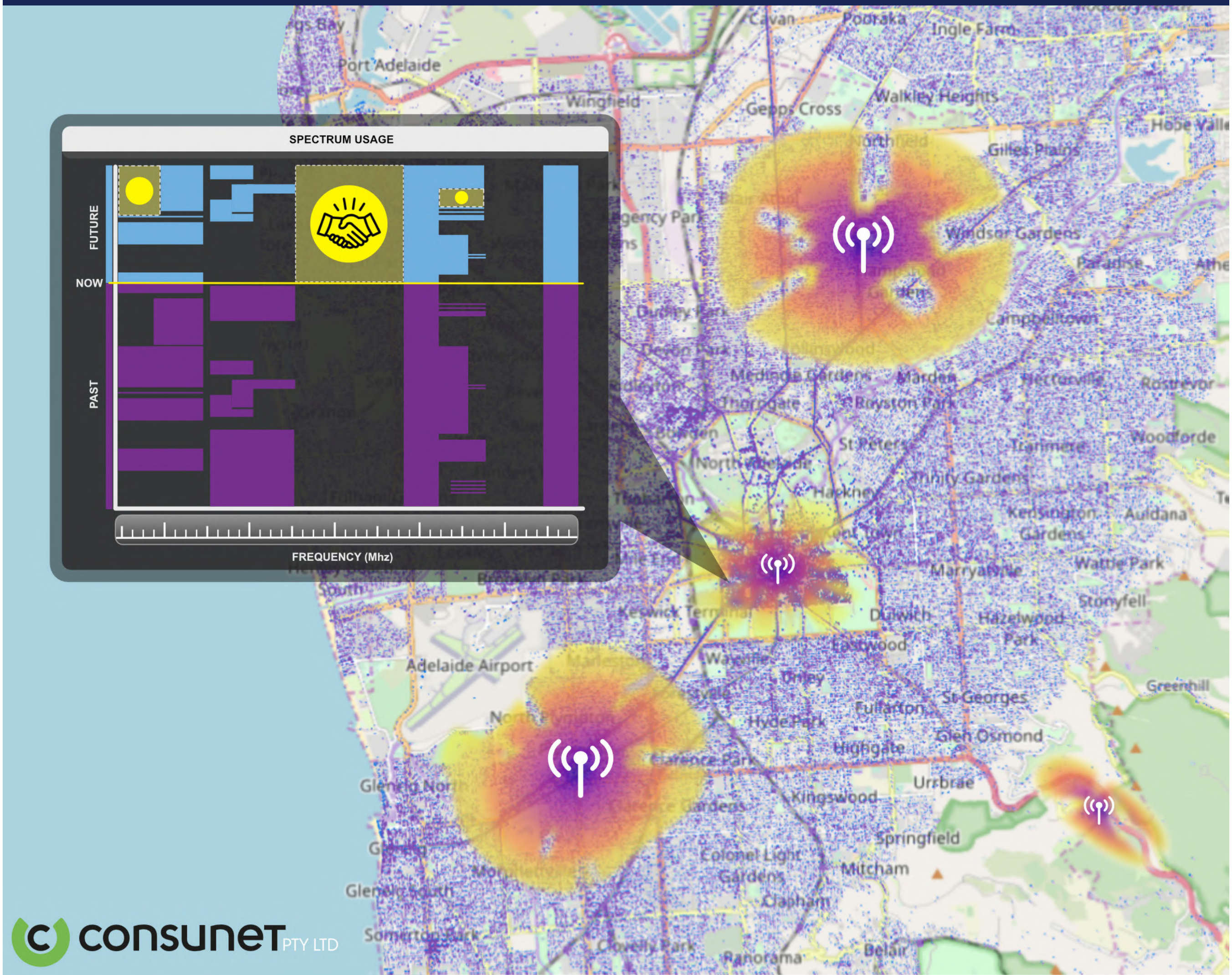
Marathon's targets are designed to mimic human appearance, motion, and behaviour. A 3D plastic mannequin acts as the target and detects hits from live rounds. The custom-designed robotic platform achieves human-comparable acceleration, top speed, and endurance. The targets are capable of building a map, localising within the map, planning paths, and avoiding static and dynamic obstacles. The robotic base is ballistically armoured to protect the electronics and actuators from bullet hits.

A custom-designed, distributed behaviour engine enables human-type behaviours. For example, when one target is hit, it sends a message to others which react by running for cover, regrouping, and staging a counter-attack.

Marathon was started in 2007 by three researchers from the Australian Centre for Field Robotics (ACFR) at the University of Sydney. The company provides a unique training capability and has supplied target systems to special forces, conventional armed forces, and law enforcement units in Australia, North America, Middle East, and Europe.

Law enforcement officers train with realistic moving targets. Image courtesy of Marathon Robotics.

Spectrum autonomy



Distributed aUtonomous Spectrum managemenT (DUST) is a Consunet led TAS project to improve the effectiveness and efficiency in which the Electromagnetic (radiofrequency) spectrum can be autonomously accessed, licensed and utilised.

To enable the Research and Development (R&D) of fundamental technologies to achieve the DUST vision, Consunet has developed a very large-scale radio-frequency simulator called Ark. This simulator enables project R&D by providing data suitable for Machine Learning, Artificial Intelligence and Data Science research and an accessible test environment. Many data sets have been created for a variety of scenarios, including a recently demonstrated bushfire scenario.

The DUST project will develop models of electromagnetic spectrum (e.g. radio and mobile) channel usage within a geographic location using historical data (shown in purple), to make predictions (shown in blue) for when these channels will not be in use. This way spectrum can be utilised more efficiently by other users (shown in gold). Image courtesy of TAS.

Cognitive Intelligence, Surveillance, Reconnaissance (CISR)

This TAS project noted above has now concluded (August 2020). Funded by RAAF Plan Jericho it culminated in a live demonstration of multiple jet platforms in cooperative and coordinated flight with dynamic multi-agent "cognitive machine" teams for cooperative detection in an environment where GPS and comms is degraded. This pathfinder project has demonstrated a proof of concept in cooperative platforms achieving identification and assessment of ground-based objects.

Boeing Australia demonstrated the unmanned AI tech to the Trusted Autonomous Systems Defence Collaborative Research Centre and Australian Army representatives during the flight test event. Image courtesy of Boeing Australia.

Contributors

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Mr Kuba Kabacinski (Consunet)
Dr Simon Ng (TAS)
Prof Jason Scholz (TAS)
SQNLDR Robert Vine (RAAF)
Mr Paul Jones (TAS)

Footnotes

1 https://www.chiefscientist.gov.au/news-and-media/2020-australias-stem-workforce-report

2 https://csbaonline.org/research/publications/mosaic-warfare-exploiting-artificial-intelligence-and-autonomous-systems-to-implement-decision-centric-operations

10

Agriculture

Growing crops, raising animals, harvesting timber, fish and other animals from a farm, ranch or their habitats

10.1 Agriculture, aquaculture, fisheries and forestry in Australia

Australia's high quality products and strong food security make it a premium global food supplier, particularly within southeast Asia[1] and the northern hemisphere due to counter-season production. Our varied climate has led to the development of a wide range of agricultural technologies, such as sensors and field robots, to help farmers make the most of an often harsh environment.

Support for digital technologies is increasing with a growing number of AgTech startups,[2] and Australia relies on technology to increase agricultural profitability and efficiency. This makes Australia well-positioned to take advantage of the anticipated increase in future demand for food for the world's growing population, with 60% more food production required by 2050 to feed 9.7 billion people.[3]

> In Australia, approximately 50% of the land mass is devoted to agriculture but $4.8b is lost due to weeds, including the cost of control measures through weed management.

The Australian agriculture, forestry, aquaculture and fisheries industry employs ~344,000 people[4] or 2.7% of Australia's working population,[5] uses 58%[6] of our land area, and contributed $6.7b in gross value added to the Australian economy as of 2018. The vast distances covered by agricultural production present numerous challenges in service delivery, freight distribution and telecommunications. While Australia exports more than 50% of the food it produces, there is tremendous waste along the food value chain, with estimates that as much as half of all production is wasted before it reaches the consumer. In Australia, approximately 50% of the land mass is devoted to agriculture but $4.8b is lost due to weeds, including the cost of control measures through weed management.[7] The ancient fragile nature of Australian soils makes many areas infertile, requiring high use of chemical fertilisers and creating high susceptibility to erosion and nutrient runoff. Degraded soil and land is estimated to cost Australia more than $5b per year.[8] An often overlooked

Snapshot: Agriculture: What's changed since 2018?

Strengths

- Australia's heavy equipment manufacturing sector lends itself to production of robotic farming equipment
- Rural Development Corporations (RDCs) support technology creation and adoption
- Strong growth in export revenue despite challenges

Wins

- AgTech continues to see increased venture capital investment, with several agricultural robotics companies raising funds
- More demand for organic and other products due to increasing health consciousness
- Drones have allowed increased application of digital twinning to guide efficient operational processes

New opportunities

- Increased move to cloud-based solutions, assisted by improved connectivity in rural areas
- Higher focus on domestic supply chains and sovereign capability in automation system development – a result of serious disruption to both international and domestic supply chains
- COVID-19 has seen greater demand for farm automation given restricted availability of internationally-sourced labour
- Greater demand for solutions incorporating carbon neutral components and environmental benefits

Challenges

- Internet connectivity as a backbone for cloud processing is still unreliable
- Lack of standards for interoperability – hardware, software, enterprise systems
- Limited legal frameworks for application of autonomous systems

Realistic 5—year goals

- New standards for data sharing of agricultural datasets, and new standards for local and international privacy
- Availability of autonomous tractors and semi-autonomous farmhands for all businesses
- Creation of demonstration sites showing robotics systems on a working farm
- Real-time spraying in horticulture

benefit of robotic technologies is the potential to apply them flexibly to reduce environmental impact such as soil damage.

Remote and regional areas of Australia – where agriculture, aquaculture, fisheries and forestry activities are concentrated – are home to 13% of Australia's population, cover 85% of the Australian land mass, and produce 40% of gross domestic product (GDP). More than 85,000 agriculture businesses operate in Australia,[9] and while the number of businesses is decreasing, the majority remain family-owned and operated. The Australian agriculture industry also supports 1.5 million people in related industries which service the sector.[10] Like most developed countries, Australia has seen migration, particularly by young people, from regional areas to major cities. At the same time, Australia's population is ageing due to sustained low fertility and increased life expectancy. This has resulted in proportionally fewer children (under 15 years of age) in the population, and a proportionally larger increase in those aged 65 and over.

> Remote and regional areas of Australia are home to 13% of Australia's population, cover 85% of the Australian land mass, and produce 40% of gross domestic product.

Approximately 37% of workers in the agriculture, forestry and fisheries industry are aged 55 or over, the most of any industry in Australia. The median age for workers in this industry is 49, while the median age of farm owners

is 61. Over the past 15 years, the median age of the agricultural workforce has increased six years, while the average age of unpaid family members working on farms has increased from 47 to 61.[10] The combination of an ageing workforce, the remoteness of most agriculture, forestry and fishing operations, and the vast distances they may cover, makes innovation and the development of new technologies a pressing need, which is where robotics can play an important role.

Internet supported technologies are estimated to make a $15.6b contribution to Australia's $100b agriculture industry by 2030,[11] consisting of decision support ($8b), monitoring and sensors ($4.3b) and robotics and automation ($3.3b). Continuing development of remote sensors, robotics and automation has the potential to replace low-skilled human labour and increase demand for a workforce with a range of technology-related skills. However, one third of farms across Australia report that access to reliable internet was impeding their uptake of new ICT tools.[12] Farmers with mobile and satellite internet connections were more likely to report issues with internet access compared to those with digital or fixed line connections.

One third of farmers identified lack of necessary skills to adopt new technology as an impediment, although this was more commonly reported in farmers aged over 50 years. 20% of farmers also reported that high upfront costs of new technologies, and difficulties around integrating new technologies into on-farm practices, as barriers to adoption. Automation in agriculture is expected to drive reductions in staffing requirements for meat, fruit and vegetable packers and bookkeepers.[13]

In coastal regions of Australia, the fishing and aquaculture sectors provide employment opportunities for a diversity of people in seafood production, whether that is on the boat, the farm or in the office. Employment is also created for people in associated businesses which transport, process, and sell seafood products in these regions. Fishing and aquaculture sectors contribute to the economic stability of these regional communities through providing a baseline of economic activity throughout the year – where other industries operate seasonally, such as tourism, or are dependent on commodity prices (mining). Aquaculture and fisheries alone are worth $3.18b in 2017-18, employing 17,000 people (11,000 people in world-catch fisheries and 6,000 people in aquaculture), while employing another 25,000 people indirectly (AFAI). The gross value of production (GVP) has increased over the last five years in Australia through increased sales of high value species and value adding by the seafood sector of $5.3b.[14]

10.2 Impact of COVID-19

The COVID-19 pandemic has emphasised that Australia is one of the most food secure countries in the world. We are net-exporters – exporting 71% of our agricultural production and importing only 11% of our food, motivated by taste and variety, not necessity.[15]

Australia's agricultural industry will drive the development of robotics and automation technologies in the near future due to the significant impact of COVID-19 dramatically reducing the supply of labour for essential agricultural tasks.[13] COVID-19 has seen an increased focus on food security, the use of local supply chains, and an increase in direct online connections with consumers – increasing the uptake of digital technologies and driving demand for online platforms that can provide such linkages.

Bushfires and COVID-19 combined as bad news for Australia's forestry sector. Large areas of both natural forests (8.3 million hectares) and commercial plantations (130,000 hectares) were destroyed. At the same time domestic and international recessions, resulting from COVID-19 lock-down measures, are expected to reduce residential construction activity and see reduced demand for timber products.[16]

COVID-19 has had a significant impact on Australia's fisheries and aquaculture industry. The impact has been complex and resulted from both demand-side disruptions to domestic and international markets and supply-side disruptions from physical distancing measures across fishing and aquaculture activities and issues in crewing vessels and sourcing inputs in some sectors. Australia exports around half of its annual fisheries and aquaculture production by value, specialising in high unit value products for the growing Asian market. As a trade-exposed industry, the seafood sector is subject to trends in world markets, and the effect of Australia's exchange rate on the price received for export-oriented species and for competing imports. Australia's reputation as a reliable and high-quality supplier of high unit value fisheries products, and its proximity to Asia's fast-growing seafood market, generally insulates Australia's trade in fisheries products from longer-term shocks. The pandemic has caused some disruption to Australia's usual trade, particularly for products that are highly export-oriented, such as rock lobster and abalone. Sporadic commodity-focused trade issues with China have posed additional challenges for exporters.

COVID-19 has highlighted some supply chain issues facing the sector. Much of Australia's seafood exports target the food services sector in Asia, mainly via air freight. Physical distancing measures and restrictions on air travel during the pandemic negatively impacted global food services and airline industries. As such, since early 2020 many exporters of seafood have used the Australian Government's International Freight Assistance Mechanism to help lower the cost of exports. Reliance by the fisheries and aquaculture sectors on Asian markets for exports is a risk that has been highlighted during the pandemic. The sector's response to this risk and the extent to which it diversifies its export markets will help determine how the sector recovers and repositions itself following the pandemic.[17]

10.3 Robotics and agriculture, aquaculture, fisheries and forestry today

Australian agriculture is truly world-leading – in efficiency, technology and environmental credibility. This helps Australian farmers attract investment from around the world, and secure new customers for clean, green produce in Asia's premium food markets. Australia invests $90.4m in the agtech sector with an additional $600m invested annually through rural R&D corporations resulting in a $20b lift in the industry's value. Australia has more than 400 agtech and foodtech companies, and supports 15 agtech incubators/accelerators.[18]

Australia was the first country in the world to develop autosteer technology to allow self-driving tractors and other farming equipment in 1997.[19] We have also led the way in camera spot spray technology used with autonomous robot weed control. The application of robots to the sector has mainly seen the use of autonomous ground-based vehicles in agriculture and forestry, experimental use of autonomous underwater vehicles in fisheries and UAVs for inspection, surveillance and mapping. Most of these applications are towards automation and digitalisation of farm and forestry management practices.[20] Land-based farming has seen the largest application of robots and sensors applied to: precision agriculture (monitoring soil and crops, collecting data and applying precise crop protection measures); weed identification and control; automation within greenhouses; crop and fruit harvesting; planting and seeding; and livestock management (such as milking of cows, herding and barn management). There is limited use in forestry and silviculture applied to cultivation, management and harvesting, as this is mainly restricted to automation of existing harvesters and extended use of drones.[20] While there is limited use of robots in aquaculture around the world so far, strict environmental guidelines in Australia may fast-track adoption in the future.

Aquaculture operations – particularly those that operate in, or discharge into, public waters – are required to comply with stringent environmental controls, monitored on an ongoing basis by state agencies. Strict food health standards also apply to both aquaculture and wild capture products. These environmental and food safety standards ensure fish grown in Australian waters are safe to eat and that seafood production does not unduly affect aquatic environments.[21]

We have also recently seen the application of new computer vision and sensing technologies to supply chain management – to help monitor fish catches, identify the species being harvested, allow real-time adjustments to protect fish species, and enabling consumers to gain direct insight into the time and location at which their fish is caught.

Drivers for the adoption of robotic technologies include: the need to improve safety; reduce costs; facilitate remote mapping of aquatic habitats supporting fisheries and species diversity; and development of new stock enhancement and management tools – e.g. technologies to support biodiversity protection and restocking strategies, and to respond to key risks to fisheries and aquaculture.[22]

10.4 The future of robotics in agriculture, aquaculture, fisheries and forestry

The trend towards increased use of robots in agriculture is growing. The market for livestock farming robots – milking, barn cleaning, robotic fencing for automated grazing control – reached US$1.2b in 2019 and is probably at saturation, but there is strong growth (30%) expected for other agricultural applications such as fruit picking.[20]

According to the UK-RAS white paper on the future of robotic agriculture,[23] the main opportunity is in precision agriculture – intelligence gathering and mission planning through the use of heterogeneous "multi-modal" platforms that combine ground-based and aerial vehicles. Large-scale arable and fruit crops require these platforms to behave in both a collaborative and cooperative manner to perform tasks in parallel, giving economies of scale. In combination with other technologies, supply chain management and tracing will be a reality in the future, thanks to robotics.

The future of robotics in aquaculture will see the onshore regulation of offshore fish farms, eliminating the need to send service vehicles and crew out to sea. A combination of autonomous vessels, drones and remotely operated vehicles (ROVs) – which can already carry out tasks such as inspections and underwater maintenance – can be used to work together to monitor fish welfare, inspect facilities, ration feed and count lice.[24] The use of disruptive technologies such as blockchain, sensors and automatic identification systems (AIS), demonstrates the potential of disruptive technology to change the processes, profitability and sustainability of the sector. Used in conjunction with robotics, these technologies have the potential to change fishing activity by providing fishers with more information so that fishing is safer (e.g. weather forecasting), more precise (e.g. satellite positioning) and more predictable. The applications of mobile internet (e.g. providing real-time market prices for fish), advanced robotics (e.g. automatic fish filleting) and interconnectedness among systems (IoT), devices and advanced sensors (e.g. electronic fish tags), all have the potential to improve compliance with regulations and traceability. These technologies may change the way fisheries economies are organised, with consumers asking for sustainably caught fish, from traceable and transparent sources, and fishers offering "on-demand" products from selective and safe fisheries.[25]

> The future of robotics in Australia in aquaculture will see the onshore regulation of offshore fish farms. This will eliminate the need to send service vehicles and crew out to sea.

The forestry sector has always been considered a physically demanding and potentially dangerous workplace, where workers are exposed to heavy and fast-moving trees, logs, and machinery.[26]

The design of forestry equipment dates back to the 1970s and redesigning forest harvesters to be autonomous has the potential to deliver social, safety and environmental benefits to forestry, including reduced soil compaction, and the ability to spot koalas and other wildlife using remote image sensing .[27] In Canada, the industry is developing highly automated machines to operate in the remote, unpredictable, often steep terrains where forestry occurs.[28] These include a mechanical log loader to automate the crane function of automated harvesting (to detect and pick up logs) and rugged automated ground vehicles. Robotic technologies are also being deployed to accurately and precisely assess forest inventories, reduce costs, increase the speed of data acquisition, and correlate ecological knowledge with remote-sensing technology to predict and quantify the fibre characteristics of trees. These technologies are enabling new forest-renewal methods that maintain and support natural biodiversity, while maximising potential forest-site productivity.

Importantly, robotic technologies can be applied to determine the impacts of climate change on forest diversity, to provide new approaches to measuring environmental risk and uncertainty, and to assess the environmental costs and benefits of different land-use strategies in terms of their impact on forest diversity.

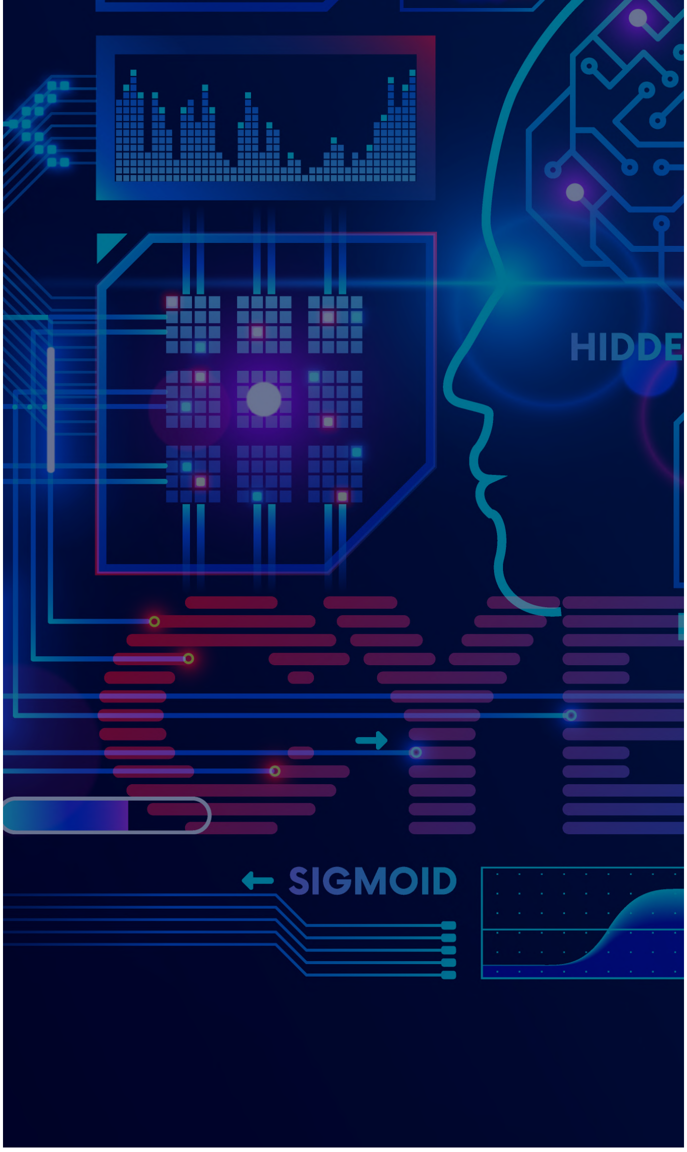
10.5 Main findings for robotics in agriculture, aquaculture, fisheries and forestry

Australia's agriculture, aquaculture, forestry and fisheries sector will grow in the future due to global population growth and Australia's reputation as a trusted food source. However, agricultural activity currently includes high levels of waste in the value chain, and places significant demands on large portions of environmentally sensitive land and water on the Australian continent and continental shelf.

The low population density, ageing population, remote location, and vast distances involved in agricultural production, present numerous challenges in service delivery, freight distribution and telecommunications. This makes innovation and the development of new agricultural technologies an area where robotics can play an important role in the form of autonomous vehicles, cloud computing (and cloud robotics), UAVs, IoT and precision agriculture. The application of robotic technologies can optimise yield, increase efficiency, and ensure sustainability in the sector.

Australia has established a reputation as a supplier of safe, high quality seafood which is produced using environmentally sustainable practices, and Australian aquaculture producers target high value domestic and overseas markets. The increasing demand for Australian native species and the proximity to Asian markets, together with world recognised seafood quality and standards, means Australian aquaculture is competitively positioned to take on high value aquaculture products. The Food and Agriculture Organization of the United Nations (FAO) has predicted that by 2018, farmed fish production will exceed wild fisheries production for human consumption, and that by 2021 more than half of the fish consumed globally will be produced by aquaculture.[21]

Case studies



CSIRO WANDA® — AI based electronic monitoring of fisheries operations

Monitoring and collecting data on targeted fish catch and unintended bycatch is necessary to ensure our fisheries are sustainable. In the past, humans have monitored fishing activities on vessels, but this is time consuming, expensive, and dangerous. Cameras are increasingly being installed on fishing vessels to monitor what is being caught, but the video is still labour-intensive to manually watch.

WANDA® is a new software that can identify which fish are being landed on board a vessel based on video from electronic monitoring. The program uses advanced mathematical and computing techniques such as deep learning to automatically detect and identify fish species. WANDA® is the product of a CSIRO research collaboration between its Oceans and Atmosphere and Data61's Imaging and Computer Vision Group, using videos captured from commercial fishing vessels to train the new software.

Additional development of physical electronic tags could enable industry, wholesalers and retailers to track the provenance of seafood through the supply chain, from boat to plate. Commercial fishing companies could use electronic tags to manage their supply chain for quality control and for end consumers to access catch information. This will provide trusted information of fish origin at the root of the seafood supply chain.

AI based fishing event detection – fisher detection, fish detection and species identification, and catch counting. Image courtesy of CSIRO.

Green Atlas Cartographer

Farmers routinely make crop management decisions that determine whether their business will make a profit or a loss. Decisions are made using low quality data, or no data at all. When data is used, it typically relies on expensive manual labour and decades of experience and judgement. The lack of good data results in: increased fertiliser usage; increased water usage; increased manual labour; inefficient use of chemicals (e.g. thinners, pesticides etc); inefficient supply chains; inaccurate yield forecasts; and reduced yield potential.

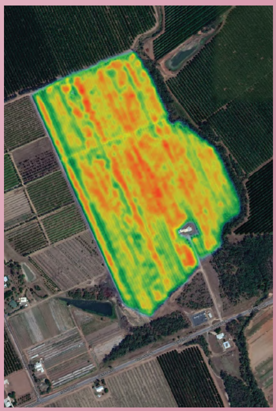
Green Atlas' Cartographer takes samples of the quantities of interest (buds/flowers/fruitlets/fruit/nuts) from every tree in an orchard by imaging them all with both cameras and LiDAR (thus capturing the inherent crop variability), in a manner that is cost-competitive with traditional techniques. This represents an entirely new category of service in this industry sector. To the best of our knowledge, Green Atlas is the only company worldwide that has successfully taken these new agricultural services to market, and is operating routinely in multiple crops on multiple continents. Australia benefits through job creation, and increased efficiencies from the tree to the consumer.

Left: Cartographer at a commercial orchard in Victoria. Image courtesy of Green Atlas Pty Ltd.
Right: Cartographers in an almond orchard (mapping mummified nuts). Image courtesy of Green Atlas Pty Ltd.

TALLYOP — The harvester-mounted vision system

TallyOp is a world first application that provides a competitive advantage to farmers, allowing them to optimise efficiency and boost yield performance to simplify and enhance farm management decisions through data collection. It is now possible to monitor the density of produce on a heat map, geo-plot 'field' boundaries, and identify high yield areas utilising an accurate and reliable yield monitoring system. This technology works for corn, macadamia nut, strawberries, avocado, mango, citrus fruit and sweet potato.

COREMATIC Engineering provides technical support and technology systems to businesses that want to de-risk innovation and automate their operations keeping full control of their Intellectual Property. Corematic believes that every aspect of agribusiness and food industries can benefit from technological advancements - from planting and watering, to crop health and harvesting, and the company has a vision to bring an advanced R&D approach to the industry.



Heatmap. Image courtesy of COREMATIC Engineering.

Aerial to tractor weed detection

InFarm's aerial to tractor weed detection platform allows farmers to save up to 97.5% of their herbicide use. It is both economical for farmers and has major environmental benefits such as reducing chemical impacts of farming on our soils, waterways and barrier reef. The platform itself is revolutionary. It captures sub cm resolution aerial imagery on a regional scale, which equates to 6TB of data per day. The images are then processed in near real time using big data analysis and artificial intelligence. Results are delivered to farmers overnight, no cloud, no internet.

InFarm's platform not only transforms the industry, it also democratises access to big data and AI, allowing remote and isolated farmers around the world to access this technology easily.

Top: Near real time detection of weeds in crop. Image courtesy of InFarm.
Bottom: VTOL drone for broadacre crops. Image courtesy of InFarm.

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11

The environment

Robotic technologies such as vision-enabled robots and robotic floats are utilised extensively in the monitoring and management of the Australian environment

11.1 Australia's environment

A healthy environment is important to the quality of life, health and wellbeing of all Australians. We are recognised as a global biodiversity hotspot, hosting almost 700,000 native species of plants and animals, many of which are found nowhere else in the world. Sixteen of Australia's unique habitats have been given world heritage listing, however we are losing biodiversity at an alarming rate and have one of the highest rates of extinction in the world. More than 10% of Australia's land mammals are now extinct, and another 21% are threatened and declining.[1]

We are the largest island continent, sixth largest country and with the world's third largest ocean territory spanning ~12m square kilometres.[2] Australia's economic exclusion zone (EEZ) is home to the world's largest coral reef, the Great Barrier Reef, considered to be worth $56b in economic and social value as an iconic asset.[3] Australia also manages 42% of the Antarctic territory, which has a fragile ecology on land, ice and sea. As an island, Australia's biodiversity has been isolated from many outside threats. However, increasing globalisation and transport by air and sea exposes Australia's environment to many biosecurity threats, including pollution, contamination, and the introduction of pests, weeds, and disease. The unique nature and richness of Australia's biodiversity means there is a national responsibility to protect and conserve native flora and fauna. For this reason, Australia invests nearly $2b in the environment each year with the value of our biosecurity system worth $314b when modelled over 50 years.[4]

> Increasing globalisation and transport by air and sea exposes Australia's environment to many biosecurity threats, including pollution, contamination, and the introduction of pests, weeds, and disease.

In this roadmap, the environment encompasses all living and non-living things that occur naturally, including climate and weather. It also includes threats to this environment such as habitat loss, pollution (e.g. litter, air and water contamination), pests and biosecurity threats.

Snapshot 〉 The environment: What's changed since 2018?

Strengths

- Australia's proximity and dependency on the marine environment have helped drive interest and innovation in the field
- Many of Australia's top research bodies have investment in marine science or marine technology thus providing a diverse body of research
- Elevation of the importance of climate and marine ecology protection, and mitigation against changing climate
- Growing emphasis on marine infrastructure investments by both government and industry

Wins

- An increase in marine industry technology research and investment with numerous solutions for both autonomous and remotely operated marine platforms
- Increased investment in Machine Learning (ML) and Artificial Intelligence (AI) research in the Australian innovation system
- Enhancements in communication supporting robotic systems – both subsea communications and via satellites, with some microsatellite startups in Australia offering new solutions

New opportunities

- Investment and support around emerging challenges in the marine domain including work on the Great Barrier Reef and the Blue Economy
- Investment in more autonomous platforms and methods COVID-19 exposed vulnerabilities and dependence on crewed marine platforms

Challenges

- Talent retention in high-demand areas of ML/AI and enabling robotic autonomy continue to present challenges in building research capability both in Australia's innovation system and robotics industry
- Lack of international standards around the development of enabling technologies in the marine sector. We have seen standardisation across aerial drones but the marine space has yet to adopt either strong technical standards or operational best practices
- Working with regulatory bodies to ensure a robust framework for the operational use of uncrewed marine platforms, both surface and subsea. The ability to operate systems with minimal supervision is key in allowing for effectively scaling observational networks

Realistic 5—year goals

- Engage with the international engineering and marine science community through forums such as IEEE Ocean Engineering Society and OceanObs to recommend technical standards, and establish best practices for the design and operation of autonomous platforms at sea
- Include the operational use of autonomous platforms as part of GBR program efforts

11.2 Robotics and the environment today

Australia is the driest inhabited continent on earth with nutrient poor, unproductive soils (only 6% arable land) and highly variable rainfall, run-off and streamflow. Our natural environment is at risk and may not be sufficiently resilient to withstand current, emerging or future threats.[5] The threats are vast and significant, with pressure from land-use change, pollution, habitat fragmentation and degradation, invasive species, fire and climate change, all of which require constant vigilance at massive scales.

Surveillance is made more difficult as most of Australia's small population of 25.7 million (80%) lives within 100km of the coastline, largely separate from the bulk of the country's biodiversity and natural assets. The lack of long-term monitoring data limits our ability to understand the pace and extent of environmental decline, which actions to prioritise and whether previous interventions have been successful. This is a particular challenge in the marine environment. Hence, Australia has a set of unique drivers to adopt and exploit robotic, remote sensing and computer vision technologies to monitor, manage, and protect the natural environment.

Urbanisation and a growing Australian population are placing localised pressures on the environment for housing, food, and water (habitat loss), waste management, and energy. Consequential effects include decreased air quality in urban centres due to pollution, risks of disease due to litter and food scraps (e.g. malaria, dengue, rabies), and contamination of food and water supplies from industrial activities. Advances in technology will lead to significant improvements in our understanding of Australia's biodiversity, including for organisms that have previously been difficult to identify and monitor. Consequently, Australia needs innovative tools to allow upscaling of monitoring programs and ways to help monitoring, intervention, threat removal, remediation, and restoration at national, as well as local scales. This is an opportunity for robotics to play a role in all these steps on land, in the air, underwater and on water surfaces.

Australia has a long and world-leading history of successful deployment of robotics for environmental monitoring and management. Vision-enabled robots are deployed in long-duration fleets to collect data, while robotic floats travel the seas collecting data on the marine environment. While the range of environmental challenges that can be tackled is wide, the type of technologies that need to be deployed are similar across all environments.

KEY ROBOTIC TECHNOLOGIES USED IN OUR ENVIRONMENT

SOME OF THE KEY ROBOTIC TECHNOLOGIES THAT ARE BEING APPLIED TO AUSTRALIA'S ENVIRONMENT INCLUDE:

- Vision-based repeat survey and change detection and quantification, habitat classification, automated threat assessment (biosecurity)
- Persistent land, sea and air robotic platforms
- Rehabilitation and maintenance robots
- Remote operation of subsea systems
- Communication technologies (both subsea and remote (i.e. 4G, Satellite etc.)
- Robust "marinised" actuation to enable intervention activities
- Miniaturisation of environmental sensors for increased platform flexibility
- Enhanced autonomy enabling deployment of marine robots at scale.

11.3 The future of robotics in the environment

Robots and sensing systems used in the environment need to be robust and persistent to achieve autonomous operation at scale across the vast distances and varied landscapes of the Australian continent. A range of technologies are necessary to help monitor and mitigate environmental challenges. Many of these are close to development, or aspects of the technology exist in prototype form but are not widely deployed.

Such technologies include:

- Autonomous vehicles to access coastal marine areas under all weather and traffic conditions. This includes travelling vast distances and operating for months at a time
- Addition of multi-modal sensor suites aligned with automated data processing workflows (e.g. hyperspectral cameras)
- Overlaid measurements for coral reef health assessments at different altitudes and resolutions, including remote sensing satellite, medium altitude drones and underwater vehicles
- Ground-based mobile robots that can safely negotiate and operate in remote and rugged terrain without supervision
- Perception-to-Action activities – real-term interaction with data, where remediation action can be taken as soon as a problem is identified (e.g. detection and extinguishing of a bushfire)
- Long-term (trusted) autonomy – navigation perception capability, long-term planning and robustness (long-term operation without need for repair). Examples include:
  - Clearing litter on roadsides where robots need to be able to operate safely near cars and people, on rough surfaces, while being able to identify a range of objects and take appropriate action (like regulatory and trust issues facing driverless cars)
  - Marine monitoring operations where the robot is required to abide by the collision regulations (COLREGs) (like driverless cars on our roads)
- Robust location detection given significant change, e.g. revisiting an area after a natural disaster
- Robust classification (of plants and animals) in outdoor environments under all weather and lighting conditions with extreme precision (i.e. 100%)
- Systems engineering to ensure robots can survive extreme conditions (fires, floods)
- High speed perception and action. For example, drones operating at low altitudes in forested areas or surface craft negotiating flooded and swift-water environments
- Improved hardware and algorithms for on-board processing. Due to Australia's sparse population, many areas do not have internet connectivity and, as such, robotic systems in these locations will need to be less reliant on the internet or cloud for perception and classification autonomy
- Miniaturised sensor suites to enable newer smaller classes of robotic systems
- Cloud robotics to offload computation to remote resources to assist robots to perform operations including physical sample and sensor reading collection.

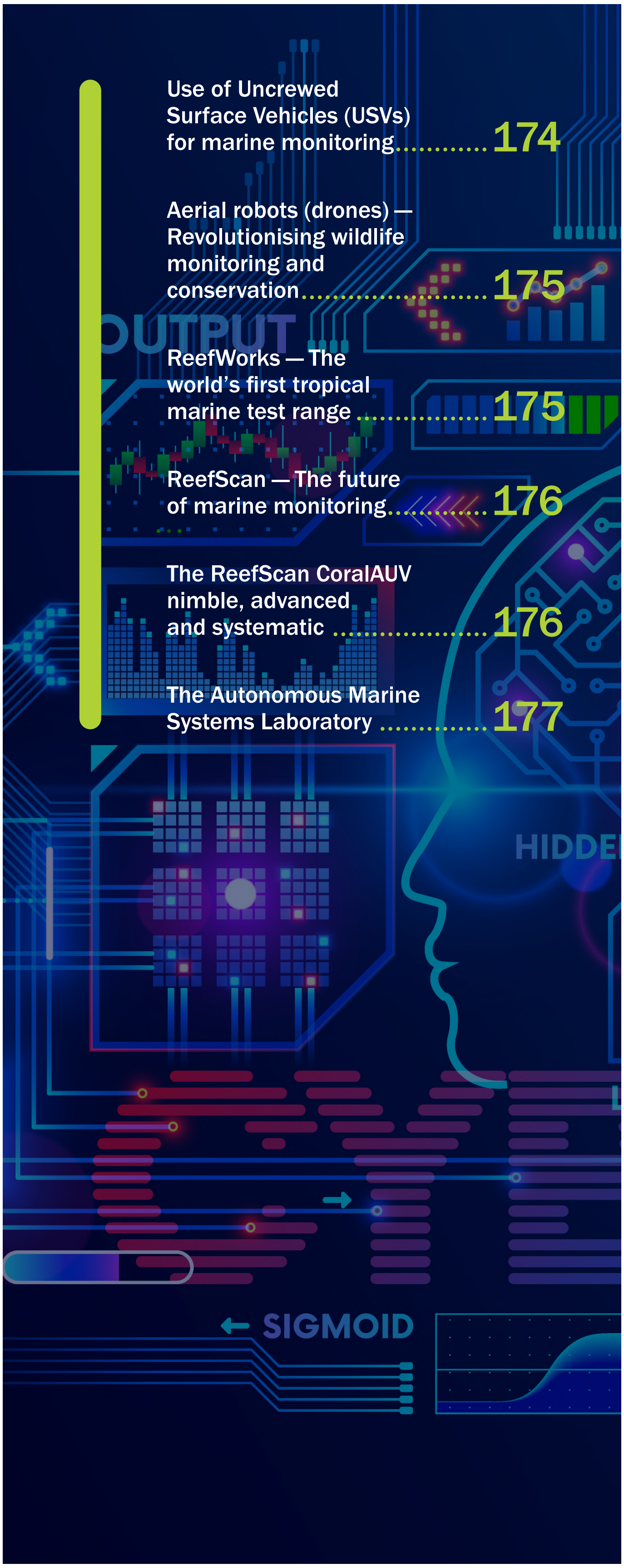
Funding sources for these activities is a key challenge for deployment and operationalisation of robotic technologies. Many of these can be applied to the environment, and also find application in solving industry-relevant issues. For example, underwater robots for reef management might also be used for underwater asset inspection, or land-based fire-fighting robots could be used for forestry or agricultural weeding/fertilising activities. Combined multi-use studies should be considered to facilitate commercialisation of ideas. Upscaling geographic extent and repeat deployments could consider not only commercial operation, but also the training and use by citizen scientists, rangers, schools and community groups. Consideration should be given towards potential research collaborations between environmental robotics researchers and those for defence, infrastructure and agriculture.

11.4 Main findings for robotics in the environment

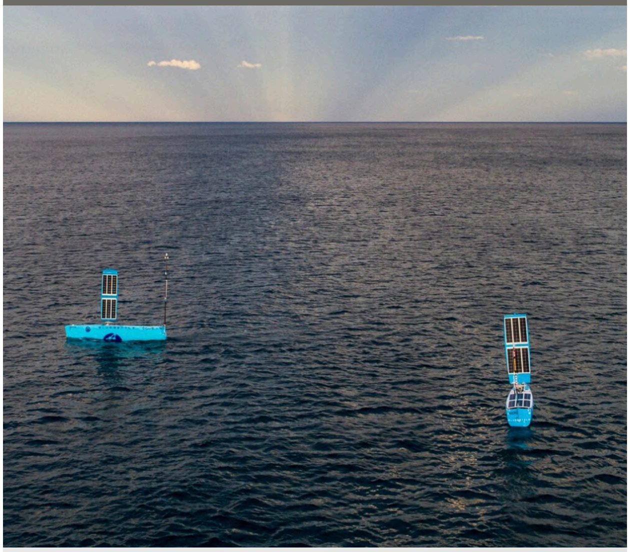
Many of the challenges for use of robots in the environment relate to the vast distances and persistence required for unsupervised operation across the varied continental and marine scapes of Australia.

The need to provide systems and processes for environmental monitoring, which are designed and built for manufacture and operation at scale, will be a key driver of adoption of such robotic systems in the future. As for the defence sector, the opportunity to deploy small robots in high volumes to conduct biodiversity monitoring will accelerate our understanding of the environment and improve our ability to manage it. While the range of environmental challenges that can be tackled is wide, the type of technologies that need to be deployed can be applied to most sectors of the Australian economy, and collaboration on platform technologies will be key to success in the future.

Case Studies



Use of Uncrewed Surface Vehicles (USVs) for marine monitoring



In the past few years there has been a sharp increase in the development and use of Uncrewed Surface Vehicles (USVs) to support ocean operations both for the scientific community, defence and other marine industries. While increased autonomy is slowly being incorporated into existing crewed vessels, the design of bespoke uncrewed systems allows for more tailored systems able to address specific mission requirements with smaller and more flexible platforms.

One company in Australia, OCIUS, has developed a Bluebottle USV that makes use of wind and wave propulsion to provide sustained observations at sea. While the Bluebottle was initially developed in support of defence applications, the platform is capable of carrying environmental monitoring payloads in support of a broad range of marine science domains, including remote sensing, oceanographic measurements and meteorological observations.

USVs are well placed to provide improved observational coverage of Australia's expansive Exclusive Economic Zone (EEZ) as well as support operations in Australia's Antarctic territories. Most recently a consortium of international partners including Australia's CSIRO conducted a number of USV deployments in the Southern Ocean culminating in a circumnavigation of Antarctica in 2019.

Bluebottles doing a persistent intelligent network patrol using solar wind and wave energy. Image courtesy of CSIRO.

Aerial robots (drones) — Revolutionising wildlife monitoring and conservation

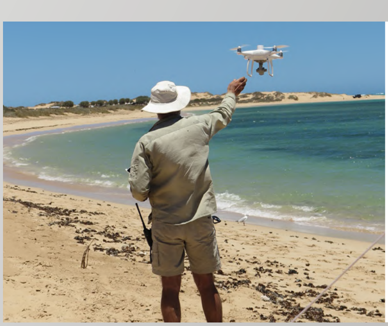
Estimating the abundance of animals is a fundamental part of conservation management – managers need to know whether fauna are stable, increasing or decreasing so that they can decide on appropriate actions. For animals that are large and conspicuous, this isn't a problem. But many animals are not. In the ocean, estimating abundance is even more difficult because of the limitations of seeing through water. If species are rare or sparse, challenges can be immense, so that we lack even basic estimates for species like sea turtles.

To overcome these challenges, scientists at the CSIRO are turning to autonomous aerial vehicles – aka drones. Drones can survey large areas far more efficiently than divers or even observers on boats. Surveys designed to detect sea turtles by scientists from the CSIRO Ningaloo Outlook team take around 90 minutes to survey 300 hectares. The drones fly pre-programmed lines, taking a picture every few seconds.

Armed with data on the number of turtles observed by the drones, the scientists then use information about how long turtles are "detectable" – for example when they are on the surface and easy to see – and therefore generate estimates of how many turtles they cannot see. Together, this gives an estimate of how many turtles are present in an area during the survey.

Left: CSIRO staff recovering a quadcopter drone during a turtle survey in Ningaloo. Image courtesy of CSIRO.

Right: A typical quadcopter drone in flight. Image courtesy of CSIRO.



ReefWorks — The world's first tropical marine test range

Australia is a world-leader in small uncrewed maritime systems development, however, to certify and commission marine technologies, especially autonomous systems into operational service, Australia needs to routinely test and evaluate these systems. The Australian Institute of Marine Science (AIMS) provides a national test and evaluation facility, ReefWorks, to enable the streamlined commercialisation of next-generation marine technologies in robotics, autonomous systems and artificial intelligence (RAS-AI).

Reefworks is designed to test marine technologies and uncrewed systems at different levels of technology readiness, as well as to verify technologies as fit-for-purpose, safe to operate and environmentally compliant. It caters for uncrewed and autonomous aerial, surface and underwater systems and other innovations or sensors that require testing and evaluation in the marine environment. Services and facilities include marine platform and sensor test tanks, tropical marine test ranges with drone corridors, a digital twin test range, laboratories, workshops, wharf facilities and infrastructure at sea.

ReefWorks expands our ability to monitor or respond to the challenges facing our marine ecosystems such as coral bleaching events and other impacts of climate change by. ReefWorks is positioned to drive value and innovation in a range of sectors including marine monitoring, reef restoration, defence, education, agriculture, filmmaking, search and rescue, transportation, storm-tracking, forecasting and mapping.

ReefWorks offers a national capability to safely test marine technology. Pictured: the AIMS-QUT reef survey trials of a WAM-V autonomous surface vessel. Photo: Geoff Page, courtesy of AIMS.

ReefScan — The future of marine monitoring

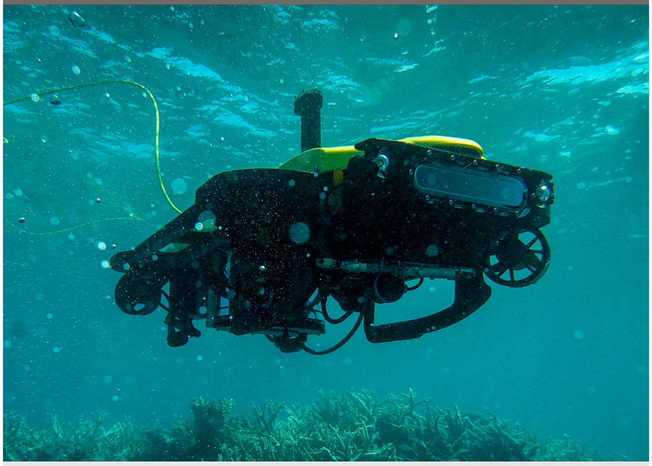
The world's marine ecosystems, critical to life on earth, are increasingly stressed and rapidly changing. It's more important than ever that we have the data to make informed decisions about the most effective way to care for, protect and sustain marine ecosystems and the communities that rely on them.

Marine monitoring is expensive, labour-intensive, sometimes dangerous, and currently only achieved at a limited scale. Current monitoring systems are only able to survey a few percent of the total target areas, with surveys often undertaken years apart or in an ad-hoc manner.

Working with innovative partners, the Australian Institute of Marine Science (AIMS) has designed a modular suite of automated marine monitoring systems that can translate field data into comprehensive information about the state and health of critical marine ecosystems such as coral reefs. ReefScan leverages technologies in marine vision, autonomy and artificial intelligence delivered in field-ready, easy to use platforms, supported by web-based automated workflows. ReefScan products can be configured to cater for a wide range of needs and environments, improving the effectiveness of efficiency of marine monitoring programs. Integrating machine learning, advanced imaging sensors and robotics. ReefScan offers an 'end-to-end' approach from monitoring design to data collection, analysis and reporting.

A family of smart, custom-designed technology will enable users to monitor much greater marie areas in exciting new ways, providing deeper insight. Pictured is the ReefScan CoralAUV. Photo: Danielle Koopman, courtesy of AIMS.

The ReefScan CoralAUV nimble, advanced and systematic



The Australian Institute of Marine Science (AIMS), in partnership with Queensland University of Technology, has developed a high-performance, reliable and cost-effective autonomous underwater vehicle (AUV). The ReefScan CoralAUV can navigate physically intricate environments exposed to strong, complex currents, to undertake high-resolution monitoring tasks that would be dangerous for divers.

It uses sophisticated optical methods to create a 3D terrain map in real time, and navigates as a diver would, relative to the terrain. It features a sophisticated georeferencing capability and a scientific payload bay for high-resolution optical (stills, stereo, video), hyperspectral and sonar-based monitoring. It has onboard AI capability to undertake analysis and detection tasks in real time.

While some AUVs have already been deployed in reef environments, they tend to be slow, expensive, complex to support, and unable to undertake large-scale mapping without human intervention. Traditional coral reef monitoring relies on human observers. It is labour-intensive, limited to diver or snorkeller depth, typically only operational during good weather conditions in areas of relatively sheltered water, mostly during daylight hours, and limited to areas that are safe. ReefScan CoralAUV is a more systematic monitoring tool than traditional methods and will be used to meet functional and operational requirements for reef, benthic and fish biodiversity monitoring programs.

Navigation sensors allow CoralAUV to undertake a highly accurate path and repeat the same mission again in the future. This provides us with a 3D 'digital twin' of areas of the reef and allows for year-on-year tracking to inform reef management and reef restoration.

The CoralAUV, with advanced capabilities, is scheduled for initial deployment and operational use in 2022. Image courtesy of AIMS.

The Autonomous Marine Systems Laboratory

The Autonomous Marine Systems Laboratory (AMSL) at the Australian Maritime College (AMC), University of Tasmania was officially opened in 2017. The lab brought together existing University research in maritime autonomy in the polar, commercial and defence spaces. Since 2017 the lab has mounted three underwater robotics campaigns under Antarctic ice, including at the Nansen Ice Sheet and the Thwaites and Sørsdal Glaciers, and has contributed data and analysis to international efforts to understand the impact of warming circumpolar water on the melt of the continent's ice sheets, and the consequent impact of sea level rise on Australia's coastal communities.

The lab is home to two Autonomous Underwater Vehicles and a growing range of tethered vehicles. The 7.5m long nupiri muka is equipped with bathymetric mapping and water quality packages and is the focal point for advanced oceanographic and topographic surveys, with an operational depth of 5,000m. The smaller REMUS 100 operates primarily in the coastal environment and supports training and consultancy services in the maritime domain, including to the Royal Australian Navy.

To bridge the gap between current capabilities and operational requirements, the Australian Defence Forces (ADF) engaged the AMC to develop and deliver a suite of operator and technical courses for Navy personnel, building on the AMSL experience of underwater missions in extreme environments.

Left: Trainees deploying the REMUS 100 during AMC Search's Mission Controllers Course in the deep-water environment of Lake St Clair, Tasmania. Image courtesy of UTAS.

Right: The University of Tasmania's 5,000m depth rated Explorer AUV nupiri muka undergoing trials at Beauty Point, Tasmania. Image courtesy of UTAS.

Contributors

This chapter was based on a virtual workshop held on 1 July 2020 with contributions from the individuals listed below:

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Stefan Williams (USyd)
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Footnotes

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2 Our natural environment, Australian Government. Accessed 26th April 2021 https://info.australia.gov.au/about-australia/our-country/our-natural-environment

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12

Space

Australia is a world leader in remote asset management in the resources sector, with remote and extreme environments being excellent testing grounds for technology that has applications in space.

12.1 Foreword

Australia is a world leader in remote asset management in the resources sector, with remote and extreme environments being excellent testing grounds for technology that has applications in space.

These national competitive strengths catalysed robotics and automation to be one of the Australian Government's seven civil space priority areas identified in *Advancing Space: Australian Civil Space Strategy 2019-2028*.

Australian robotics have niche and relevant capabilities ripe for translation into the space sector - advanced perception, artificial intelligence and machine learning, and rugged 'working' field robotics that can work collaboratively being just some examples. This translation is already beginning with robotics projects being awarded grants under the Australian Government's Moon to Mars initiative. We encourage Australia's roboticists to look to space as a new arena of opportunity for their activities and join the Australian Space Agency on our mission to transform and grow Australia's space sector for generations to come.

Enrico Palermo
Head
Australian Space Agency

Australian Space Agency

Snapshot — Space: What's changed since 2018?

Strengths

- Australia's geographic position is ideal for monitoring satellites, space debris and weather
- A strong resources sector capability that is exploring the opportunity to be spun into space
- We are involved in several multilateral space projects as our location makes us vital contributors to global deep space observation and communication systems

Wins

- Establishment of the Australian Space Agency
- Growth of the industry is anticipated to benefit regional Australia – for example launch site planning and Moon and Mars robotic analogues in remote locations
- Australia was one of the early nations to sign the Artemis Accords
- The Moon to Mars initiative ($150m over five years) is awarding grants for robotic-related projects

New opportunities

- Reduced satellite launch costs and an increase in launch opportunities continue to improve access to space
- Expenditure on national security is boosting investment in sovereign spacecraft and satellite systems
- There is rising demand for space exploration services
- New flight and supply chain opportunities available due to the NASA Artemis program and the Commercial Lunar Payload Services
- Manufacture of satellite payloads and supply of ground station services

Challenges

- Prior to COVID-19, higher wages overseas led to a skills shortage and difficulty retaining talent
- Lack of a mature supply chain and domestic capability means complex space systems are procured from overseas organisations
- Lack of space robotics heritage and experience

Realistic 5—year goals

- Australian ecosystem to be designing, developing and deploying robotic systems in space
- Australia to be a key supplier due to the miniaturisation of technology and increased uptake of nanosatellites

12.2 Australia's space industry

Australians rely on space-based technology to provide essential data for everyday activities – from the day's weather forecast and emergency management to internet access and online banking. Space captures the imagination and inspires us all. The global space industry is continuing to develop new technologies that improve life on Earth and offer huge economic opportunities as well as creating jobs.

Australia's location in the southern hemisphere, in line with the longitude of Asia, creates advantages for participation in the international space industry supply chain.[1] Australia has well-positioned ground stations across a 4,000 kilometre baseline that can observe many satellites, space debris, and weather conditions. Australia's clear skies, low noise, and low light interference make it a suitable location for ground station operations, and satellite calibration and validation activities. Australia is also well-positioned for satellite communications and control operations including access to many satellites for Earth observations from space (EOFS) and global navigation satellite systems (GNSS).

The opening of a rocket launch facility in Woomera, South Australia in 1947 marked the beginning of Australia's involvement in space activity. However, it was not until the introduction of space-enabled services such as domestic satellite telecommunication and broadcasting services in the 1980s and, more recently, the advent of the internet, that these services have become embedded in the Australian economy.

Many industries rely on augmented GNSS as well as EOFS. Australia and New Zealand are currently partnering to implement a satellite-based augmentation system (SBAS) named Southern Positioning Augmentation Network, or SouthPAN to improve the accuracy of GPS and other positioning services without the need for mobile or internet coverage.[2] An independent analysis by Ernst and Young (EY) has found improved positioning technology will deliver more than $6.2b in benefits for Australia, and more than $1.4b in benefits for New Zealand, over the next 30 years.[3]

Robotics Australia Group has identified signs of acceleration in the development of Australia's domestic space industry capability in recent years. For instance, since the Australian Space Agency (the Agency) was launched in 2018, the Australian Government has invested more than $700m in the civil space sector. Australian company Southern Launch was granted the first civil launch facility licences in 2021.

The Agency's economic snapshot of the Australian space sector: 2016-17 to 2018-19[4] (the Economic Snapshot), estimated that in 2018-19 there were 481 organisations employing 11,560 people in the Australian space sector with a total revenue of $4.6b. The Agency also estimated that the two years to 2018-2019 saw:

- An 11.3% increase in the number of organisations operating in the Australian space sector from 2016-2017 to 2018-2019
- Increased employment with over 1,100 direct space jobs created between 2016-2017 and 2018-2019
- Steady increase in space sector revenue, from $4.3b in 2016-2017 to $4.6b in 2018-2019, a 5.8% increase over the two years (an average annual growth rate of 2.9%).

While Morgan Stanley reports that globally the space industry is expected to grow from US$350b to over US$1.1 trillion by 2040.[5]

12.3 Impact of COVID-19

The space industry has been moderately impacted by the COVID-19 pandemic, with a weakening in advanced manufacturing and demand for navigation services, while demand for satellite communications for TV has increased. While isolation measures have restricted overseas recruitment of talent, it has also helped with talent retention as people are less likely to move overseas.[6]

12.4 Space robotics in Australia today

Australia has global competitive advantages in trusted remote operations and autonomous systems from our resource industries; as well as strengths in niche field robotic systems and related technologies, resource technologies, and planetary science. Australia can leverage our capabilities to realise a long-term flagship role in key areas, which would add unique value to the global space exploration ecosystem and further our endeavours, with associated market opportunity. A number of significant initiatives and priorities are already underway.

Australian Government civil space priorities

The Australian Government is investing in the space sector through a number of initiatives to realise its goal to triple the size of Australia's space industry to $12b and create up to 20,000 new jobs by 2030. The Australian Space Agency is working to transform and grow a globally responsible and respected Australian space industry to lift the broader economy, inspire and improve the lives of Australians. This vision is set out in *Advancing Space: Australian Civil Space Strategy 2019-2028*,[7] with robotics and automation on Earth and in space identified as one of seven national civil space priority areas.

Several initiatives have been created that support Australia's ambitions in the space industry and in particular in the area of robotics. Exploration Services has been identified by the Australian Space Agency as a key cross-cutting area central to the Moon to Mars initiative.

Modern Manufacturing Initiative

The Modern Manufacturing Initiative (MMI) is the centrepiece of the Australian Government's Modern Manufacturing Strategy (MMS). The MMI is designed to help manufacturers to scale up and create jobs to lift manufacturing capability, drive collaboration, and identify new opportunities to access domestic and global supply chains.

Space is one of six National Manufacturing Priorities under the MMS. The Space National Manufacturing Priority roadmap will help to lift space manufacturing capability, driving collaboration by helping Australian businesses demonstrate their space-qualified products, and identifying new opportunities for space manufacturers to access domestic and global supply chains. The roadmap identifies robotics and automation as key opportunities in the development of products that go into space.

Image credit: Australian Space Agency.

Space Automation, Artificial Intelligence and Robotics Control Complex

In 2020, Fugro Australia Marine was awarded a $4.5m federal grant to establish the Australian Space Automation, Artificial Intelligence and Robotics Control Complex (SpAARC) in Western Australia. As one of seven Space Infrastructure Fund projects commissioned by the Australian Space Agency, this facility will help build the Australian space industry by supporting the development and operation of robotic and remote asset management activities.

> Australian Government is investing in the space sector to realise its goal to triple the size of Australia's space industry by 2030.

Australian Government Moon to Mars initiative and Artemis opportunities

The Australian Government's Moon to Mars initiative (the Initiative) positions Australian space industry and research institutions to make a significant contribution to NASA's plans to return to the Moon and on to Mars. Through this, Australia is positioned to work alongside many nations in a global effort, and access opportunities that would otherwise be unavailable.

Applications for the Initiative opened in February 2021, with the initiative providing $150m to support Australian businesses and researchers to access national and international space supply chains, create jobs in Australia and support the growth of industries across the economy through the development and application of space technologies. The Initiative is comprised of three interconnected programs:

- Supply chain program
  targets projects and activities that build capability in Australia's space industry and support Australian industry to deliver products and services into domestic and international space supply chains.
- Demonstrator program
  supports demonstrator and pilot projects which showcase Australia's strengths to the world. These projects provide a pathway for Australian industry and researchers to rapidly develop and demonstrate products and projects, including in space, that will create new capability and enable new business ventures, revenue streams and the creation of new markets.
- Trailblazer program
  Australia's flagship mission supporting NASA's Moon to Mars activities that demonstrates and develops Australia's strengths, ingenuity and capabilities, while inspiring the nation.

The Supply Chain and Demonstrator programs form the foundation of the Moon to Mars initiative, and are complemented by the Trailblazer program as the flagship element of the Initiative.

12.5 Space robotics in Australia in the future

In the future, there will be complex crewed and uncrewed space missions supported by robotic elements in orbit, automated laboratories on the surface of exploration sites, and mobile units directly supporting human explorers working together in human-robot teams. Among the first steps necessary to achieve this vision will be the development of remote operations as a foundation service to support and sometimes control ongoing missions.

There will be a need for robust rovers to explore, with landers acting as base stations, and automated laboratories working at the direction of human operators and, increasingly, to perform valuable science without direct human intervention. In-situ resource utilisation (ISRU) extraction will be a long-term goal, to generate products (including robots) made from onsite materials.

Australia also serves as a natural living laboratory for testing space robotic technologies before deployment. Many remote areas of Australia with low vegetation cover and sparse population form ideal testing grounds, providing a library of terrestrial analogues. For Australia to grow a trusted reputation in off-Earth robotics, developers of space robotic systems need tools and methodologies to ensure that such systems will work reliably and safely, in the harsh conditions of space, according to the following design principles.

Design principles

Engineering rovers and robots that can withstand the physics of space is a non-intuitive experience for traditional Earth-based practitioners. Space robots may be: surface-based or in a microgravity environment; and either, internal within a pressurised atmosphere or external in the space environment. Surface-based external robots such as rovers must be resilient through launch, descent and landing where the equipment will experience high levels of acceleration and vibration. Temperature variances, pressure, contamination, materials, and radiation must be carefully considered in the design. Finally, the entire system must operate without failure or isolate failed subsystems and continue the mission with reduced functionality. This is important as there will be no ability to repair the system should a problem arise during the mission.

Thermal

Surviving in the extreme temperatures of space is difficult. A robot on the lunar surface, for instance, needs to have materials and power that can withstand 127 °C days and -173 °C nights. Additionally, night and day last for 13 and a half Earth days, so a considerable amount of thermal management and long-term power sources are required. Transition to or from shadow can represent a dramatic plus or minus 100 °C swing in temperature. If the robot is expected to work in a vacuum, engineers must consider additional factors since air convection is impossible.

Radiation

High ionising radiation levels outside of the Earth's protective atmosphere present a significant threat to reliable sensing and computing. Radiation tolerant systems are therefore required for space robotics. Although the amount and type of radiation may change depending on the robot's location and the radiation atmosphere around the body, engineers must carefully consider the effects of a single event upset (SEU) or "bit flip" in processors, memory, or power transistors. In addition to this, they must consider the challenges of Single Event Latch-ups and long term accumulative Total Ionising Dose which will cause destructive failures. While there are radiation-hardened compute solutions available, robot creators must consider that the processor speed and architectures could often be orders of magnitude less capable than their on-Earth counterparts.

Contamination

On Earth, we experience a world in which gravity is one of the predominant forces. In microgravity environments, the electromagnetic forces can become primary and cause difficulty with contaminants becoming attracted to sensor surfaces, solar panels, antennas, heat sinks, etc. Additionally, because there is no air in a vacuum, removing the contaminants cannot be solved by merely shaking or moving through the atmosphere. Contamination can be particularly troublesome to a robot's design since interacting with the dust, ice, or particles may be the mission's entire purpose. In thermal management, particulate material can also become an insulator keeping harmful heat near the robot rather than transferring the energy to the surrounding environment. Careful design considerations must account for fractional gravity environments and how robot surfaces can remain as uncontaminated as possible.

Vacuum

Working in a vacuum presents several engineering challenges. Engineers must carefully follow space manufacturing standards to ensure that electrical connections, mechanical lubrication, sensor optics and material outgassing requirements can accommodate or safely adjust to this state of operation. Any air molecules trapped in a solder joint or electrical component during manufacture, for example, will expand and dramatically destroy electronic circuit boards or components when exposed to a vacuum. Vacuum adds additional complexity to the already extreme thermal management mentioned previously, as there is no air to provide convection and move heat away from components. The heat will tend to 'pool' around sources and cause failures that would otherwise not be a problem in an air atmosphere.

Distance

The distance between the robot and the location in which it is operating has two direct effects on design. First, the speed of light will inherently delay communications. The round-trip time to the lunar surface is approximately 2.6 seconds, and the delay to Mars can be between four to 24 minutes. Those times also assume a direct line of communication; relaying through other spacecraft or ground switching times may increase transmission time. Secondly, as distance increases, the amount of bandwidth decreases for the same amount of power and coverage. As a result, systems that can operate autonomously with significant delays and limited bandwidth will provide superior value and reliability.

> Surface-based external robots such as rovers must be resilient through launch, descent and landing where the equipment will experience high levels of acceleration and vibration.

Traditional internet protocols do not work reliably over significant delays and can be wasteful in low-bandwidth regimes. Delay and disruption tolerant networking are essential when operating robots at great distances and over communication links that lack continuous network connectivity. Modern robots destined for other terrestrial bodies will benefit significantly by using and improving flexible network protocols that leverage delay-tolerant networking schemes and allow prioritisation of network data.

Compute

From a computing standpoint, space represents one of the most challenging environments in which robots could work. As mentioned above, vacuum, radiation and thermal environments present significant engineering barriers. As such, engineers must carefully choose and design algorithms supporting computer vision, navigation, sensors, knowledge representation, and artificial intelligence to work on computing platforms that are heavily Size Weight and Power (SWAP) constrained.

Sensing

Sensors and sensing algorithms must be carefully selected. Concerns and considerations for computing also apply to sensors since they contain logic, memory, and interconnected components. As such, very few off-the-shelf sensors are likely to be used for extended missions. Early algorithms, prototypes, and testing must adopt flexibility in the sensors that can be used. It is unlikely that state-of-the-art Earth sensors will be representative of their flight-compatible counterparts. For robots operating in a vacuum, algorithms and sensors must operate robustly in high contrast environments where the difference between light and shadow is unlike anything experienced inside the Earth's atmosphere. Finally, simulation and high precision modelling of sensors, algorithms, and the robot's interaction in the planned environment are vital to mission success.

Movement

Nearly all planetary surface robots have used wheels as their mode of locomotion. The mechanical simplicity, ease of modelling, and reliability make wheels ideal in relatively flat terrain. As robotic designers begin to explore more challenging environments, wheels alone may not suffice. For instance, on the lunar surface, lava tubes may provide existing infrastructure and protection from temperature variances and radiation. On Mars, deep craters and geographic features larger than any on Earth may hold the key to important volatiles for future human visitors. Robots that can climb, crawl, roll, descend and jump might become key to future missions. Examples of prototype space robots exist in the literature, and modern roboticists can benefit significantly from exploring mobility and design alternatives.

Materials

Material selection for robots in space presents unique challenges. Mass reduction is the foundation of any significant object launched from Earth. As such, lighter metals for robotics structures such as aluminium, titanium, and composites are typically used. Unfortunately, these materials and metals are not ideal compared to heavier metals for heat transfer (copper), radiation protection (lead), and durability (steel and plastics). Designers must carefully balance, optimise, and compromise material selection based on mission requirement and environmental constraints that may sometimes seem in direct conflict.

The above points enumerate just some of the changes needed between Earth-based robotics and building robots for in-space utilisation, especially planetary exploration. Fortunately for today's robotic designers, there are successful lunar reference missions to learn from. The Soviet Union's Lunokhod and the Chinese Yutu help roboticists understand how to operate in dusty bodies with no atmosphere. Five successful Mars rovers by the United States teach us how robots might work in a different but equally harsh Martian environment. Robots are mobile, but engineers can also learn valuable lessons from stationary landers humans have sent to terrestrial bodies such as Venus, Mercury, Saturn's moon Titan, asteroids, and comets.

Design Principles for robotic platforms must take into account both program and system designs. Naturally not all of them are applicable to all missions. Following are some of the principles that must be considered:

Platform architecture

- Community and ecosystem focus on development of capable platforms
- Individual science, research and commercial groups focus on payload development

Focused on the support of lunar build up

- Development of capacities designed to deliver services on the Moon to support ongoing operations

Small and the many

- Many small but different systems working together to achieve a goal

Collaborative robotics

- The capability to work together with partner robots and future systems to jointly complete tasks

Surface/field robotics

- Lunar surface as the near term focus area of operations

Common software and architectures

- Extensible and supplier agnostic
- Collaborative and community set standards and software

Persistent and enduring operations

- In support of long-term presence off Earth

Production at a long-term base

- Doing the same task to produce or achieve a goal
- Focused operations in a fixed area opposed to exploring over the horizon

Australian manufactured systems

- Platform systems locally built for Australian but also export markets
- Software for sensing and robotics
- Focus on low mass, high value systems and components

Terrestrial analogues

- Proof of viability by the use of terrestrial prototypes
- Extensive in-analogue testing

Integrated into Australia's remote operations ecosystem

- Interoperability with
  - Space Automation, Artificial Intelligence and Robotics Control Complex (SpAARC)
  - Responsive Space Operations Centre (RSOC)
  - Analogue site operations

Many missions with high iteration

- Test business models with lots of small missions rather than one big mission
- Test, break, learn, rebuild

The "ility's"

- Reliability
- Maintainability
- Interoperability
- Upgradeability
- Dependability
- Scalability.

12.6 Main findings for robotics in the space industry

The Australian robotics community has a unique opportunity to extend itself into the growing space robotics ecosystem – delivering technology returns to Earth, and energising Australians to tackle the biggest challenges both on and off Earth.

Space-enabled services boost the productivity of all sectors of the Australian economy. Australia's strong education system, geographic location in the Southern Hemisphere for satellite ground stations, world-class capabilities in ground systems, software, and applications, and close strategic alliances with existing space powerhouses position the nation for success. The establishment of the Australian Space Agency in 2018 has already seen the domestic space industry grow, with better pathways being established from research to commercialisation. The growth of opportunities in the space industry acts as a strong incentive to encourage Australian graduates and researchers with space capabilities to remain in Australia.

Contributors

This chapter was based on a virtual workshop held on 9 July 2020, attended by 58 people, with contributions from the individuals listed below:

Ross Dungavell (CSIRO's Data61)

Jonathon Ralston (CSIRO)

Mark Micire (Woodside)

Footnotes

1 ACIL Allen (2017) Australian Space Industry Capability, Department of Industry, Innovation and Science, Canberra.

2 Geoscience Australia. (2020) Australia, SouthPAN to position Australia and New Zealand into the future. Geoscience Australia. Accessed 9 July 2021 https://www.ga.gov.au/news-events/news/latest-news/southpan-to-position-australia-and-new-zealand-into-the-future

3 Ernst & Young (2019) SBAS Test-bed Demonstrator Trial: Economic Benefits Report. Frontier SI.

4 Australian Space Agency (2021) Economic Snapshot of the Australian Space Sector 2016-17 to 2018-19. Accessed 9 July 2021. https://www.industry.gov.au/sites/default/files/2021-02/snapshot-report-australian-civil-space-sector-2016-17-to-2018-19.pdf

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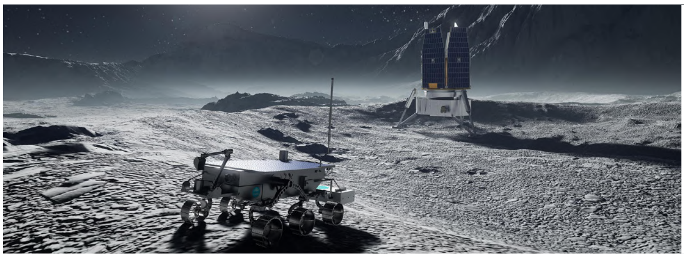
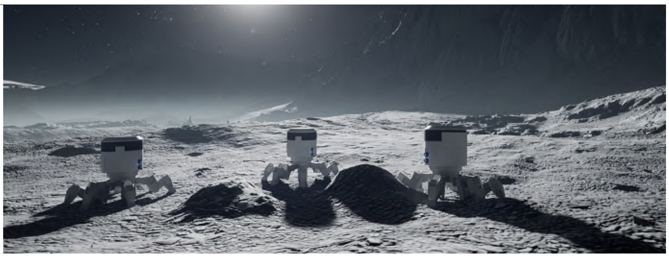




Left: Image credit: CSIRO.
Right: New Robotic platforms are required to meet the challenges of lunar operations and they may look different to terrestrial robot designs. Image credit: CSIRO.

13

Drones

Drones and robotics are often discussed in tandem. Most of the issues surrounding drones also affect robotics but there are issues that are unique to drones. An aircraft will have similar hardware challenges to a ground robot for example however their risk profile is very different.

Image courtesy of CSIRO's Data61.

13.1 What is a drone?

All drones are robots, but not all robots are drones. The key feature distinguishing drones from other robots is their ability to fly. How are drones different from the aeroplane you might take to get to your next far-away destination? If the pilot is on-board the aircraft, then it isn't a drone.

When people think of a drone, typically a multirotor (and more specifically, a quadcopter) comes to mind. This is thanks to the prevalence of companies creating consumer hobbyist drones in this exact configuration (see 'Definition of Uncrewed Aircraft Systems' overleaf). However, drones aren't limited to such a narrow definition. They can be fixed-wing, like an aeroplane, or rotary, like a helicopter or multi-rotor (which has multiple propellers). There are even hybrid drones which use pieces of different styles to make something more versatile, like a tilt-rotor. No matter what they look like, they all fly, and they all have no on-board pilot.

There are also many names for drones. Until relatively recently, the term "drone" had negative connotations and so the term "Uncrewed[1] Aircraft System" (UAS) was created. UAS encapsulates both Remotely Piloted Aircraft Systems (RPAS) and Autonomous Aircraft Systems (AAS). The way in which these categories are broken down under the broad umbrella of "aircraft" can be seen in 'Definition of Uncrewed Aircraft Systems' overleaf. A drone purchased for hobby purposes is typically going to fall into the RPAS/model aircraft category, while systems that do not require a pilot to complete their mission fall into the autonomous category. As flight control and planning software becomes more advanced, the line between these two categories becomes more blurred. For the purposes of this roadmap, we are considering both of these categories listed under "UAS" but will continue to use the word "drone".

> Drones can be fixed-wing, like an aeroplane, or rotary, like a helicopter or multi-rotor. No matter what they look like, they all fly, and they all have no on-board pilot.


Example quadcopter

Snapshot — Drones: What's changed since 2018?

Strengths

- Drones handle jobs that are dull, dirty, or dangerous
- Australia allows novel drone system testing
- Drones are relatively inexpensive technology

Wins

- Drones from all over the world can be tested at Australia's purpose-built test facilities
- Australia has the capability to create an independent drone development system
- Drones are now largely accepted by the public

New opportunities

- The addition of use-cases for logistics and delivery, and urban air mobility
- Creation of the Uncrewed Traffic Management (UTM) system which would seamlessly integrate drones into existing airspace
- A supported and connected drone ecosystem within Australia to remove supply chain challenges
- Technical developments such as swarming (single operator, multiple drones)
- Development of sovereign capability for the creation of drones from start to finish (design, manufacturing, testing, and training for the drone and associated systems), including the air vehicle, software, sensors, accessories and support

Challenges

- Overcoming factors such as noise, safety and privacy concerns to increase societal acceptance
- Illegal drones
- Finding ways to adequately measure and assure the safety of drones as a system, (including autonomous elements)
- Enforcement of existing drone regulations, such as registration of commercial drones

Realistic 5—year goals

- Establishment of a 'safety and trust assurance of drones' program for independent evaluation of platforms and their software
- Increases in the level of autonomy and decision making afforded to drones and the systems that use information gathered by them
- Operations beyond visual line of sight (BVLOS) becoming more widespread through the introduction of clear and accessible regulation, equipment and operating standards
- The development of a counter-drone industry to combat illegal drone operations
- Creation of Australian drone life-cycle (from concept and design, through to manufacturing and testing, and finally end of life recycling of the platform), and system management (including software, sensors, payload, supporting equipment, and training)
- Urban air mobility (UAM) and drone delivery. First moving packages and cargo through urban areas and eventually people in 'air taxis'

Definition of Uncrewed Aircraft Systems (UAS) or "drones" as used by this document[2]

13.2 Why do people want to use drones?

Drones (and robots more generally) are a good alternative for tasks that are dull, dirty, or dangerous. If the task is monotonous or repetitive, people eventually lose focus and make mistakes when their attention wanes. Replacing the person with a drone can not only remove a large portion of the human-error element, but it can also be more efficient leading to cost savings. When people are not required to complete the simple and boring tasks, this frees up humans to work on the elements of a process that require more nuanced decision making.

When people can be removed from being directly involved in a task it can make it easier to keep people safe. For example, drones could be sent to take atmospheric measurements over the Fukushima nuclear plant where the environment is too contaminated ("dirty") for people to safely work. A drone could be used for target practice allowing soldiers to get real-world experience without putting additional pilots at risk.

There are many cases where drones have been used to make tasks more cost effective, safer, and more efficient at completing the task, particularly when compared to crewed aircraft. One such example is from Murdoch University's cetacean research unit which employed drones to survey marine animals when they had traditionally used piloted aircraft. [3]

13.3 The drone industry in Australia

How are drones used?

Drones are a means of achieving a goal, and, unless you are flying for fun, the drone is simply a tool in a larger problem-solving method. For this reason, the use of drones spans many different industries, making it difficult to clearly define the true breadth of drone technology.

Drones, like any technology or tool, can be used for both good and bad. A decade ago, the word "drone" had an extremely negative connotation. However, it has come to be more associated with a typical consumer-style remotely piloted air vehicle. While drones are still occasionally adapted for nefarious use or used in a way that is unwittingly breaking the law, the vast majority of uses now are legal and for the betterment of mankind.

Some examples include:

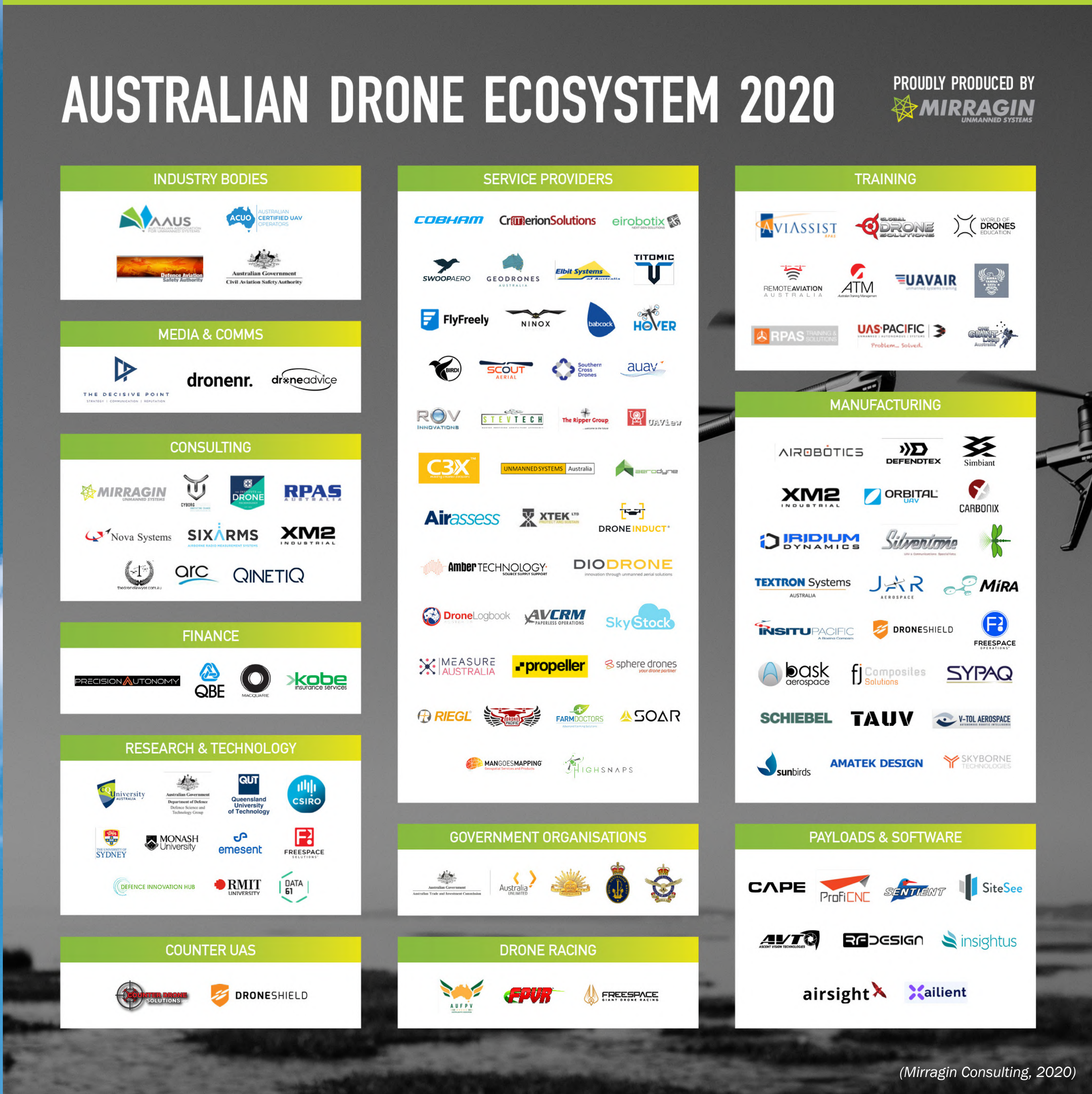
- Westpac's Little Ripper surf life saving drone which drops a flotation device to struggling swimmers[4]
- Swoop Aero's platform being used by the NHS to pick up and deliver urgent COVID-19 test material in the UK.[5]

The ways that drones are used fall broadly into three categories: entertainment (such as drone racing competitions or joy flights), information gathering (real estate photography, surveying, or coastal mapping), and payload delivery (package transport and delivery). However, the impact of drones extends far beyond these seemingly simple uses. The true breadth of the industry and the implications, even excluding the economic factors, is immense.

How did we get here?

Some of the earliest drone activity in Australia was conducted by Aerosonde. In 1998, they successfully flew the first drone across the North Atlantic in under 27 hours. Since then, the industry has grown substantially. Australia is well placed for a globally competitive home-grown drone industry. As shown in the following map of companies contributing to the drone ecosystem, Australia has world-class companies supporting the design and manufacture of the drones themselves, and their payloads. There are also groups that provide drone specific training, and companies that will help implement drones effectively and efficiently in an organisation. Additionally, there are multiple service providers for hire who can conduct a range of drone-related jobs across the country.

Map of the companies contributing to the drone ecosystem in Australia



Highlights in the history of the Australian drone industry

1998	Aerosonde Mk2 was first uncrewed aircraft to fly across the North Atlantic (3270 km) achieved in <27 hours
2002	CASA introduces first regulations concerning drones
2007	First Outback Joe competition (now Medical Express Challenge)
2009	First ArduPilot (open-source flight control software) board released and code repository created
2010	Murdoch University used Insitu's ScanEagle for surveying marine environments
2012	PX4 released (diydrones.com/profiles/blogs/introducing-the-px4-autopilot-system)
2013	DJI Phantom released Pixhawk flight controller board released
2016	CASA updates drone regulations with a sub-2kg exempted category DJI Mavic pro released
2017	First *World of Drones Congress* in Brisbane (held annually) Launch of Queensland Drone Strategy
2018	Westpac Little Ripper drone saves swimmers FAI First World Drone Racing Championship won by Australian Rudi Browning
2019	Alphabet's Project Wing conducts first drone delivery service in Canberra suburbs
2020	Boeing unveils their first Loyal Wingman aircraft as part of the Airpower Teaming System (boeing.mediaroom.com/2020-05-05-Boeing-rolls-out-first-Loyal-Wingman-unmanned-aircraft)
2020	First test flight of Boeing's Loyal Wingman and expanded orders from RAAF

Drone operators in Australia

Australia's largest drone operator is the Australian Army. In 2007, the ScanEagle and Skylark were the first drones introduced into operation with 20th Regiment, Royal Australian Artillery. This rapid technology adoption has led the way for drone acceptance across the country.

Currently, there are more than 2,100 licensed drone operators in Australia (see graph below) and this looks set to increase. With an average company size of 4-6 people, it is estimated that this alone results in 10,000 flying drones. This does not include those drones flown under the exempted, excluded or hobby categories, which would significantly increase the number of flying drones in Australia.

Drone rules and legislation

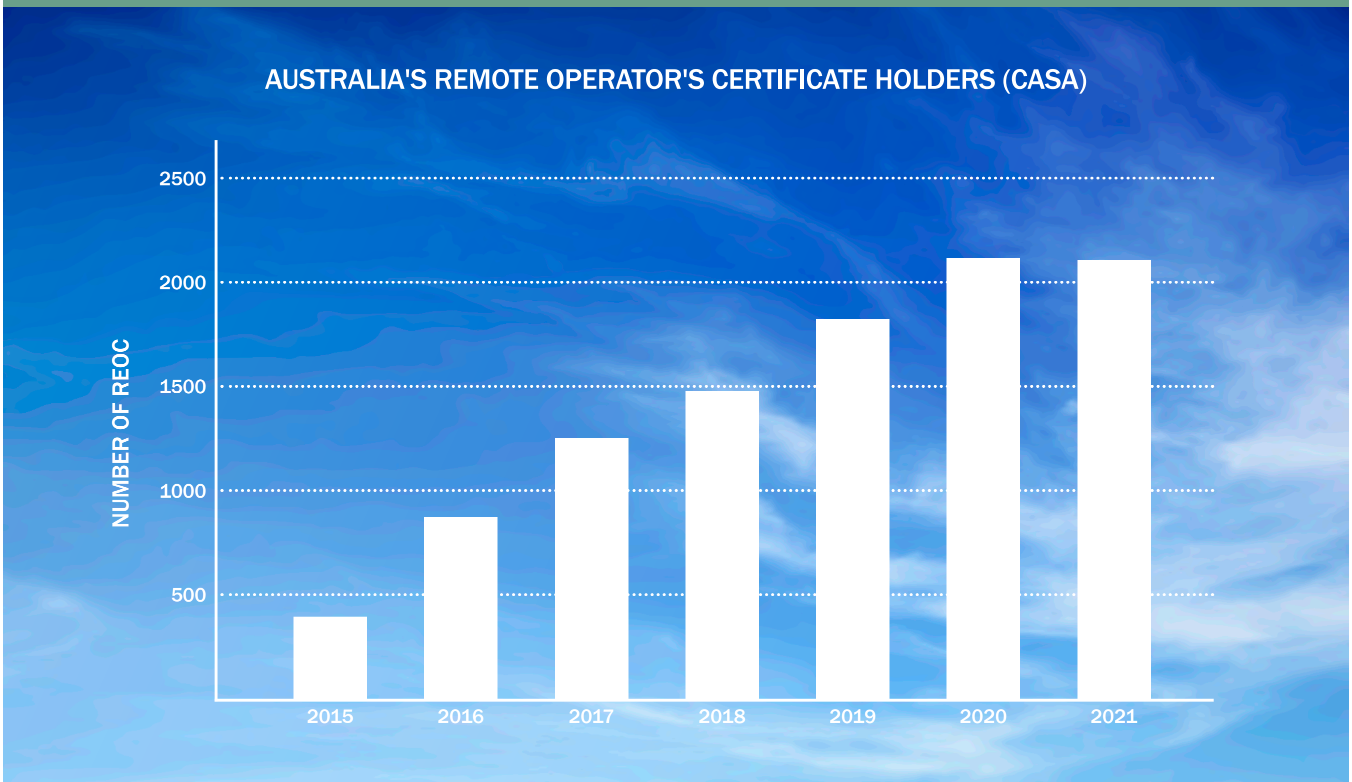
Civil Aviation Safety Authority (CASA) regulates aviation across Australia, including drones. Typical drone rules include:

- The drone must be always within unaided eyesight (e.g. during daylight, without binoculars)
- Drone altitude must remain below 120m above ground level (AGL)
- One pilot per drone
- Fly at least 30m away from people not involved in the flying.

In 2016, CASA amended the Part 101 regulations. These were amended again in 2018 to move with the changing industry. The changes involved removing some of the license restrictions on drones weighing less than 2kg.

It is possible to obtain permits to fly much heavier (and larger) drones, such as those up to 7kg, 25kg and 125kg. Likewise, it is possible to obtain permissions to fly at night and beyond visual line of sight (BVLOS). Australia is the only country where it is possible to get a license to operate a commercial drone delivery service. In other countries, it might be possible to acquire exemptions to perform this activity, but typically it means airspace is restricted to military bases. This license, spurred by the capacity for BVLOS flight in Australia has led companies like Alphabet (Google's parent company) to conduct world-first delivery trials, through Project Wing, in Australia.

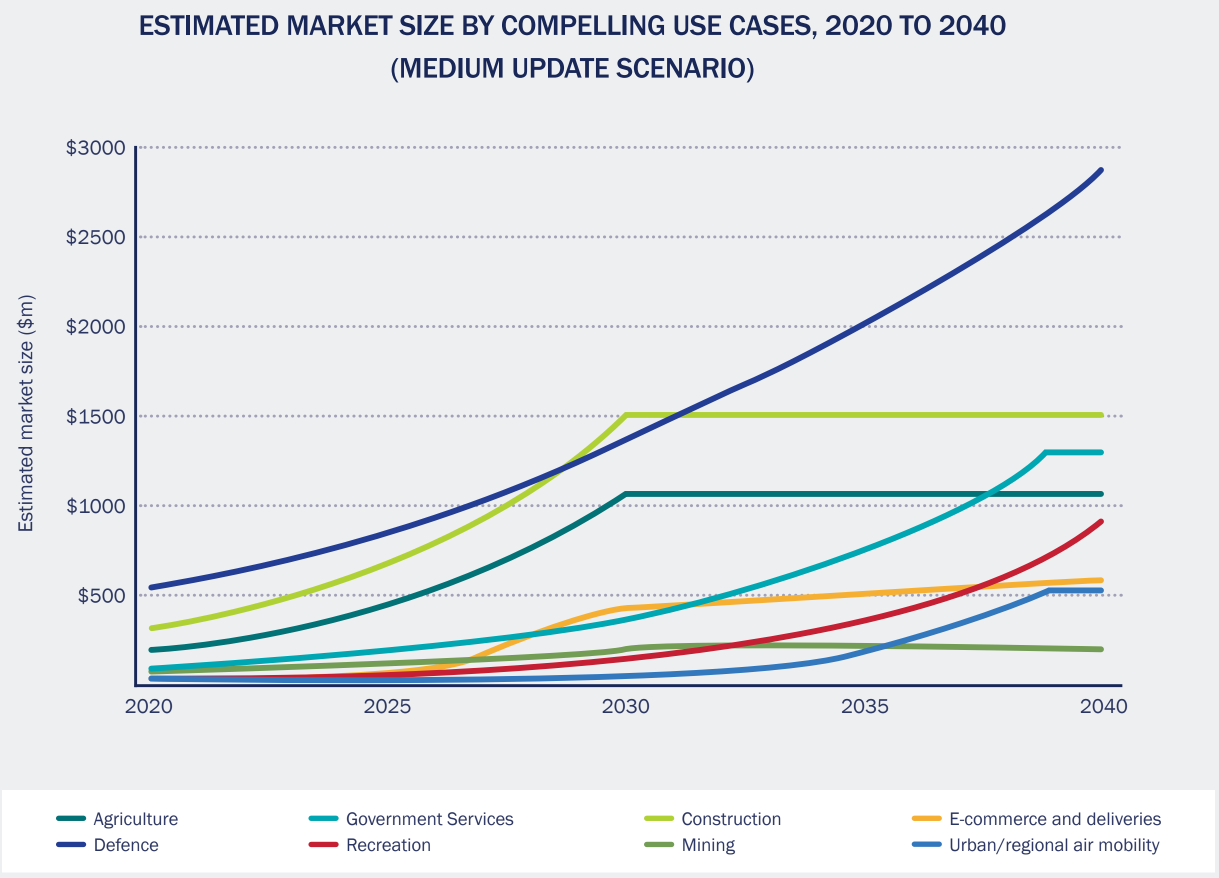
Number of Remote Operator's Certificates (ReOC) holders per annum



Data supplied by CASA RPAS Branch.

**2021 data is provided as of 15 March 2021 (incomplete year).*

Estimated drone market share for application area[12]



What are drones currently worth to Australia?

Globally, the drone toy market alone was estimated to be in the realm of US$440m in 2020. Increased adoption of the technology means that drones aren't just restricted to Christmas and birthday presents, they are also employed as tools across a range of industries. The commercial drone market was valued at US$14b in 2020 and is expected to increase in coming years.[6] When you include all aspects (economic value including jobs and education) of drones, globally the drone industry was estimated to be worth approximately US$100b between 2016 and 2020.[7]

In Australia, Deloitte Access Economics estimates drones contribute $5.5b to our economy which will expand to $14.5b by 2040. This growth is supported by information from drone software developer DroneDeploy, who state that Australian users of its technology grew by 190% in Q1 2021 compared with Q1 in 2020.[8] The growth looks set to be driven by industries such as agriculture, construction, mining, and defence, as shown in the estimated market share (see graph above).

While the dollars and the number of users might be relatively easy to measure or estimate, the additional value that drones add to our world is immeasurable.

13.4 Impact of drones in Australia

Even if you don't own or fly a drone yourself, there are still concerns that are often raised. These concerns include the safety of the platform, and, in the case that they have on-board cameras, privacy. One additional issue that has proven to have a negative impact on the perception of drone use is the noise. Complaints were received during the Canberra drone delivery trials[9] and similar concerns have been raised regarding Uber Air's potential activities.

Such issues have shone light on an interesting gap in regulation – there is currently no regulation or legislation enforcing limits on drone noise. Despite CASA taking responsibility for complaints during trials, including those about noise,[10] it is not responsible for the enforcement of noise limits. In fact, no agency accepts responsibility for enforcing any limit, even if the public deem it to be an unrealistic level.

Australia as a drone test-zone

Australia has already seen some impressive technology from international companies trialled here. For example, Project Wing (a company owned by Google's parent company Alphabet) conducted delivery of food, drinks, and medications to residents of Canberra's outer suburbs.[11] Uber Air has also announced plans to trial their air taxi service in Melbourne, Australia, from 2023, citing CASA's welcoming attitude to new aircraft and systems as one of the motivating factors for their choice of location.[13]

BAE Systems recently tested their PHASA-35 high-altitude pseudo-satellite (HAPS) from the Woomera test range. This style of vehicle is particularly useful as a supplement or replacement to satellite coverage. It can be launched more rapidly than traditional satellites and will prove useful in disaster relief or scientific mission scenarios.[14] Similar HAPS vehicles are also made by Airbus, who created the Zephyr which set a world record for flight in Western Australia in 2018.[15] High-altitude capability is at the forefront of research with the HAPS Challenge that went out to Australian industry in March 2021. Sponsored by Trusted Autonomous Systems, SmartSat CRC and RAAF Air Warfare Centre partnered with the Sir Lawrence Wackett Defence and Aerospace Centre at RMIT University, Earth observation, and positioning and navigation (as an alternative to GPS) are two major expected applications of this technology.[16]

In order to accommodate some of the testing required by programs, such as the HAPS Challenge and Boeing's Loyal Wingman project,[17] the Queensland government has created a custom drone testing facility in Cloncurry. The Queensland Flight Test Range is the first of its kind in Australia and includes a large hangar, 2km runway, 30km x 20km airspace for altitudes up to 6,000ft, monitoring equipment including RADAR and other supporting amenities.[18]

13.5 Future of drones in Australia

How will drones impact Australia in future?

The drone industry in Australia is not going away. In the coming 20 years, Deloitte predicts that drones will result in a $14.5b expansion of GDP and create over 5,500 new jobs per year.[19] The industries expected to reap the benefits of this growth include agriculture, mining, transport, and construction.

This growth will not be hampered by technical capability. There are plenty of technical experts and companies creating world-class systems in Australia. However, there are other implementation challenges that will slow progress.

To fully realise drone capability, safe airspace integration (not accommodation) of drones, and comprehensive uncrewed traffic management (UTM) must become a reality. As it currently stands, only remotely piloted aircraft, rather than totally autonomous air vehicles are allowed into the civil aviation system. A pilot in command is still considered essential. However, for applications in agriculture, mining, transport, and construction, it may be more desirable to have a fully autonomous drone conducting data-gathering sweeps of an area at regular intervals, with a pilot overseeing the same flights every hour. To make this a reality, a centrally managed UTM system will be required. This will avoid any accidents due to failure to pass information between management systems.

Drones represent a low barrier to entry. They can be cost-effective and easy-to-use platforms that perform a wide array of tasks for an even broader range of domains. This allows them to be quickly adopted by people who don't necessarily have an aviation or technical background. Plug-and-play style drones are extremely popular for casual pilots and hobbyists and often end up in the hands of children, viewed as "toys". Framing drones as "toys" has added a great deal to community acceptance of the platforms, but has perhaps done a disservice in that they are often used so casually and without proper regard for aviation safety rules.

In many cases, it is possible to overcome negligence with proper education, but it would also be helpful to ensure the overall safety of the drone as a complete system – air vehicle, and software (including the autopilot and navigation functions). A critical portion of this problem is assuring the decision-making, and this lies at the heart of autonomy.

A portion of the safety challenge that is unique to drones, rather than robotics as a whole, is the air- and ground-risk factor. Questions are still being debated and answers to the following are continuously under refinement.

- How do you measure 'safety' of an UAS?
- How do you prove it is 'safe'?
- When is it safe 'enough'?

Part of the solution to ensuring UAS are safe enough, is done through legislation. Drone use in Australia is regulated via use and weight categories, with registration of drones required for businesses as of January 2021.[20] Currently hobbyists flying only at a model aircraft club do not need to register their drones. However, in future, registration may extend to all uncrewed or remotely piloted aircraft.

Having these rules is important, however enforcing rules such as these can be difficult. In some instances, people are simply unaware of the rules – this makes education a priority. In other cases, people deliberately flout the rules for selfish or malicious reasons – this is where counter-drone technology becomes important.

An additional part of the safety challenge is insurance. An operation over a single private property (e.g. a farm) might require one simple approval, whereas a complex drone operation in a city might require approvals and insurance for multiple conditions from multiple approving-bodies. This type of process should be centralised and streamlined if urban drone delivery or drone taxis are to become commonplace. At the moment, it still remains a question how to go about even obtaining all those approvals in the first place – how do you get approvals from all the people who own the properties in your flight path? These can include private citizens, companies, government bodies and councils.

Where is Australia's advantage in the global drone industry?

Australia has a significant amount of research and development capability through facilities such as the TAS and other research institutions. Several topics of interest have repeatedly emerged:

- Counter drone technology
- Swarming/flocking
- Urban air mobility
- Logistics and delivery

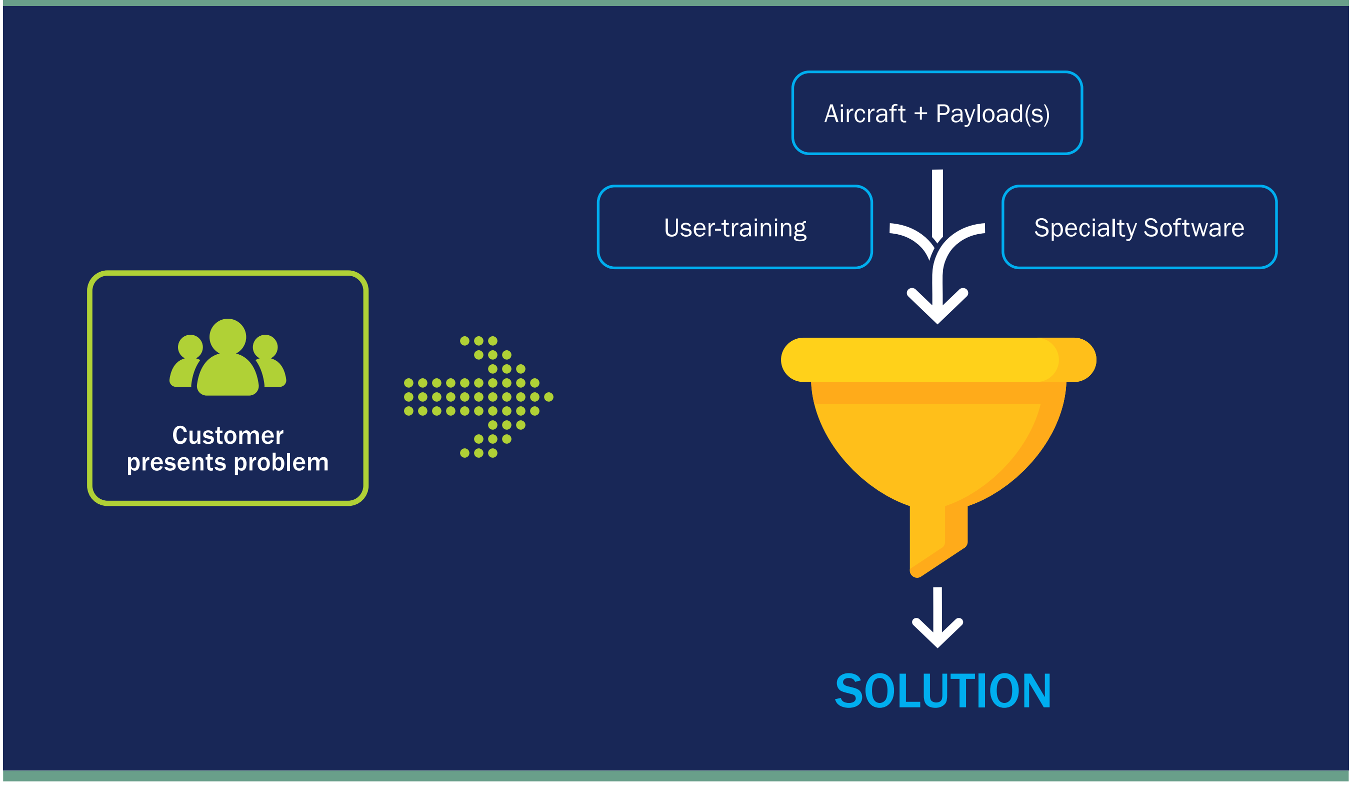
While Australia is unlikely to become a mass-manufacturer of consumer drones, we certainly have the technical capacity to be world leaders in drone technology and implementation across a wide range of fields. Crucially, Australia also has the space and facilities to test emerging drone technology.

Both the Education and Skills chapters of this roadmap cover robotics courses and education options in Australia in depth, however, with a rise in popularity of drones, more specialised educational resources are developing. Typically, software or mechanical engineering degrees are focusing more and more on this type of technology, with some institutions creating bespoke courses at a higher education level. You can now get a degree in drones![21, 22] However, there is still a need for short-courses or bridging courses to allow employees with previous technical training to officially and efficiently upskill.

> Drones represent a low barrier to entry. They can be cost-effective and easy-to-use platforms that perform a wide array of tasks for an even broader range of domains.

Australia has a wide array of technical specialists capable of creating new technology to assist with any challenges the future holds. Our training organisations are aware of the legal requirements and best practices for operating and maintaining these uncrewed systems. When industries and companies want to make use of drone technology, they should be looking to companies who can help them bridge this knowledge gap and assist with finding the right solution to their problem. The general problem solving approach is shown in diagram on the following page.

Diagram of problem solving for industry. Experts consider all aspects of the problem and tailor a solution unique to the customer's needs



13.6 Summary of main findings

Using drones can have cost, safety, and time benefits. This allows processes to become more efficient and frees people to work on more complex tasks and decisions. This will be of particular benefit to the agricultural, mining, and construction industries over the coming years. The drone industry in Australia, and across the world, is worth a lot to the economy (both fiscally and in terms of job prospects). It is predicted to grow from $5b to $14.5b in Australia over the next 20 years. Education about drones and their associated systems will be key to enabling full participation from all industries.

Drones, as part of a larger group of robotics, is a rapidly growing industry. Australia has huge potential to be world leaders in the field. We are uniquely placed as a test-bed, and the government should be supporting policy to allow critical research and development to happen here. Test facilities will be crucial for future developments such as integrated air traffic management systems which will have to keep crewed and uncrewed vehicles safe, as well as people and property on the ground. The regulatory space is relatively well placed and currently welcoming the trialling of new technology and systems. This trend must continue if Australia is to maintain and grow its place as a world leading test facility and drone-operations thought leader.

Case studies

Payload developer — AVT Australia

AVT Australia specialises in the design and development of gyro-stabilised imaging systems for intelligence, surveillance and reconnaissance (ISR), target acquisition and counter UAS operations. AVT Australia's systems are supporting airborne, ground and maritime missions in over 50 countries, serving the defence, aerospace and uncrewed systems industries.

AVT Australia's CM62 Micro Gimbal is a next-generation tactical ISR system that weighs as little as 260g to deliver superior capabilities for small uncrewed aerial system (sUAS) operations. Its low power draw allows the sUAS to achieve long flight endurance. The compact system incorporates an electro-optical sensor and a custom LWIR core for day and night operations. Excellent zoom capabilities facilitate long-range detection and identification, whilst the aircraft maintains a safe standoff distance. The CM62 is optimised with onboard video processing features, including multi-sensor streaming, encoding onboard, recording onboard, object tracking, electronic and roll stabilisation, scene steering and geo-positioning information. With an IP67 rating, the CM62 is ruggedised to endure extreme environments experienced in tactical sUAS operations.

AVT Australia's CM62 Micro Gimbal mounted as a payload for demonstration. Images courtesy of AVT Australia.

Drone manufacturer — Freespace Operations

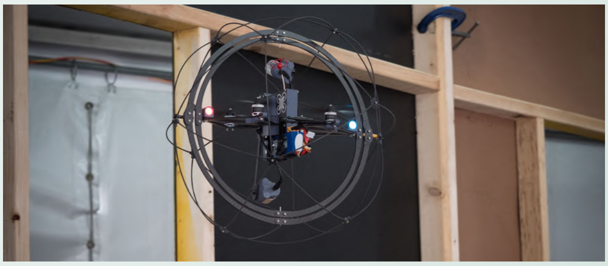
Freespace Operations is an Australian RPAS manufacturer specialising in the design and operation of industrial heavy-lift multirotor drones. Freespace has extensive expertise in systems ranging from 10kg to 150kg MTOW (maximum take-off weight) aided by their in-depth knowledge of the ArduPilot autopilot system. The 'Callisto' is their company flagship product which allows various field changeable power, propulsion and payload configurations with new products also in development stages: Callisto 50 Octocopter; Callisto Lite Octocopter (Cconfigurable for <25 kg TOW applications); Callisto Hybrid-Petrol ICE Power Module.

These aircraft with heavy payload capacity of up to 25kg allow Freespace Operations to assist both defence and commercial projects. They are designed to suit a wide range of heavier payloads, harsher wind/environmental conditions and remain airborne for a much longer time than consumer off-the-shelf solutions – this includes marine, mining and alpine environments. For example, the Callisto RPAS is being configured to carry the Riegl VQ-840-G bathymetric LiDAR which weighs approx. 15kg when fully integrated to the RPAS.

Freespace Operations also supports the Spektreworks 'Cobalt' series of VTOL fixed aircraft in Australia. Cobalt Vertical Take-off and Landing (VTOL) - comes in hybrid and electric versions.

Callisto heavylift octocopter (image supplied by Freespace Operations).

Drone operator — Astra Drone Solutions



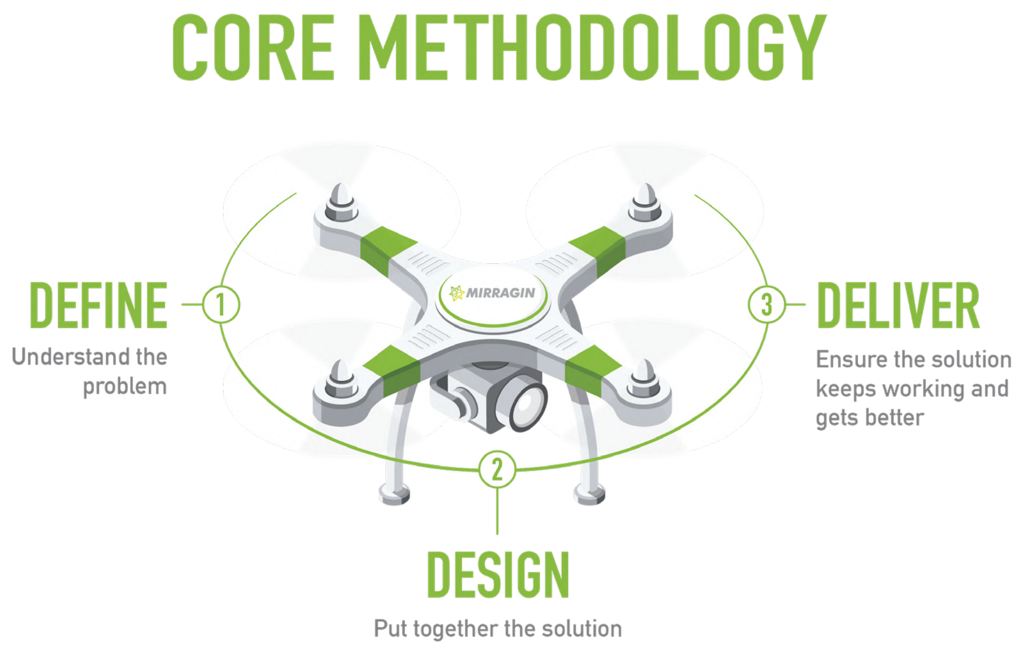
Astra Drone Solutions is an Australian UAS services and engineering company that specialises in performing confined space and complex environment inspections. Founded in 2017, Astra has built a reputation for delivering high quality data from some of Australia's most hazardous underground mines. These inspection tasks are primarily conducted using Astra's in-house developed UAS, the Astra EXO.

This UAS is uniquely identifiable by its spherical protective cage and modular payload system. This protection mechanism allows the EXO to withstand low energy impacts while being able to safely roll along any surface including ceilings and walls. The Astra EXO is being used by customers all across Australia.

Upper-left: Astra EXO drone for mining stope inspection. Image courtesy of Astra Drone Solutions.

Bottom-right: Example images of a mining stope taken by the Astra EXO drone. Image courtesy of Astra Drone Solutions.

Consulting organisation — Mirragin RAS Consulting



Mirragin is a drone consultancy and project management company, which helps organisations to successfully implement drone programs, to reduce costs, increase capability and to save lives. With a deep knowledge of the uncrewed system industry and advanced robotics and autonomous systems technologies, Mirragin can assist with: Strategy and Project Management; Technology Selection, Integration and assessment; Risk Management.

Mirragin specialises in uncrewed, autonomous and robotic systems, as well as the artificial intelligence required to support and drive these systems. They have a strong understanding of technological developments and latest trends in industry. Mirragin also has an extensive understanding of the uncrewed systems and emerging technology industry in Australia. This allows Mirragin to bring together operators, UAS and payload manufacturers, software designers, and training organisations to provide the best outcomes for industry.

Mirragin Consulting's core methodology approach to solving problems. Image courtesy of Mirragin.

Control system and software — ArduPilot

ArduPilot is a trusted, versatile, and open-source autopilot system supporting many vehicle types: multi-copters, traditional helicopters, fixed wing aircraft, boats, submarines, rovers and more. The source code is developed by a large community of professionals and enthusiasts, a large proportion of whom are Australian based. The open-source nature of development has allowed fast integration with other software and hardware, notably Pixhawk flight controllers (with ports available to other controllers), ROS, MAVROS and MAVLink, and Mission Planner, and companion computers like Raspberry Pi or Arduinos. It remains reliable due to the prioritisation of bug fixes over new features, and versions are extensively tested before being released as stable.

ardupilot.org   ardupilot.org/dev/docs/common-contact-us.html

Contributors

This chapter was constructed with contributions from the individuals listed below:

Nicola Kloet (Mirragin)

Rob Sutton (Mirragin)

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Footnotes

1 Previously "Unmanned"

2 Definition of Uncrewed Aircraft Systems (UAS) or "drones" as used by this document. Image adapted from CASA AC101.01v3. Civil Aviation Safety Authority (CASA), (2019) Civil Aviation Safety Regulations (CASR) Advisory Circular (AC) 101-01 v3.0, https://www.casa.gov.au/standard-page/casr-part-101-unmanned-aircraft-and-rocket-operations

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14

Education

Education is crucial in order to provide a pipeline of suitable employees capable of meeting the requirements of our thriving robotics industry

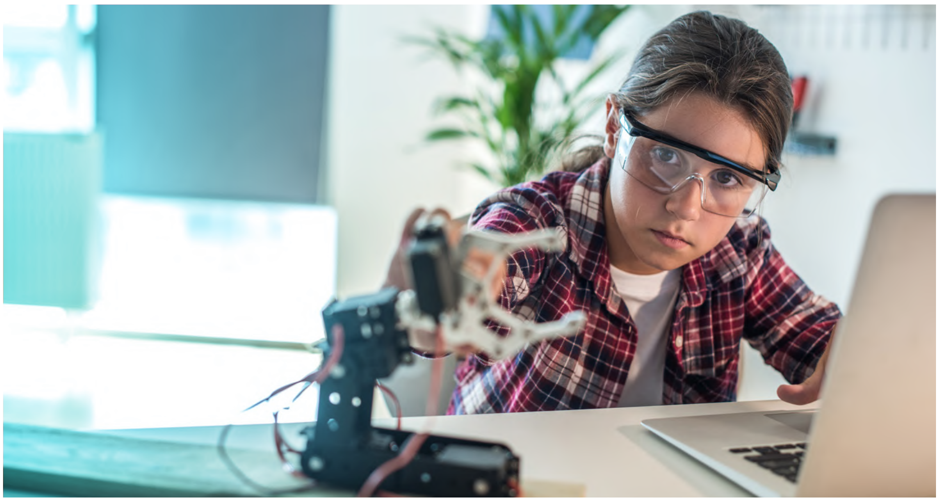
14.1 Education and training in Australia

Australia invests a lot into education and training and the industry generates $134b in revenue and employs more than 765,000 people — almost 5% of Australia's working population.[1] The Australian government aims to invest $32.4b into Australian schools by 2029 representing an annual increase in funds from 2018 of $1.0b each year.

In order to have a thriving robotics industry in Australia, it is important to have a workforce that has the capability to meet the requirements of a competitive business. The Education side of the equation is crucial to provide a pipeline of suitable employees.

Robotics education in Australia runs a wide and varied range, from students in Prep using simple robots to learn directional terminology all the way through to academics in higher education performing world leading research. This chapter seeks to give the reader an overview of what is happening in each domain, covering five broad sectors; Foundation to Grade 10 Education, Senior Secondary, Vocational Education and Training (VET), Higher Education (University) and education provided by other organisations.

Case studies are provided for each specific domain to better illustrate the use of robots in each of these settings.



Snapshot · Education: What's changed since 2018?

Strengths

- Increasing awareness within schools of the need for STEM related skills
- Popularity of robotics with students driving implementation within schools
- Governments support for STEM programs

Wins

- Increasing number of mechatronic students graduating from Australian universities
- Robotics and coding are useful tools to deliver the Australian school curriculum
- Teaching of robotics and coding is compulsory in all Queensland State Schools with robots available for loan to schools through a lending library

New opportunities

- COVID-19 created an acceptance of online learning which has opened up more resources to support education

Challenges

- Continuation of funds to schools for equipment and professional development
- Gender diversity in robotics is not improving, despite a decade of women in STEM initiatives
- Decline in international student enrolments and revenue due to COVID-19

Realistic 5—year goals

- Tighter mapping of robotics as a way of addressing curriculum requirements
- Additional courses (Secondary, VET) utilising robotics
- More communication between industry and education about required skills

14.2 Robotics in education

It is interesting to note that, unlike other areas of robotics in Australia, robotics education has two distinct, but related aspects to it:

1. The explicit teaching of robotics knowledge and understanding
2. The use of robotics as a pedagogical tool to assist and enhance learning across all aspects of the curriculum.

Teaching of robotics: Explicit robotics subjects can be found in Senior Secondary, VET and the Higher Education sectors. These subjects teach students all the skills necessary to understand how robots work. They might include topics such as electronics, mechanics, programming, control systems, maintenance etc.

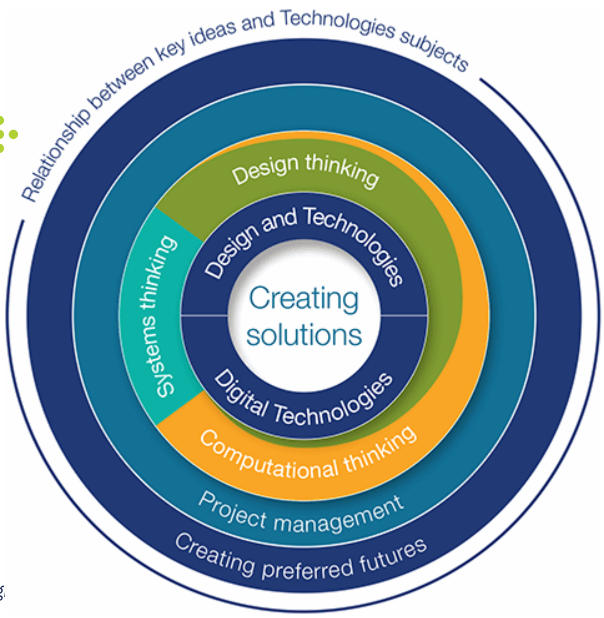
Robotics as a pedagogical tool: Robotics platforms have improved in useability over the years to the point where they are relatively cheap, with a wide range of uses and very small learning curves to get them up and running. As a result of this, the use of robots as pedagogical tools to assist and enhance learning across all aspects of the curriculum are becoming more and more popular. Robots are being actively used to support learning in subjects as diverse as Mathematics, English, Science, even Music.

Foundation — Grade 10 education

Primary education in Australia encompasses students from approximately five years of age (Foundation) and runs for between six and seven years of schooling. Grades 7-10 are sometimes referred to as Middle Years. Primary and Middle Years Education focuses predominantly on the use of robots as a pedagogical tool. Robot platforms are easy to use for novice students and serve as a way to engage students with the curriculum requirements necessary at school.

All states in Australia follow either the curriculum guides set down by the Australian Curriculum, or a version that is very similar. Within the Australian Curriculum lies the subject 'Technologies', which can be further broken down into Digital Technologies and Design and Technologies. The following graphic and table outlines the topics that are taught within this subject.

RELATIONSHIP BETWEEN KEY IDEAS AND TECHNOLOGIES SUBJECTS



Source: https://www.australiancurriculum.edu.au/f-10-curriculum/technolog structure/ - accessed 15th Nov 2020

TABLE 2

Design and technologies	Digital technologies
Knowledge and understanding	**Knowledge and understanding**
Technologies and society • the use, development and impact of technologies in peoples' lives **Technologies contexts** • technologies and design across a range of technologies contexts	**Digital systems** • the components of digital systems: hardware, software and networks and their use **Representation of data** • how data are represented and structured symbolically
Processes and production skills	**Processes and production skills**
Creating designed solutions by: • investigating and defining • generating and designing • producing and implementing • evaluating • collaborating and managing	**Collecting, managing and analysing data** **Creating digital solutions by:** • investigating and defining • generating and designing • producing and implementing • evaluating • collaborating and managing

It is worth noting that the teaching of robotics is not specified within the curriculum documentation. Instead teachers are free to use a variety of different tools to meet the teaching of the Curriculum's requirements. Robotics is a fun and engaging tool to meet these requirements.

Generally speaking, the programming of robotics falls into the Digital Technologies area, whereas the construction of a robot will address the Design and Technology area. It's important to note that the Technologies subject is not focused on teaching a particular platform, but rather the skills required to build or operate a platform.

In a Primary Education setting, it is common to have a single teacher responsible for a whole class for the majority of their teaching week. This permits the teacher more scope and flexibility to blend different learning objectives into rich tasks that concurrently cover several topics. As a result, this means that the use of robotics can be an effective and engaging way of covering multiple subjects. In Middle Years education we start to see the introduction of specific subjects not necessarily integrated with other subjects.

While the predominant use of robots at this age level is as a pedagogical tool, extra-curricular activities like robotics competitions are increasingly becoming popular, which serves to teach students explicit robotics knowledge and understanding. Students learn how to build and program robots and have the chance to create their own unique solutions to address the open ended challenges that these competitions promote.

The Technologies subject is required to be taught from Foundation through to Grade 8, with schools given the option to provide the subject as an elective in Grades 9 and 10.

In the Australian Curriculum, as well as specific subjects that are required to be taught, there are multiple 'General Capabilities' that are defined, concepts that are expected to be embedded into all areas of the curriculum. Robotics is a tool that neatly fits one of these General Capabilities – Information and

Communication Technology (ICT). This means that robotics can be used as a tool to enhance other areas of the curriculum and there are many examples of robotics being used to supplement subjects such as English, Mathematics, Science, Geography, Music and Art.

Senior secondary education

Senior Secondary education encompasses students in Grades 11 and 12. Once students get to Secondary schooling, we start to see more explicit teaching of robotics-related content.

While not common, there are options for mature aged students to complete secondary education level standards through various organisations.

All states within Australia have different subjects at this level and below represent some of the options available to students.

QLD: Digital Solutions – Engineering

NSW: Design and Technology – Engineering Studies - Software Design

VIC: Systems Engineering – Product Design and Technology

SA/NT: Design, Technology and Engineering – Digital Technologies

ACT: Electronics and Mechatronics – Robotics and Mechatronics

TAS: Design and Technologies – Digital Technologies

WA: Engineering Studies

These subjects dive into significantly more detail around the construction, programming and use of robots in society.

14.3 Vocational Education and Training (VET)

Vocational Education and Training (VET) qualifications have been developed with the specific goal of preparing students with skills for work. VET is designed to help people to join or rejoin the workforce, move into a new career or gain additional skills in their existing career. VET qualifications have a very practical focus. As well as specific skills for your chosen occupation, a VET course will often include generic work-based topics such as workplace health and safety.

VET Providers can include:

- technical and further education (TAFE) institutes
- adult and community education providers
- agricultural colleges
- private providers
- community organisations
- industry skill centres
- commercial and enterprise training providers.

Some universities and schools also provide VET in addition to their other offerings. VET sector qualifications include:

- Cert I-IV
- Diploma
- Advanced Diploma
- Graduate Certificate.

Robotics at TAFE institutes are a relatively new avenue, with multiple states now offering courses that involve the use of robots:

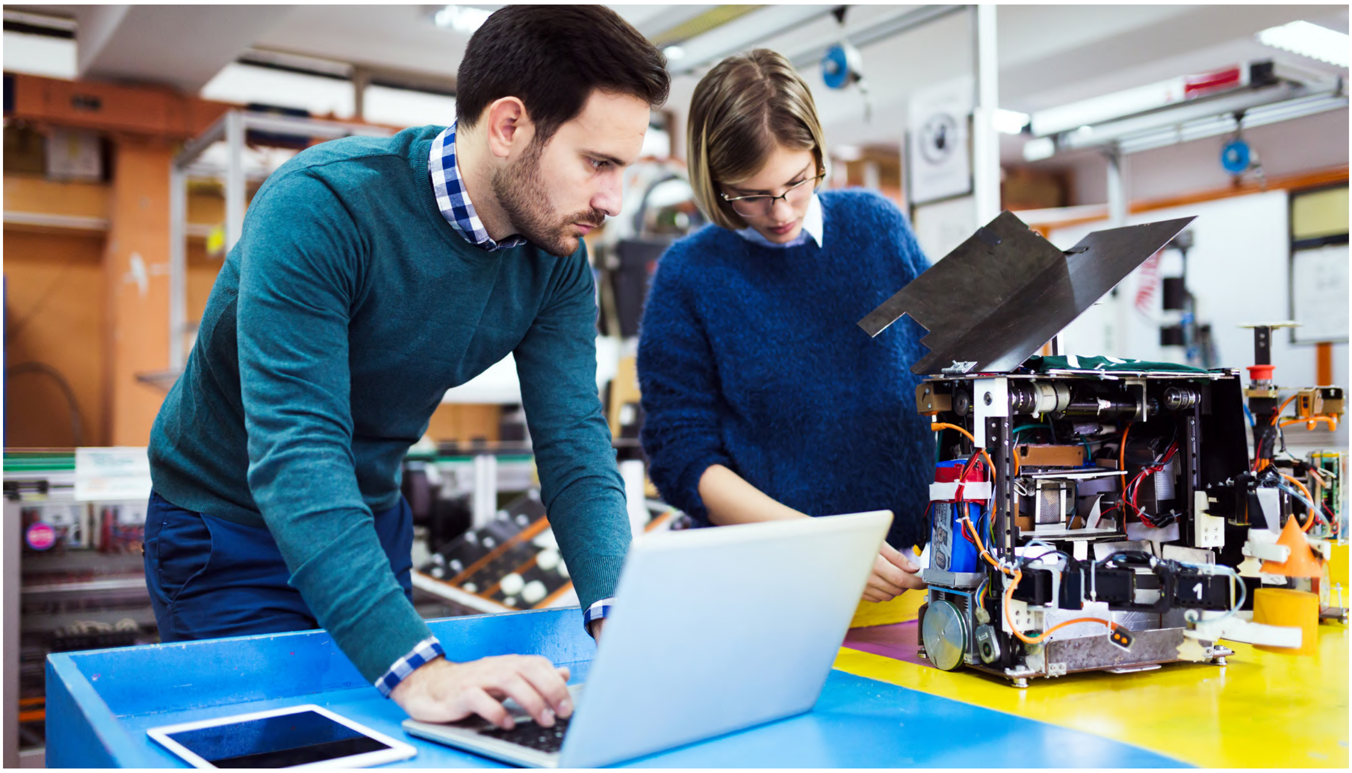
- **TAFE WA**
  - 22527VIC Cert II Integrated Technologies (Robotic Control Systems)
  - 22519VIC Cert IV Integrated Technologies (Robotic Control Systems)
- **TAFE SA**
  - Diploma of Applied Technologies
- **TAFE QLD**
  - currently working with CSIRO and BHP to develop a robotics course
- **TAFE NSW**
  - Skillspoint program offerings
- **VIC (14 TAFEs)**
  - Robotics appears in some Engineering courses.

Training to prepare students through Vocational Education and Training for a career in robotics is very embryonic in Australia. There are some TAFEs starting to look into it and others who are keen but not sure where to start. The costs involved to purchase equipment and find skilled teachers creates a roadblock for many.

Currently, there is no specific qualification related purely to robotics, more broadly it appears in Engineering qualifications. In the future, with the support of industry and government, we would expect to see a qualification related directly to robotics.

14.4 Higher education

Robotics offerings at a Higher Education level can be accessed via a number of different paths. Out of the 43 accredited universities within Australia, there are three main qualifications that learners can pursue; Bachelors, Masters and Doctoral degrees.



The field of robotics is extremely broad, and as such there are a variety of different courses that could be undertaken, each with varying levels of robotics as part of their course work.

Examples of Degree options:

- Electrical Engineering
- Mechanical Engineering
- Computer Systems
- Software Engineering
- Mechatronic Engineering
- Mathematics
- Data Science
- Information Technology
- Artificial Intelligence

A typical Engineering degree is four years in length, but there are Science degrees that are three years and it is possible to combine degrees to be awarded a double degree in five years. Masters degrees and PhDs can range from three years full-time and upwards.

Some universities allow students to start specialising straight away, whereas others provide generic first year plans to give students a taste of all the various fields before making specialisation decisions in their second year.

The typical cost for tuition for an Engineering degree in 2020 is approximately $7,000 per year.

This means a four year Engineering degree might cost up to $28,000. Mechatronics engineering, a hybrid of mechanical and electrical engineering degrees is often considered a direct path into robotics, although there is no professional accreditation for the degree and, to become a professional engineer, a graduate will need to choose to be either a mechanical or electrical engineer. The number of mechatronics graduates is growing every year in Australia, which indicates a pleasing increase in capability. The Australian Council of Engineering Deans reports that Honours degrees awarded in Mechatronics have almost doubled from 2016-2019 from 364 to 668[2] with domestic students making up ~73% of total student numbers.

The purpose of higher education degrees is arguably to provide students with the skills and accreditation necessary to go on and find employment in the robotics sector. Work in the sector may begin before completion of the degree through things like work experience and work placements. For example, in an Engineering degree, all students are required to complete ten weeks of industry work before they can graduate. Engineering degrees have a capstone project, two semesters long in final year, where students undertake a sizeable engineering/research project to put their engineering knowledge into practice, as well as develop their skills in project management, report writing and presentations. These projects can be done within a company.

This results in a large cohort of Engineering students and graduates, at different points in their learning journey, looking for work. One of the challenges facing higher education and industry is a way of coordinating the needs of industry looking for talent with the talent looking for work. Industry needs to be aware of the university cycle – students select their capstone project topics in late February, and they are in serious job hunting mode around July. Employing a student part-time, over the summer, for work experience or for a capstone project provides a means for industry and students to get to know each other, and this could lead to a permanent arrangement.

The purpose of higher education degrees is arguably to provide students with the skills and accreditation necessary to go on and find employment in the robotics sector.

University engineering education is highly constrained. On the one hand Tertiary Education Quality and Standards Agency (TEQSA), the independent national quality assurance and regulatory agency for higher education, sets rules about what constitutes an Honours degree, and Engineers Australia, through periodic accreditation, strongly influences what is taught, and how. Teaching has to balance abstract theoretical knowledge with the practical. Typically the theory is covered in lectures, bedded down and applied to problems in tutorials, and put into practice during laboratory settings. For a variety of reasons it is not practical for universities to have large amounts of industrial gear for teaching – class sizes are large, laboratory space is limited, and expensive assets become obsolete. This has, in the past, set up some friction between academia and industry. From a simplified point of view, academia seeks to teach students the skills and concepts necessary to be able to solve a variety of general problems, whereas industry often requires employees to be already proficient on specific hardware and software platforms. A certain amount of 'on-the-job' training is always expected, but reducing that where possible is of particular interest to industry. Progress is being made, however, with many higher education institutes having industry advisory boards that work with course designers to mutually benefit both sectors.

14.5 Other robotics education avenues

Outside of these formal applications of robotics in the education sector, lie a variety of different entities that also have a hand in promoting robotics. These may be in the form of competitions that students can enter, companies that manufacture robotics specifically for the education market, and organisations that promote robotics in an educational setting.

While these entities do not contribute to any formal qualification or recognition, they provide another example of engaging activities that continue to promote robotics in the education sector. Robotics education within the confines of a mandated curriculum gives a broad introduction to the field to all students, whether they are interested or not. These additional activities that exist outside the classroom offer the Robotics industry a unique opportunity to tap into and support students who are genuinely passionate about robotics and are likely to become the workforce of the future.

Case Studies

Trinity College

Trinity College is an Anglican K-12, co-educational, day school in the northern suburbs of Adelaide, South Australia. It comprises four EY-10 Schools (soon to be five) and a Senior Year 11-12 School. The objective is to embed science, engineering and technology skills into students to inspire innovation and foster well-rounded life capabilities including self-confidence, communication and leadership.

At a Junior School level Trinity College has looked at a bottom up approach to help build the foundations. This has been done via mapping the Digital Technologies curriculum through the Digital Technologies Hub K–6 continuum and ACARA. This whole school approach targets the students coding, problem solving, collaboration and critical thinking skills.

Each year level works with a different device specific to their age group and is challenged with a series of learning opportunities to learn and extend themselves. In the first half of the year, students work in a more virtual, non-robotic environment with programs such as Code.org, then in the second semester, delve into practical hands-on experiences with the devices.

Teachers are provided support in class to show best practice and help them develop the skill and confidence to teach in areas they are not necessarily confident in, accepting the fact that they are learning just like the students. Robotics platforms used include Bee Bots, Cubetto, Micro Bits, Edisons, Mbots, Ozobot and Ev3 / NXT's.

As students progress through the years, the complexity of what they are doing increases. This has seen a noticeable increase in not only the skill of the student with coding and robotics through critical and creative thinking, but also in the use of the language associated with robotics (e.g. Year 1 and 2 being able to explain algorithmic thinking, or Year 5's being able to talk about 'if statements' and cause and effect). The language is the key as much as the use of robots in the classroom as it allows cross curricular to be happening in Maths and Science.

Outside of the classroom learning, students that wish to develop further in a team setting are provided the opportunity to explore robotics in a competitive environment as part of either Robocup Junior in the Junior / Middle years or FTC in the Senior years. Students from Year 4 upwards participate in Robocup and have the opportunity to compete at a local, state or national level, which Trinity has been doing for 15 years.

Left: Year 1s independently programming Microbits. Image courtesy of Trinity College.

Galen Catholic College

VEX Robotics was introduced to North East Victoria in October 2016, after being inspired by the 2016 National Science week theme Drones, Droids and Robots. Local teachers, both Secondary and Tertiary, along with students, parents and interested community members organised a workshop to investigate VEX Robotics. Three schools then took up the challenge of setting up a VEX Robotics Program, with funds and support from LLEN networks. Galen Catholic College and Borinya Community Partnerships set up their programs as extra-curricula with it being optional participation for all levels. Wodonga Middle Years College, introduced it into their mainstream curriculum.

Thanks in part to the great collegiality shown by the schools and community support in the region, Wangaratta was awarded the honour of hosting the 2016 and 2017 Australian National VEX Robotics Championships. The success of these championships and publicity gained in the region, sparked an interest in robotics.

The schools continued to work closely together to develop their programs, and host their own local program development sessions inviting other schools to join. St Anne's Primary in Albury, and Beechworth Montessori became the next schools to take on VEX Robotics also as an extra-curricular offering. In 2019, Galen Catholic College also introduced VEX Robotics into its mainstream curriculum and continues to run both programs.

With the growth of student/schools involvement, the region now has enough teams to support local competitions, from three teams in 2016 to 20 teams in 2019. The teams also travel together to Canberra, Melbourne and Adelaide to compete in the larger competitions, creating great camaraderie and collaboration. At each competition the senior students encourage and assist the junior students and new teams.

Success at the 2017 VEX Australian Championships has inspired robotics in the area, with significantly higher participation from our region at subsequent competitions.

Success with robotics in our region has come through strong collaboration and building networks. This has allowed our students to grow, develop into STEM leaders and inspire not only each other but the whole community.

Albury Competition with students competing with Wodonga, Albury and Galen teachers and senior students running the event. Image courtesy of Galen Catholic College.

Pembroke School

In 2018, Pembroke identified robotics as an area that was worth exploring in more depth. It offered opportunities for students to develop knowledge in programming and engineering concepts as well as better understand how these areas tie into developments in industry and technology in general. Increased automation, programming and innovative technologies called for a curriculum that would support students in preparing for a rapidly evolving workplace.

In Junior School students are exposed to robotics through LEGO EV3 robots as well as exposure to drone technologies using block based programming software.

In Middle School students build upon skills developed in Junior School with a focus on automation processes and how we might be able to replicate these processes through the use of Vex IQ robots. There is more of an emphasis on the sensors and actuators used as well as a deeper understanding of the programming required. By Year 10 they learn how to program complex robots and drones using Python and C++ text based programming.

In Senior School students begin some deeper investigation into automation, particularly autonomous vehicles, the ethics surrounding their use, and how they function. There is more emphasis on sensors, particular vision, touch and distance sensors, and how we can use these to replicate real world automated processes through open ended design briefs that require students to develop solutions to complex problems. Students are introduced to engineering concepts and are required to engineer components using advanced technologies such as 3D printing that will complement their solutions.

Students are provided with opportunities to further develop their skills through the school's successful Robotics Co-curricular Program.

Pembroke School students Rosa, Emily, and Alinda demonstrate their robotics programming to Chief Scientist for South Australia Caroline McMillan and Principal Luke Thomson. Image courtesy of Pembroke School.

St Mary's Primary School

The Robotics curriculum at St Mary's spans from Foundation through to Grade 6. Foundation to Grade 2 students explore and learn how Beebots, Ozobots and Spheros work. They initially play with the robots to see what they do, how they work and the components that make them work.

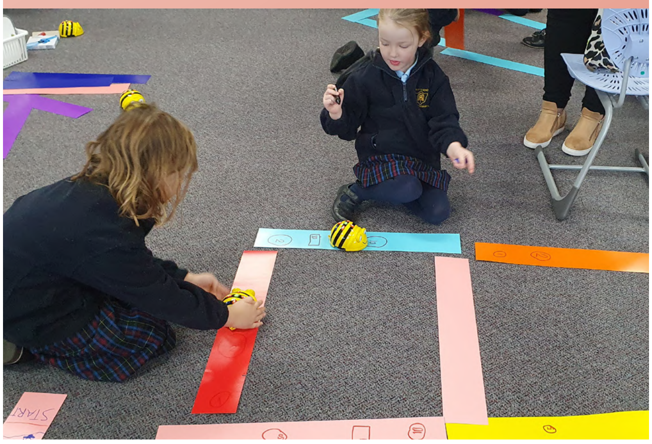
Primarily using Beebots, the focus with the Foundation children is to make robotics fun but challenging, and this involves Beebot races and obstacle course races. Students are given a variety of materials that cater for different challenges, such as a variety of vinyl mats to get from one location to another, maze materials, roads and obstacles to create their own courses to navigate. The aim is for them to be unafraid of exploring and to develop confidence in using different robots.

As they progress through to Grade 2, challenges become harder and the requirements become more demanding. Students are expected to represent their code in a visual way and set their work out sequentially. Through Grades 3 to 4, they are introduced to Lego WeDo 2.0 and Scratch while continuing to use the Ozobots. It is during these grades that students begin to code the Ozobots online and explore more uses for them. We begin to explore creating robots rather than just being a user through Makey-Makey.

In Grades 5 and 6, the focus is on being a creator rather than a user with the introduction of Micro:Bit and Lego Mindstorms. In 2019, the school entered the regional Robocup Junior competition in Horsham, taking out first place in the line following competition.

Every year level explores the uses of robotics in everyday life so the students can see the relevance of what they are working on in school. A 3D printer has now been added to the classroom and with this technology, students can design and build housing units for Microbits and Makey-Makeys to add another layer into the robotics unit.

Foundation students Elli and Maddi work together to create and code a roadway for their Beebot. Image courtesy of St Mary's Primary School.



VEX Australia

The VEX Robotics Competition, presented by the Robotics Education Competition Foundation, is the largest and fastest growing middle school and high school robotics program globally with more than 24,000 teams from 70 countries playing in over 1,700 competitions worldwide. Each year, an exciting engineering challenge is presented in the form of a game. Students, with guidance from their teachers and mentors, build innovative robots and compete year-round.

In addition to learning valuable engineering skills, students gain life skills such as teamwork, perseverance, communication, collaboration, project management, and critical thinking. The VEX Competition prepares students to become future innovators with 95% of participants reporting an increased interest in STEM subject areas and pursuing STEM-related careers.

There are four different VEX Robotics Competitions to participate in:

1. VEX IQ Competition – VEX IQ Challenge is for primary and middle school students. Two robots compete in the Teamwork Challenge as an alliance working collaboratively to gain the maximum points in 60 seconds. Teams are randomly drawn to work together to amass the greatest point score, with each team having a unique robot, each match is unique, thus requires strategy, communication and collaboration.
2. VEX Robotics Competition – VEX Robotics Competition is for middle and high school students and like IQ, teams form randomly drawn alliances and are competing against another two-team alliance. The idea of alliance once again highlights the future skills of communication, collaboration and analysing the strength and weaknesses of each teams' skills/bots to form a winning strategy.
3. VEX U Competition – The potential for this is growing as the VEX alumni growth is currently being developed.
4. VEX AI Competition – Brand new global pilot competition for 2021 season. Four Australian teams out of 50 world-wide will be part of this pilot season.

The competition is fully autonomous and will use an array of new sensors including the Game Positioning System (GPS), AI Vision Sensor, VEX LINK Communications, and a Sensor Fusion Map. Each team brings two robots that they design and build to work as a team. Teams can 3D print, machine parts and use custom electronics. This game will take students' future work skills to the next level. It is an exciting development for VEX robotics.

Two Teams competing in the Secondary School Division at the 2019 VEX Robotics Australian National Championship held at the Adelaide Convention Centre. Image courtesy of Robotics Education Competition Foundation.

Wyndham Tech School

Robotics training is in full swing at Wyndham Tech School. Hosted by Victoria University Polytechnic in Melbourne's West, the Tech School is providing 24,500 secondary school students from 34 partner schools access to the skills required for many of the jobs that haven't been created yet.

With state government funding for ten Tech Schools across Victoria, these high-tech learning hubs offer innovative, problem-based education programs aimed at providing students with practical experience using the latest technology and equipment. Each Tech School is unique in its course offering, with programs co-designed with local industry partners and specialists in school networks. The distinctive and highly interactive learning environments help students to develop the Science, Technology, Engineering and Mathematics (STEM) skills they need to compete in the future global jobs market.

At Wyndham Tech School, students from 34 partner schools are introduced to robotics in Year 7, continuing to build on these skills right through to Year 12. Wyndham Tech School's unique offer includes projects co-delivered by industry partners for students to problem solve, design and develop solutions using a variety of robotics. Access to both service robots and industrial robots used in industry provides opportunities to set up collaborative solutions, challenging curiosity and extending creativity. A key feature of the Wyndham Tech School's programs is the professional development undertaken with teachers to enable them to apply and continue the learning introduced by the Tech School in their own school.

A few years ago, access to this type of training and technology across secondary schools in Melbourne's West was varied and inequitable. The Tech School evens the playing field by providing all students the opportunity to engage with robotics in a contemporary and supportive environment.

Located at Victoria University Polytechnic's Werribee campus, Wyndham Tech School helps to introduce students to the diverse career possibilities available through TAFE and the University environment, strengthening their interest and opportunities for post-secondary education and training.

Factory of the Future, students will be working with Industry Partners to work on projects that reduce production time. Image courtesy of Wyndham Tech School.

Chancellor State College

Chancellor State College is a P-12 campus on the Sunshine Coast in Queensland. The College Primary Campus has an extensive range of curriculum offerings that are aligned to ensure a seamless digital learning pathway through the years of education.

Primary campus students will have opportunities to engage with multiple platforms including Lego WeDo, BluBots, Lego Spike and EV3, and Arduino all as part of their delivery of curriculum learning. The curriculum is mapped against a College-created scope and sequence for delivery which emphasises the development of functional skills as roboticists. Students in Prep and Year 1 begin to develop algorithms and the functional use of syntax when giving a digital system instructions, this is further developed within Year 3 where they continue the development of these algorithms to include the use of peripheral devices within their design solutions. This is then continued further within Year 5 where students begin to include branching and user input.

The College has committed to the use of mostly Lego-based platforms to provide students with a continuity between platforms. There is a consistent feel between the Lego software and students understand and feel comfortable using the Lego bricks and pieces as they have often had exposure to them at home.

Students engage in many different coding platforms. The emphasis however, is always on computational and design thinking. Image courtesy of Chancellor State College.

The mechatronics degree at QUT

At Queensland University of Technology (QUT) mechatronics is a major in the engineering degree, leading to the award of a B.Eng. (Honours) (Mechatronics). Entry requires a selection rank of 75 and Maths C (advanced maths) is strongly recommended. It is a 4-year program, but students can obtain a double degree in five years by combining engineering with Industrial Design, IT, Maths or Science.

The first semester is common to all engineering students and covers engineering principles, design and energy. In the second semester students start streaming into majors with computation and foundations of electrical and mechanical engineering. Mechatronics has three design units, starting in the first semester of second year where students design and build a line-following robot. In the third year students tackle a more complex project, to reflect their increased ability, and in the final year the project also brings in aspects of product design and entrepreneurship. Projects typically involve working in teams, since team skills are critically important in industry and learning about personal dynamics is considered as useful as technical knowledge.

Study in areas like digital systems, signal analysis, control, and autonomous systems is included. Most units have hands-on practical or laboratory sessions and assessment is based on assignments, exams and practical work. Apart from a major in mechatronics, students can add a second major, an additional focus on topics such as aerospace, computer and software systems, mathematical sciences, mechanical or medical engineering. Or, students can do two minors each with a less intense focus drawn from a large list of options such as aerospace, biotechnology, electrical engineering, engineering management, manufacturing, materials, medical engineering, mechanics of machines, robotics, project collaboration, software engineering and many more.

There are two robotics units: Introduction to Robotics covers the kinematics of robot arms and an introduction to computer vision – this course is available free online as the QUT Robot Academy; and Advanced Robotics covers mobile robots – motion models, control, path planning, localisation and SLAM.

Final year also brings a two-semester capstone project where students bring their research and design skills to bear on a significant problem. Their “client” might be a company, or it might be an academic at QUT. In addition to the technical project work, students also need to create a project scope, create Gantt charts to manage time and delivery of milestones, write reports and give presentations.

Mechatronics students Emily Corser and Sean Wade McCue with RangerBot at QUT's display at Qode. Image courtesy of QUT.

Australian Army Drone Racing Team — Army Cadet Drone Racing Camp

Since its formation in 2017, the Australian Army Drone Racing Team has been a leader in getting Australian youth excited and inspired in STEM. Drone racing sells itself! It is fast-paced, fun, exciting to fly and thrilling to watch. Learning by doing in drone racing develops STEM skills, fosters lifelong learning and instils a sense of curiosity, confidence and teamwork.

In January 2020, the Australian Army Drone Racing Team delivered the first ever Drone Racing Camp to 22 Australian Army Cadets as part of their elective training program. The five day camp assumed no previous knowledge of participants, with the only requirement being an interest in drone racing.

The unique curriculum, underpinned by an applied learning approach and delivered by highly-skilled and passionate drone racers, was a winning combination. With the emphasis on hands-on learning, cadets built their own drone on day one, developing skills in critical thinking, problem solving and troubleshooting. Day two saw cadets learning to code and program their drone. By day three, the cadets were out flying the course and practising on the simulators. Cadets were encouraged to explore design options and build modifications to improve and enhance their drone. Crashing was an opportunity to problem solve, reinforce STEM skills and learning through repair and rebuild, and build confidence to experiment.

Drone racing has an easy entry point but requires continued commitment and practice to progress beyond a beginner level. The camp provided valuable learning opportunities for cadets to draw on the knowledge and skills of the Army Drone Racing Team pilots, build resilience through crashes and drone malfunctions plus foster teamwork by supporting others experiencing the same challenges.

Drone racing as a sport piques the interest of young people into the aerial robotics world, and has real-world application within the STEM disciplines and the rapidly expanding technological career pathways. The success of the drone racing camp was evident in the excitement and enthusiasm of the cadets to further develop their drone flying skills, and aspire to be selected as a pilot on the Australian Army Cadet Drone Racing Team.

There are now Drone Racing Teams representing the Australian Army, Navy and Air Force with its pilots drawn from a diverse and varied range of employments. The Military International Drone Tournament to be held in 2021 will see Australian Defence Force Teams race against teams from New Zealand and the UK. It just may be the Australian Army Cadet Drone Racing Team who are the ones to beat.

Craftsman Dylan Field, pilot name BurntFPV, coaches student drone racing pilots at Army Cadet Drone Racing Camp. Image courtesy of the Australian Army.

CQ Gladstone District STEM Cluster

The Central Queensland Gladstone District STEM Cluster is made up of primary and secondary state schools in the Gladstone Region. The cluster leaders have coordinated and fostered a productive and ongoing partnership with local industry organisations Queensland Alumina Limited (QAL) and Rio Tinto Yarwun. This education-industry partnership has effectively developed and refined an innovative project scope aimed at engaging students in Years 3-10 to undertake context-specific robotics challenges that mimic real-world industry processes.

Students, supported by teacher-coaches and STEM professional mentors, are guided to design, build and program Lego Mindstorm robots to solve real-world industry challenges, including: navigation safety and collision avoidance whilst transporting bauxite from the Gulf of Carpentaria to the Port of Gladstone; utilisation of short-cuts during bauxite ore transport to increase company productivity; accuracy in unloading of the bauxite cargo upon entry into port; and the extract of alumina through the refinement process known as the Bayer Process, including digestion (navigation through a series of pressure tanks and spin through a series of flush tanks), clarification (mud waste slurry is sent to the red mud dam), precipitation (via chemical processes) and calcination (precipitate is located in a kiln, pushed through the kiln, and deposited at the end of the kiln ready for transport to the local smelter). In 2020, the project scope was refined to incorporate an Acknowledgement of Country challenge component, as an opportunity to foster student engagement in reconciliation, respect and recognition of the Aboriginal and Torres Strait Islander histories and cultures.

The partnership and the associated robotics challenges were initiated in 2018, with QAL and Rio Tinto Yarwun contributing expertise in industry processes to assist the state school cluster leaders with development of the Beginner and Advanced robotics mats and challenges for the newly formed Gladstone Robotics Competition. The industry partners also contributed STEM professional mentors to visit participating schools to support students with developing their digital solutions for the Gladstone Robotics Competition and provide financial support to purchase competition resources. The competition mats, challenges and handbook engage students in the Digital Technologies, Science and Maths curricula, as well as cross-curriculum priorities, and support the development of career pathways into local industry.

Each year, the cluster leaders train teachers in a teachers-teaching-teachers model in the use of Lego Mindstorm robotics to support students to solve the industry-modelled challenges. Students then spend several weeks at their home schools preparing for the large culminating event showcasing their efforts, the Gladstone Robotics Competition.

QAL Electrical Engineer Russell Stewart judges a team entry into the Gladstone Robotics Competition Beginner Division. Image courtesy of Central Queensland Gladstone District STEM Cluster.

Glasshouse Christian College

The Glasshouse Christian College (GCC) AgriTech Agricultural Consulting program aims to have senior students become capable and confident in using a drone for the purpose of crop monitoring and management, and integrate EM and LiDAR layers to provide conceptual agronomic consulting services for the local farming community.

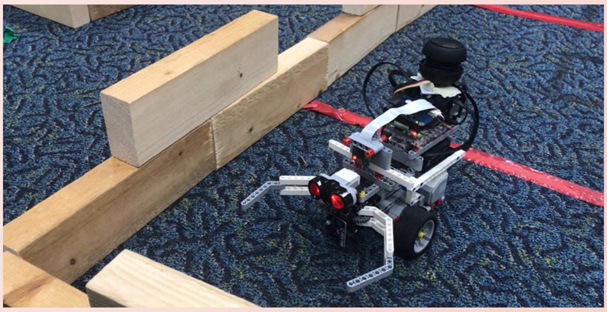
Initially, students learn the background theory of land management and plants and soil health, along with the technologies of NDVI, EM and LiDAR. Links are made in the field during practical components that examine soil types and textures (EM link), plant stress investigations using a hand-held Green Seeker (NDVI link) and topographic variations (LiDAR).

Once drone safety and flying capabilities are established, students start to conduct NDVI mapping. The drone that is used to scan the different crops is a Phantom 3 fitted with a Sentera NDVI camera, and the images captured are uploaded to Drone Deploy to generate a NDVI map that represents plant health. The maps are analysed independently to establish some basic conclusions on plant health alone. The map is then opened in Google Earth, along with LiDAR and/or EM to determine if the plant health correlates with soil factors (EM) or topographic factors (LiDAR). Finally, analysis and recommendations for the producer is compiled and the use of these technologies in agriculture evaluated.

These activities reflect a staged approach to suit various year levels and QCAA Senior Agricultural Science General Senior Syllabus.

Travis from Glasshouse Christian College flying a drone over a potato crop in the Darling Downs region to determine plant health using NDVI and DroneDeploy at early establishment phase. Image courtesy of Glasshouse Christian College.

Marist College Ashgrove



At Marist College Ashgrove, Year 12 Digital Solutions students developed a website-controlled fire fighting robot using LEGO and a mini-computer called the Raspberry Pi. The robot was required to: navigate a maze; record turns, movements, the locations of fires in a database; and rescue a hypothetical victim. Students were to remotely control their robots via an internet connection – therefore some type of real-time mapping or visual display was encouraged.

Prior to this project, students had learnt Python coding, web development, and databasing and SQL. This project required students to utilise and apply their prior knowledge to create a new and innovative solution. This task was full of rich new learnings in the areas of: networking (VNC, SSH), operating systems (Linux); programming (threading, path-finding, interfacing); web development (Bootstrap, JSON, AJAX); and databasing (SQLite).

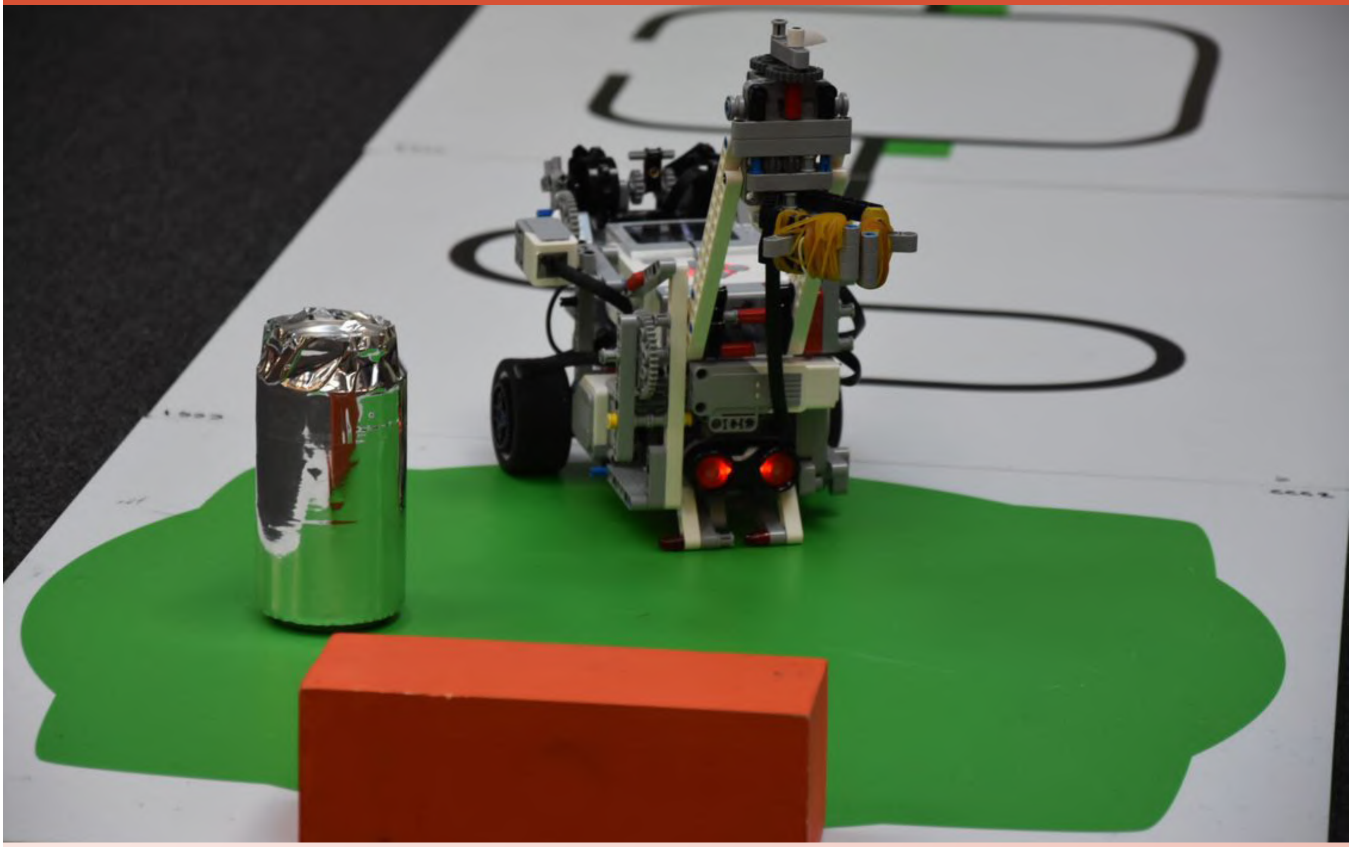
Students' projects were outstanding. Some students enhanced their robots with streaming video through the PiCam, others used Javascript Turtle to draw a map of the robot's path, and some also attached speakers - robots began to play music such as: 'Stayin alive' by the Bee Gees, and employed speech synthesisation. Consequently, robots could speak commands, and reassure victims (with a Scottish accent).

To interface between the LEGO Ev3 motors/sensors and the Raspberry Pi, an adapter called the BrickPi (available from Dexter Industries) was used. Each Raspberry Pi hosted a Flask web server which was used to interface with the robot and the database. Students were given access to a very basic purpose-built Flask template on GitHub. This template scaffolded some of the technologies they would need to apply.

Overall, the project was a nice addition to the senior curriculum at Marist College, and prepares students for an Internet of Things future where devices (and robots) will increasingly be connected and controlled online.

Speakers provide an awesome soundtrack to groove along to while working. Image courtesy of Marist College Ashgrove.

RoboCup Junior Australia



RoboCup Junior is a project-oriented educational initiative for students. It is designed to introduce RoboCup to primary and secondary school children. The focus in the junior league is on education. RoboCup is an international effort whose purpose is to foster Artificial Intelligence (AI) and robotics research by providing a standard problem where a wide range of technologies can be integrated and examined. As well, the initiative serves as a basis for project-oriented education.

RoboCup Junior Australia and the RoboCup Junior Educational Competition were introduced to the world in Melbourne in 2000. The timing was perfect and it was tagged "The educational game of the new millennium". Since then, RoboCup Junior Australia has experienced exponential growth where well established committees host major competitions in every Australian state and territory.

The competitions have multiple divisions – where autonomous robots are designed, built and programmed to partake in Soccer, Simulated Rescue, Rescue Maze and OnStage Theatrical Performances. Each of these categories have progressive stages based upon the experience of the students. Each category requires a minimum of two students per team. RoboCup Junior does not require nor suggest a specific platform, but allows the students to choose the robotic platform(s) they wish. This enables innovation and experimentation with new technologies. It also encourages students to explore and utilise more advanced electronics and sensors. Students progress from using educational kits to creating custom robots with 3D printed parts, and custom electronics.

The programming languages used range from block based (horizontal and vertical) to complex text based languages. As the development of languages emerge, the use of them for the robots at RoboCup Junior has been seen.

Participation rates have steadily increased in regional and state competitions as well as the annual Australian Open National Competitions. In addition, more and more regional competitions are being run throughout each state and territory, further increasing the number of students, teams and schools who have connected with RoboCup Junior Australia. All competitions are open entry, meaning no qualification is required to participate at state/territory or national level. The last census done indicated that more than 300 schools, 1,200 teams and 3,500 students participated at the state and national level. Additionally, many students only participate in regional competitions, or at school competitions without attending a state event. The total participation is estimated to be more than 5,300 unique students.

RCJA is thankful for the very long time support of Modern Teaching Aids.

Rescue Competition, Line follow and lift - LEGO MINDSTORMS. Image courtesy of RoboCup Junior Australia.

Brisbane Grammar School Robotics

Beyond curriculum subjects at Brisbane Grammar School (BGS), students are offered a range of opportunities to experience and build robots.

Lunchtime clubs for Year 5 and 6 students incorporate LEGO Mindstorms, LEGO Spark and MBot platforms for students to develop basic programming and building skills. Students explore the potential of these kits as well as being given specific tasks to achieve, such as LEGO sumo competitions, programming challenges and design constraints.

Year 8 students take part in a four-day immersive robotics design thinking project called Robots to the Rescue (R2tR). Students use the design thinking process, select a real-word problem and develop a robot prototype that could help solve that problem. They design their robot on paper, build a cardboard model and finally build a working LEGO Mindstorms robot prototype that is displayed to parents and peers during a product 'pitch.' Representatives from the QUT Design department were influential in the creation of this program.

From Year 7 to 12, students take part in the BGS Robotics Club. This is an activity that runs all year. An application process helps ensure that students value their place, this helps cap the numbers for this very popular activity. Students in the BGS Robotics Club take part in the FIRST Tech Challenge robotics competition. BGS attended the state competition for the first time in 2018 and had two teams invited to attend the national competition in 2019.

In 2020 the BGS team was invited to represent Australia in the FIRST Global Challenge as 'Team Australia'. Collaborating with students from three other Queensland teams, the BGS students took part in three months of STEM challenges, social media outreach and technical challenges. Each country can only elect one team and Team Australia competed against more than 190 countries.

For students wishing to learn the fundamentals of hardware, Mechatronics is a technical club in which students design, build and program their own circuit boards to then build working robots. Students also develop a 'club project' which is usually a large robot contributed to by many students from the club.

In 2019, BGS was invited to join the only Queensland FIRST Robotics Competition team (FRC). This complex competition involves robots that weigh more than 50kg, are powered by a car battery and are predominantly custom made. BGS aims to have its own FRC team in the next couple of years, allowing students considering Engineering or Mechatronics at university to gain this valuable experience.

Team members preparing for the nationals in the FIRST Tech Challenge Robotics competition. Image courtesy of Brisbane Grammar School.

One Giant Leap Australia Foundation

The Kibo Robot Programming Challenge (Kibo-RPC) is an educational program in which students solve various problems by programming free-flying robots (Astrobee and Int-Ball) in the International Space Station (ISS). It is hoped that, by providing these students with the opportunity to work with professional scientists and engineers, they will be inspired to develop their own educational and professional goals to a high level.

Participants have the chance to learn cutting-edge methodologies and hone their skills in STEM. The Kibo RPC also expands international exchange by encouraging students to interact with other global participants. This program is hosted by the Japan Aerospace Exploration Agency (JAXA) in cooperation with the National Aeronautics and Space Administration (NASA).

The scenario for 2020 was: Emergency alert is activated!!! A meteor has crashed into the International Space Station (ISS) and the air is leaking out somewhere. As a team, create your own program to operate the Astrobee and Int-ball and stop the ISS air leakage.

Educational Objective: A simulation can only approximate the real world. Participants are expected to learn techniques for creating simulation programs that perform well in the real world despite uncertainties and within margins of error. Students learn the necessity of controlling and correcting positions and orientation of a free-flying robot and how to perform assigned tasks in the onboard environment through simulation trials. 2020 was the inaugural year of this Challenge and there were seven countries involved – Australia, Indonesia, Taiwan, Japan, UAE, Thailand and Singapore.

The Astrobee robot onboard the International Space Station. Image courtesy of JAXA/One Giant Leap Australia Foundation.

Social robots for empathy in education

Since 2018, Nvoke Future Learning has been delivering tailored social robotics programs to grades 5-8 in South East Queensland schools using humanoid robots, Pepper and NAO by SoftBank Robotics as the tool for learning. Social humanoid robots provide a vehicle for simulation of social and emotional regulations, enabling students to practice empathy in a safe environment.

Within the overarching theme of empathy, students work in project teams taking on coding, user experience, design and communication roles to identify and solve problems for their community by developing an application for the robot, boosting their confidence, knowledge and engagement in the program.

The class explores the social and ethical implications of the introduction of robots in our society, which allows them to identify key challenges and opportunities to consider as they create the future of robotics in their community. By working together to develop interactive, robot-based solutions, students develop patience and empathy for both the robot, and their fellow humans, and as a result of completing the program, students have found they are better able to communicate and express themselves.

Nvoke Future Learning has improved outcomes for regional and remote students, parents, and communities via engaging with schools, activating interest, promoting awareness and ensuring inclusivity for all. These technologies are able to truly transgress socio-economic barriers and therefore contribute to brighter futures.

Pepper robot with Pittsworth State School students and Nvoke Future Learning team. Image courtesy of Nvoke Future Learning.

Micromelon Robotics

Micromelon Robotics has been developing classroom equipment and software since 2017, with the core goal of building tools that lower the barrier of entry to text-based programming for school students. With simple and intuitive classroom tools, students are able to focus on problem solving and creative thinking in the context of robotics, as well as continuing their learning into more advanced topics like 3D printing, electronics and computer vision.

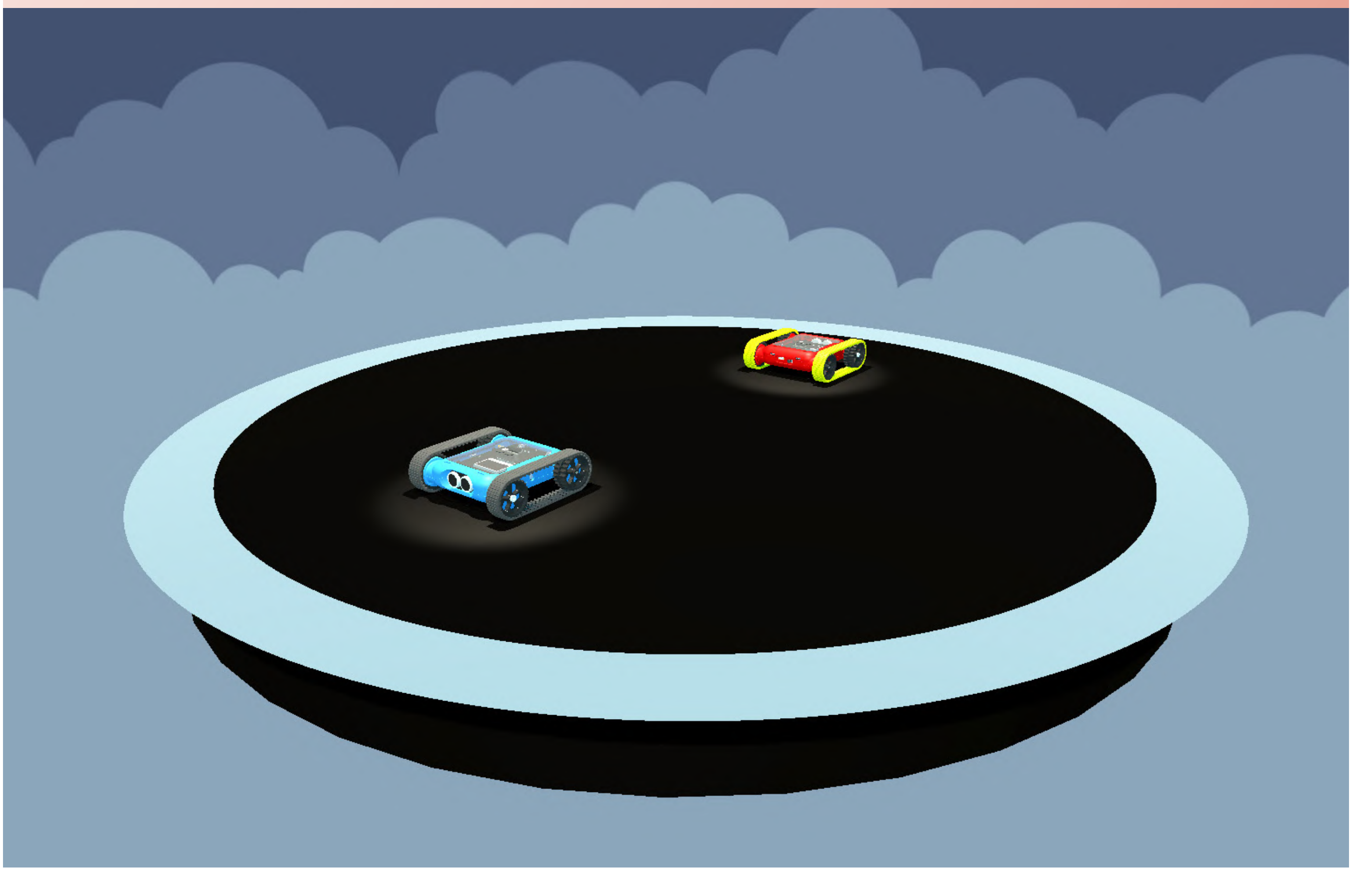
As with many engineering challenges, the key to understanding what is going on is to visually see how it relates to things that you may already know. Throughout school trials, Micromelon has developed software in combination with a programmable robot that allows students to code using drag and drop blocks simultaneously with Python. This allows for students to see exactly how their Python code alters the structure of visual elements that they already understand.

Because the students can watch the text and blocks update live no matter which part they edit, they are able to begin interacting with text based code without fully leaving the comfort zone of a drag and drop environment. This results in students beginning to edit text based code gradually, while being able to spot and correct errors by looking at the visual elements. While each student is able to progress at their own pace, teachers are able to push students' comfort zones by restricting their editing method.

One of the most important aspects of robotics is troubleshooting and debugging. When a student's robot exhibits unexpected behaviour, they often fall on whichever style of code they are more comfortable with. To help students while debugging, features were added that highlighted each line of text code and corresponding block live as the robot was running their program. This visualisation of their code as it runs on a physical robot reinforces the link between blocks and text, and helps them to find problem sections of code.

To expand the ways students can visualise their code and with the rise of remote learning, these features are now being integrated into the Micromelon Robot Simulator. Students, whether remote or in the classroom, will be able to attempt different and more difficult challenges. The simulator also opened up the important discussion of designing for ideal vs physical hardware in school trials, which was released in late 2020.

Virtual Micromelon Rovers ready for a SumoBot competition. The Code Editor runs the same program on a real rover or a simulated one. Image courtesy of Micromelon Robotics.



Robocoast

The Sunshine Coast has a great history of individual schools doing well at state robotics competitions. By themselves they were struggling to attract enough funding to take students to the next level of preparation for university entry into courses such as Mechatronics at QUT. Forming a hub of ten schools back in 2017, Robocoast enjoyed sponsorship from local council and Modern Teaching Aids, which helped fund a local robot sumo competition that grew from eight teams entering in 2017 to 160 teams in 2019.

Students and teachers, returning from competitions held overseas, provided workshops not only in robotics and coding, but further skills such as 3D drawing, laser cutting and 3D printing, which are fundamental in producing world-class machines. In 2019, Robocoast ran workshops for 1,900 students and 350 teachers from over 100 schools as well as providing speakers for a number of education conferences across the states.

In 2020, Robocoast was selected to be the organisation to introduce Australia to the RoboRave program of robotics challenges, which has spread through 35 countries around the globe. 110 teams came together in the University of the Sunshine Coast Stadium for what might well have been the largest robotics competition for students in the southern hemisphere in 2020!

In the space of five years the Sunshine Coast morphed from a sleepy backwater in robotics education to a dynamic focal point in Australia, and has emerged a global leader in competitive robotics. The fundamental belief of this not-for-profit is that once students have the confidence to teach their peers, then excellence will follow.

As the students in those robotics teams have matured, they have been encouraged to start their own mini tech-companies. Five such businesses have been doing well, offering workshops based out of the University of the Sunshine Coast and Peregian Digital Hub, selling tickets on Eventbrite.com and building their own fan base of robotics stars for the future.

Image courtesy of Robocoast.

Contributors

This chapter was based on a virtual workshop held on 20 August 2020 with contributions from the individuals listed below:

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Nicci Roussow (Exaptec)
Gail Bray (Wyndham Tech School)

Footnotes

1 Caldwell, J.P. (2021) Education and Training in Australia, IBISWorld AU Industry Report.

2 King, R. (2021) Professional Engineering Graduates by Branch of Engineering, ACED Australian Council of Engineering Deans.

15

Skills

Rapid technological change is transforming the workplace. The introduction of robotics, automation, and artificial intelligence means education and training are a priority, with the loss of 75 million jobs predicted globally by 2025

15.1 Introduction

Rapid technological change is transforming the workplace. The introduction of robotics, automation, and artificial intelligence (AI) is asking educators, students, and the Australian workforce to prepare for the future of work – to ensure that all Australians are equipped with Industry 4.0 relevant capabilities.[1]

Education and training are a priority, with the loss of 75 million jobs due to technological-driven change predicted globally by 2025. Notably, this loss is offset by the expected creation of 133 million jobs, an increase of 58 million jobs in the coming five years.[2] Of key importance is that the creation of any work roles from our digital transformation will require skills investment.

How we prepare for the future of work, whilst supporting our present needs, is a complicated question. Knowing which skills to prioritise for our businesses and people to succeed requires close cross-sector collaboration between government, education and industry. The World Economic Forum[3] suggested that from 2020 most occupations would have one third of their skill set built on skills not considered crucial in 2015. Support for the STEM curriculum – focused on applied education in the disciplines of science, technology, engineering and mathematics – in vocational education training is being paired with skills for core Industry 4.0 fields. Industry needs, prioritising such areas as automation, AI and machine learning, may offset this grey area of the future of work. Additionally, focus on soft skills to develop the human qualities of workplace roles, e.g. complex problem solving, emotional intelligence and creativity, is strongly advocated.[2]

Industry 4.0 forecasts massive disruption to workers as they adapt to advanced technology in the workplace.[4, 2] The skills gap is fundamentally a mismatch between the skills that workers in the economy possess versus the skills demanded for work roles. Before Industry 4.0 businesses would commonly recruit new staff to future proof emerging skills gaps in the workplace. But, due to the acceleration of change, the high frequency of emerging skills and the low numbers of workers pre-trained with those emerging skills make these recruitment strategies much less viable. Instead, to bridge the skills gap, existing workers are required to either upskill, which is training in new skills to continue their role, or reskill, where they retrain for a different role. Job displacement is therefore much more normalised under Industry 4.0 work conditions. However, the risk of widespread job displacement under Industry 4.0, when workers are unable to overcome the skills gap, is structural unemployment brought about by technological change making job skills obsolete.[3] Given resource constraints are defined as Australia's premier barrier to change management and future workforce planning, creating access to upskilling or reskilling is an imperative for the new robot economy.

Snapshot — Skills: What's changed since 2018?

Strengths

- Both industry and the higher education and skills training sector (with support from key stakeholders) have reacted proactively to current and future skills shortage in the robotics field
- Governments are future proofing our workforce by introducing students to Industry 4.0 skills from an early age
- Australian universities have designed/redesigned Mechatronics engineering programs in response to demand from industry
- Funding is available to retain staff through skills development, industry and education institutions engaging in Industry 4.0 capabilities

Wins

- Company professional development for micro-credentials is increasing
- Increasing demand for both the professional and paraprofessional Industry 4.0 workforce with adoption of automation
- Vocational education models are evolving to include non-formal education, and access to online self-paced learning
- Mechatronics engineering has experienced growth of 600% over the past two decades

New opportunities

- As a result of COVID-19, the utility of Industry 4.0 relevant skills were tested across workplace, school, and government spaces
- Federal Government funding of $500m allows educators to deliver Industry 4.0 skills

Challenges

- Complex systemic barriers to upskilling and reskilling highlight the requirement for inclusive curriculum and access
- Limited professional development opportunities for educators, and gaps between the industry requirements and the outcomes delivered by education institutions are a concern
- A lack of preparedness for vocational education needs arising from Industry 4.0, and the education facilities inability to adapt fast enough, makes it difficult to align the strategies of innovation and the workplace

Realistic 5—year goals

- Gather data on the key metrics of Industry 4.0 training to provide cross national uniform program and policy guidance that is evidence based
- AISC revision of the IRC structures to better integrate small to medium enterprise employers into a VET development consortium
- Delivery of free, open access micro-credentials on entry level Industry 4.0 topics, and inclusion in a national online library of industry-recognised micro-credentials
- A campaign for stronger inclusion of soft skills in the curriculum and key performance indicators
- Micro-credential courses for the workplace, emphasising common Industry 4.0 technician or paraprofessional level technology management skills, and inclusion in a national online library of industry-recognised micro-credentials

15.2 Skills in the robotics industry today

Technology is the driving force of Industry 4.0, so it is understandable that tech absorbs our focus, particularly during early stages of innovation. However, overlooking how we integrate technology, people, and processes is to the detriment of achieving an Industry 4.0 capable workforce. As we support workers involved in digital transformation, defining their individual roles and responsibilities, skill gaps emerge.

To systematically address the wide range of training and support required to successfully upskill a population, engagement from key stakeholders is necessary. Here, key stakeholders are defined as government policy makers, educators, industry leaders and employers, social services, unions, advocates, and the individual workers themselves.

The national skills deficit is predicted to reach 29 million by 2030, with poor digital literacy a prominent concern.[5] Robotics applications in Australian industry sectors are expected to become ubiquitous in the coming five to ten years, raising the question of how these robots will be designed, fabricated, programmed, run, and serviced. Answering this question with a future focus, a number of Australian universities have either redesigned their Mechatronics engineering programs or developed new Mechatronics engineering programs in the past few years.[6] This has happened due to the continuous demand from the industry to train new graduates with robotics and automation skills to aim for the future industrial environments. Several TAFEs are also upgrading their courses on industrial automation and control to fulfil the industry demand.

Not only the industry and skills training sectors, the government also has a good understanding of the current and future skills shortage in the robotics field. This is clearly visible from the amount of funding allocated by both federal and state government budgets into improving STEM education and coding in schools, and improving tertiary and vocational study opportunities directly related to robotics and industrial automation fields. These are clear indications that the stakeholders are aware of the skills gap resulting from the current education and training model in Australia and the urgent need for addressing the issue. Both industry and the higher education and skills training sector have reacted proactively with the support from government as well.

> Robotics applications in Australian industry sectors are expected to become ubiquitous in the coming five to ten years, raising the question of how these robots will be designed, fabricated, programmed, run, and serviced.

Primary and secondary education

The current Australian school curriculum recommends Digital Technologies be introduced in grade 2 and embedded into the curriculum from grades 3 to 10 progressively. The Federal Government has allocated more than $64m funding for early learning and school STEM, with funding for educating all Australians in digital literacy and STEM totalling $1.1b under the National Innovation and Science Agenda.[7]

State governments also funded the same objective to boost up the essential skills of the future robotics and industrial automation workforce. In Queensland the 2020 Premier's Coding Challenge aimed to promote project based learning in STEM across scholastic grades 3 to 10.[8] In Victoria, there is focus on increasing the participation of school students in STEM, and community awareness of STEM has been identified as one of the eight top priorities.[9]

Upskilling leads to increased innovation

There is a mutual correlation evident between innovation and upskilling, such that increasing outcomes for one variable stimulates the other.[10] Reinforcing innovation as a growth factor in Australian industry success cases has, most notably, been investment in training and development initiatives.[11] Additionally, the $1.5b Modern Manufacturing Strategy aims to drive economic growth, investing in higher value jobs and improving the resilience of supply chains following the COVID-19 pandemic. There is also a continuation of the Manufacturing Modernisation Fund, co-funding $52.8m to invest in transformative and innovative technologies and processes. Beyond upgrading SME manufacturing processes, the fund intends to grow a skilled workforce inside small business.

Engaging with supported workplace skills programs means that workers can develop technical as well as soft skills, such as problem solving and communication, to optimise equipment usage, whilst improving the resilience and cognitive flexibility needed to adapt to ongoing technology-driven innovation.[3] With funding available to retrain staff through skills development, industry and education institutions engaging in Industry 4.0 capabilities can set targets to balance performance and innovation, driving our national economy.

Immediate need for short courses in Industry 4.0 relevant skill sets

It has been estimated that only one third of Australian employees have the necessary entry-level skills for Industry 4.0 technology integration in the workplace, with another third allocated as unskilled, and the remaining third categorised as having an unknown skill level.[12] This is on par with global estimates indicating 54% of the workforce will need reskilling between 2018 and 2022.[2]

For reskilling, training defined as short courses of less than one month appears appropriate for 13% of the workforce. In comparison, courses of less than six months duration are cumulatively appropriate for 35% of the workforce, whilst courses of six months or longer for 19%. With regards to upskilling, "shop floor" industry data is limited due to the ad hoc nature of on-the-job training. It is forecast that upskilling short courses of less than one month duration on relevant topics such as digital literacy, cybersecurity, and other Industry 4.0 specific skills would benefit the majority of employees (estimated over 50%). The strong benefits for employees to access upskilling short courses are time and cost savings, thanks to minimal downtime due to training.[2] There is a huge opportunity for the Australian VET and non-formal education sector to capture a training market where conventional long term courses may not fulfil the requirements.

To meet this acknowledged need, the Federal Government is funding reform of the vocational education sector, with $500m to upskill or reskill 340,000 school leavers and unemployed persons nationally. There is a clear opportunity for formal and in-formal educators to capitalise on their potential to deliver Industry 4.0 skills, but for most educators this requires a pivot in training focus. A secondary opportunity is to train the trainers, with their upskilling an investment – role modelling the lifelong learning model.

> It has been estimated that only one third of Australian employees have the necessary entry-level skills for Industry 4.0 technology integration in the workplace.

Barriers to upskilling

As noted, a key recommendation from the first Robotics Roadmap was to, "equip all Australians with Industry 4.0 relevant skills".[1] Barriers to upskilling and reskilling the populace fall into a number of categories: situational, institutional, dispositional, academic, employment training opportunities, and barriers based on culture. Whilst the COVID-19 pandemic response has rapidly brought forward change management practices in educational and professional settings, the reality is that technology-driven change does not meaningfully address complex systemic barriers or encourage the lifelong learning approach that Australians who face such barriers need to find equity in education and employment.

As outlined in the Organisation for Economic Cooperation and Development report,[13] the underlying ethical question is how we build curriculum and access that is inclusive, with sustainable development for all. This is a shared responsibility – a challenge for government policy makers, educators, industry, unions, social services, advocates, and it also holds individuals accountable to partner in the process of lifelong learning.

Demographic trends require careful analysis, but to speak in broad terms socially disadvantaged groups face the greatest barriers. In Australia these groups include Aboriginal and Torres Strait Islander peoples, regional Australians, older job seekers, people living with a disability or mental illness, refugees, single parents, and women.[14] Such groups are vulnerable to poverty and not addressing the widening skills gap worsens barriers to employment equity. Equipment and baseline skills, such as digital literacy, are needed before mainstream opportunities can become viable for disadvantaged students.

A related challenge to national employment equity is the rise of robots in the Australian workplace, which is negatively impacting employment in emerging economies. The International Labour Office found developed nations are re-shoring work, where production is brought back to the developed nation, as it is more profitable to do so under Industry 4.0 than off-shoring to low-cost developing countries.[15] Re-shoring is thus forecasted to present issues for Australian international trade relations with developing nations.

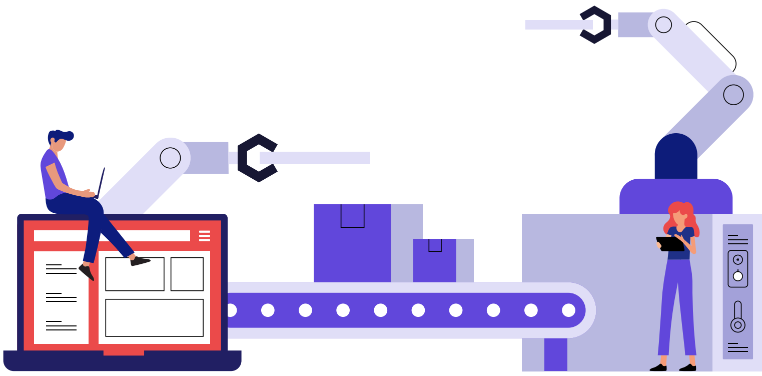
15.3 The future of skills in robotics

The increasing installation of industrial robots in workplaces by Australian manufacturing and service industries follows trends across the US, Japan, and China. By 2030 it is estimated 20 million existing jobs will be performed by robots globally.[16] However, humans won't be jobless if our existing workforce is trained to work for and with robots.[4] This opportunity creates a new professional and paraprofessional workforce domain, reinforcing why Australia needs to align vocational education and training with Industry 4.0 capabilities.

To illustrate, the mining and resource industry is a leading sector in employing autonomous vehicles in transportation. As of February 2020, Australia leads the world by operating 369 autonomous haul trucks out of the global total of 459 with a year-on-year increase of 32% compared to 2019.[17] These trucks are sophisticated computer controlled robotic vehicles operated and maintained by a specially trained workforce. This example demonstrates that with resources, market need, and applied vocational training Industry 4.0 career pathways can transform Australia into a global leader.

Agriculture increasingly deploys robotic applications to fill gaps in labour availability. For example, like many operators in the food supply chain, mango farms heavily depend on seasonal workers, such as backpackers. There is a clear need to develop fruit picking robots, which involves highly specialised skills of image processing, embedded and mechatronics systems design, and agronomics. The world-first mango-picking robot is the result of university collaboration with industry.[18] Here, mechatronics can meaningfully solve a labour crisis for producers, whilst substantially improving on the job safety in ongoing and adapted agricultural roles, and open agribusiness to the robot service industry.

These industry examples demonstrate the increasing demand for both the professional and paraprofessional Industry 4.0 workforce with adoption of automation. Reshaping the labour market means harvesting the multiple benefits of robotic labour, such as productivity increases and reduction in costs and wastage, whilst moving human capital into parallel or newly developing domains of work.



Evolution of vocational education models, including micro-credentials

Formal education systems can no longer independently prepare graduates for work, given the range and rapidity of emerging skills gaps across industry roles. The challenges of formal qualifications include time to completion, unacknowledged partial completion, limited recognition of prior learning, and unclear learning outcomes for employers. Vocational education models in Australia are therefore evolving to include non-formal education.[19, 20] Designed either as an alternative or complementary system to formal education, non-formal education does not necessarily provide a continuous path structure. It can often be sourced online, as workshops or short courses, and may be industry-recognised but not accredited. Non-formal education models reduce barriers to upskilling and reskilling. There is equity in the right to access non-formal education across demographics such as age, location, language, level of education, and gender. Non-formal education contributes to programmes on technical and soft skills, as well as offering support for sociocultural development.[21]

Formal education providers including universities and TAFE are increasingly offering micro-credentials with government support. Micro-credentials are content-targeted short courses offered as a complement to traditional coursework and have been forwarded as the solution to emerging skills preparation.[19, 13] Recently topics to upskill current workers in the robot economy include AI, cybersecurity, IoT, cloud computing, blockchain, robotics and big data. Unlike a university degree or vocational qualification, micro-credentials are agile training solutions that can take as little as one hour to complete. They can be aggregated to build larger and more recognisable credentials, such as robotics service technician.[20]

Easy access to digital resources and self-paced learning environments through online micro-credentials offer individuals the ability to take control of their learning experiences and upskill themselves.[22] Furthermore, embedding micro-credentials into company professional development has enabled employers to upskill a cohort of experienced, university qualified workers. For example, Telstra partnered with the University of Technology Sydney to deliver a suite of micro-credentials for their staff and successfully upskilled on data analysis, advanced data analytics, and machine learning – minimally disrupting work whilst enhancing team collaboration and cohesion.[23] Queensland's Department of Employment, Small Business and Training (DESBT) is implementing a micro-credentialing pilot program over three years (2019–22) to support adoption of workplace innovation and improve productivity.

The rise of mechatronics engineering courses

With fewer than ten accredited courses available cross nationally prior to 2000, the relatively new multidisciplinary field of mechatronics engineering has experienced massive growth over the past two decades – showing a rise of over 600%.[6] Originally incorporating both mechanical and electronics systems, mechatronics also covers robotics, communication, systems, control, and product engineering. Broadly, this branch of engineering aims to generate design solutions unifying the subfields, which is how advanced technology is developed in real terms. Given the rate of new graduates, paired with clear industry and community need during the rollout of Industry 4.0, Australian tertiary educators have successfully met the market – adapting to educate this emerging labour force.

Appendix C summarises the accredited mechatronics courses currently on offer across Australia's university and TAFE programming.[6]

Transition to online technologies

COVID-19 accelerated the need for the adoption of new workplace practices/technology due to rapidly changing work conditions. Both physical distancing laws and the ability to work from home saw a range of virtual platforms offset the inability to be in person at meetings, network events, and classrooms. Video conferencing apps saw a surge in use, online interactional spaces such as visual collaboration software and task management tools like JIRA and Miro also rapidly entered the common home office tool kit, and training options using virtual and augmented reality technology entered professional and education facilities at higher rates of adoption than previous. Clearly, barriers to Industry 4.0 adoption that might have continued unchallenged given the noted pre-pandemic complacency are lessened due to immediate operational needs when working under pandemic guidelines.[12, 24]

COVID-19 provided the opportunity for Australians to test the utility of Industry 4.0 relevant skills across workplace, school, and government spaces. Wage subsidies, such as the Job Keeper valued at $130b, aimed to facilitate the retention of staff during the pandemic and helped offset immediate costs of on-the-job training for employers.[25] Post-pandemic, decreasing investment in the technology that supports agile workplace practices is unlikely, given the demonstrated benefits seen by organisations and staff who overcame the hurdle of COVID-19 restrictions.[16]

Australia achieved a "new normal", in less than twelve months, defined by agility and adaptation to technological-driven change. Given that disruption from rapid technological change is standard for Industry 4.0 workplaces, this attitude of resilience and focus on upskilling is predicted to strongly benefit Australians as we continue on the trajectory of an industrial revolution.

Industry employers as vocational education collaborators

There is an apparent lack of preparedness for vocational education needs arising from Industry 4.0 in Australia, undermining workforce strategy alignment with innovation strategy.[3] Key to successfully disrupting education is resource constraints. Professional development opportunities for educators are limited compared to the new skill sets required. Thus, in-class learning may more reflect what the teacher understands than what the students need for industry roles and activities,[13] and gaps exist between the skills needed by industry and the general outcomes delivered by education institutions.

Given emerging skills shortages, there is a fundamental challenge of whether formal and informal education facilities can adapt fast enough to the needs of people employed, or seeking employment, in the new and transitioning job roles. The "Connecting Education to the Real World" report[26] addressed this challenge by recommending the teaching profession be strengthened, both in teacher quality and respect for educators, as well as harnessing technology to supplement, not replace, high quality educators.[26] This report also advocated for vocational education and training (VET) systems to foster agile and reciprocal partnerships with their respective industry employers, not just industry leaders.

SME owners have a more immediate relationship with staff and often work in the business themselves, meaning they are far more closely attuned to what training is needed. SMEs seek VET programs that: are agile, accessible, and meet their immediate needs; conform to policy, legislation, workplace health and safety requirements; and minimally affect work hours.[27]

The Australian Industry and Skills Committee (AISC) have actioned a range of Industry Reference Committees (IRC), which operate as the formal channels to advise on, develop, and review industry-specific skills training packages. IRC personnel are industry leaders, peak bodies, and unions. Whilst small business is acknowledged, true representation is debatable due to SME employers having high diversity with low availability.

There is an underlying challenge for the AISC to operationalise SME inclusion within the AISC ethical practice guidelines to form an agile, responsive, timely VET system that meets the rapidly evolving on-the-job requirements. After all, Australian SMEs may fund a fair share of the development and running costs of highly specialised job-focused short courses.

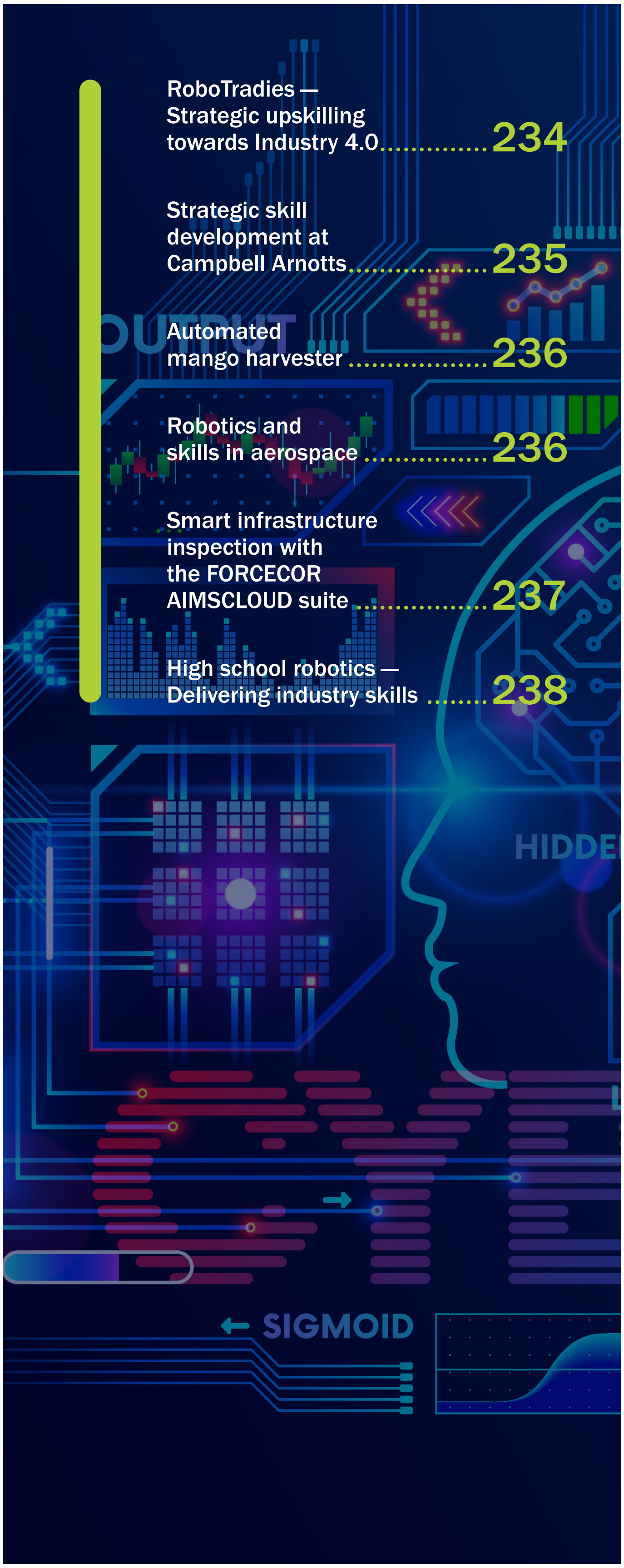
15.4 Main findings for skills in the robotics industry

Equipping the Australian population with Industry 4.0 skills is increasingly a national priority. Technology-driven changes are already occurring in classrooms and workplaces across the country, but these can appear reactive and ad hoc rather than proactive strategies. Frameworks to develop inclusive workforce-critical digital capabilities, technical skill sets, social and emotional skills, as well as adaptability and resilience require national leadership. Thus, strengthening our economy to withstand future disruptions requires government, education, and industry stakeholders to collaborate on workforce skills training and support.

Long term goals for Industry 4.0 vocational education may best define Australia's purpose in engaging learners, set financial expenditure targets, determine appropriate return on investment, ultimately demonstrating how VET assists economic growth. For the purpose of this publication, we have set five specific goals that we consider can be reasonably accomplished in the next five years – and against which Australia can measure its progress, and determine areas for improvement, to meet long term goals:

1. Delivery of free, open access micro-credentials on entry level Industry 4.0 topics, such as digital literacy, available on an ongoing basis. Inclusion in a national online library of industry-recognised micro-credentials.
2. Development of micro-credential courses for the workplace based on industry need, emphasising common Industry 4.0 technician or paraprofessional level tech management skills, e.g., cobot programming, using an internet of things dashboard. Inclusion in a national online library of industry-recognised micro-credentials.
3. AISC revision of the IRC structures to better integrate small to medium enterprise employers into a VET development consortium. The underlying goal is an agile and timely system with capacity to quickly address common emerging skill gaps for workplace training, potentially linked to micro-credentials course development.
4. Gather data on the key metrics of Industry 4.0 training such as type, engagement, utility, rate of completion to provide cross national uniform program and policy guidance that is evidence based. Informed decisions from this data can be applied in government (e.g. resource allocation), education (e.g. professional development for adult educators), and industry (e.g. encourage businesses to become proactive about upskilling, such as scout-shape-shift media campaigns).
5. A campaign for stronger inclusion of soft skills in the curriculum and key performance indicators. According to the World Economic Forum,[2] skills to focus on are: complex problem solving, creativity, people management, critical thinking, coordinating with others, emotional intelligence, judgement and decision making, service orientation, negotiation, and cognitive flexibility.

Case studies



RoboTradies — Strategic upskilling towards Industry 4.0

PTE Hydraulics, a specialist manufacturer making strong moves towards an Industry 4.0 smart factory, is aware that project success is built on teamwork, not machines alone, and that operators need support and training. PTE Hydraulics has engaged the industrial psychology program, RoboTradies, which runs in parallel with both design/build and integration of new robotic cells and IOT.

The aim is machine usage, but also clearer communication across levels of staff, with minimal time off tools. RoboTradies engages staff with individual assessment, job analysis and support, followed by tailored training and reinforcement of learning for the manufacturing teams over the course of the project. The immediate outcome for PTE Hydraulics is improved performance with the robotic cells and IOT, but long term the goal is to run a SME smart factory that engages and retains all staff.

Strategic upskilling, that is planned and paired with a project's technology roll out, shows the road to successful job displacement. Training and support opens new work profiles for existing staff. For PTE Hydraulics machinery upgrade projects are not a standalone investment, but part of a schedule of works, where investment in staff technical and soft skills form stepping stones for professional development. This is a strong case outlining how Industry 4.0 skill gaps lead to upskilling and then job displacement that positively impacts the workforce.

Large scale metalworking equipment requires trained staff; automation for smart factories are providing the next generation of skills to metal fabricators. Image courtesy of Freelance Robotics.

Strategic skill development at Campbell Arnotts

Operating in Australia since 1962, Campbell Arnotts now employs more than 2,000 persons nationally. Underlying this fast-moving consumer goods company's successful expansion into Industry 4.0 food processing is the understanding that employees working across the business, from factory floor to management, need strategic skill development to ensure Campbell Arnott's digital transformation. Automation is optimising factory operations.

Since 2015 Campbell Arnott's have invested in innovative infrastructure, including $500m on upgrading existing plant and an additional $3m on the Culinary and Innovation Centre in Sydney, to elevate the food processing standards across the Asia-Pacific region. From production scheduling, inventory management, order fulfilment, equipment operations and maintenance, through to machine learning and robotics, Campbell Arnott employees benefit from in house vocational training to improve decision making and outcomes across every step of the supply chain.

Robotic Palletising and AGV for Sydney Warehouse. Photo: William Phan.

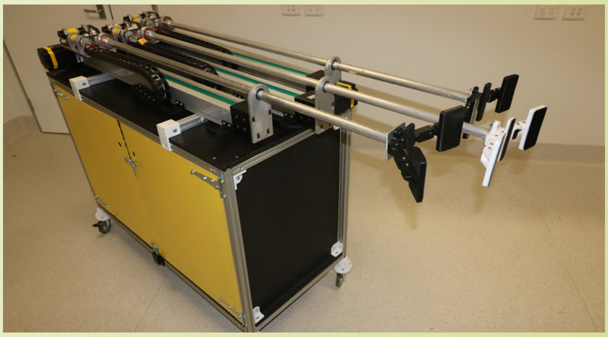
Automated mango harvester

CQU University developed an automated mango harvesting unit which is capable of detecting and locating mango through intelligent image processing and then moving and activating harvesting arms (manipulators and end effectors) on a mobile platform.

This project is industry funded, including support of Horticulture Innovation Australia, with industry experts, university researchers and students working on different aspects. Prof. Kerry Walsh is the project's team leader, with the customised deep learning machine vision algorithms developed by Dr. Anand Koirala and Dr. Zhenglin Wang.

The mango picking manipulator and the end effector was implemented by a final year engineering student Ruan Nortje as his final year thesis project under supervision of Assoc. Prof. Preethichandra. This activity provided an excellent opportunity to apply engineering knowledge and skills gained through the undergraduate course, producing a good example of university training involving interaction with industry and academic experts in robotics and automation field for future industrial applications.

Automated mango picking system. Image courtesy of Prof. Kerry Walsh.



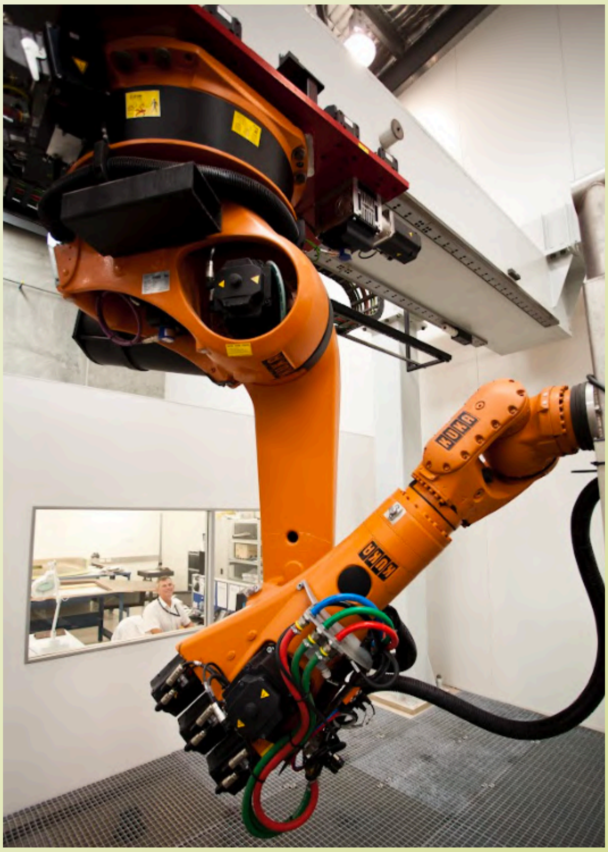
Robotics and skills in aerospace

The aerospace industry, across Commercial and Defence, is facing a general shortage of highly skilled personnel in the Avionics/ Systems/Software knowledge areas. Qualifications in these disciplines are directly transferable to emerging technologies such as robotics, machine learning, data analytics and addictive manufacturing, which are set to revolutionise the aerospace industry.

While the aerospace industry needs expertise and skills on previous and current generation technology, it is leaning forward to embrace these emerging technology trends and preparing the workforce of the future.

To meet this challenge, Airbus is actively working with Queensland schools through the Queensland Government's Aerospace Gateway to Industry Schools Program (AGISP), and with Aviation High through the Federal Government's Pathways in Technologies Program (P-TECH), which is focusing on data analytics. Work experience, work place tours, mentoring and challenging project activities are provided by Airbus to students with a passion for aerospace.

Airbus is also working with a number of universities for work experience opportunities and with a number of universities and innovative Small to Medium-size companies in the area of research and development.



Robots offer large payloads with the pinpoint accuracy required for successful project delivery in the aerospace industry. Image courtesy of Freelance Robotics.

Smart infrastructure inspection with the FORCECOR AIMSCLOUD suite

Smart city solutions provide digital insights into our urban and rural infrastructure to better manage these assets in both the short and long term. FORCECOR highlight the positive impact of infrastructure service robots through the deployment of their AIMSCLOUD system, which uses robotic platforms linked to the cloud for software interface.

AIMSCLOUD/Structures is a software system tailor made for the management of bridges, large culverts and other structures. It stores inventory, condition status, maintenance schedules, Timber Drill reporting and Scour Sounding information. The system analyses trend information and forecasts future inspection requirements according to the relevant standards.

AIMSCLOUD/Drainage custom stormwater drainage inspection software features GIS/GPS capabilities to record and log defects and maintenance actions for all types of stormwater infrastructure. The system is a graphical connection to the AIMSCLOUD – POLE hardware. The hardware comprises up to 4mp imagery with 45x Optical zoom. Location information is recorded via RTK GPS with up to a 20mm accuracy. All information is recorded wirelessly to the SIM DRAINAGE system for graphical display, condition information, and report generation.

In addition to providing periodic inspections and asset management services, AIMSCLOUD has been operational across Moreton Bay Regional Council as a permanent smart city initiative since 2020, with ongoing Council investment expanding the smart system due to its ease of use and success with Council operations and planning.

Image courtesy of Mark de Hayr at Forcecor.

High school robotics — Delivering industry skills

The Centre of Excellence in Automation and Robotics at Alexandra Hills State High School is delivering dynamic and innovative programs that develop industry-driven skills and equip students to enter work roles not yet fully defined. A unique approach to drone (UAV) education is one example of the Centre of Excellence moving beyond the standard curriculum.

In addition to completing a Certificate III in Aviation (Remote Pilot - Visual Line of Sight), with the opportunity to obtain commercial UAV licencing (CASA RePL), students solve real-world problems - completing infrastructure inspections and wildlife monitoring using visual and thermal imaging, using industry-standard software for drone-based landform surface mapping and using aquatic drones (ROVs).

The Centre of Excellence has engaged with scientific organisations and technology companies (e.g. Australian Centre for Robotic Vision, Haddington Dynamics, BIA5, Verterra and GreenBio) to develop industry-driven projects including: advanced manufacturing with 3D printing and laser technologies, programming collaborative robots, design of fire-fighting robotic vehicles and vertical farming with automated irrigation and robotic harvesting. In 2020, Alexandra Hills State High School was also selected as a founding member of the ICT Gateway to Industry Schools Program (Queensland) and is working with primary industry partner Freelance Robotics to support student pathways into university or the workplace with Industry 4.0 technology.

Access to an industry standard Drone (UAV) Licence course - the Certificate III Remote Pilot Licence, followed by Civil Aviation Safety Authority (CASA) Remote Pilot Licence and Aeronautical Radio Operator Certificate (via RTO 32292) - readies the students at AHSHS for Industry 4 employment. Image courtesy of Freelance Robotics.

Contributors

This chapter was based on a virtual workshop held on 29 May 2020 with contributions from the individuals listed below:

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Footnotes

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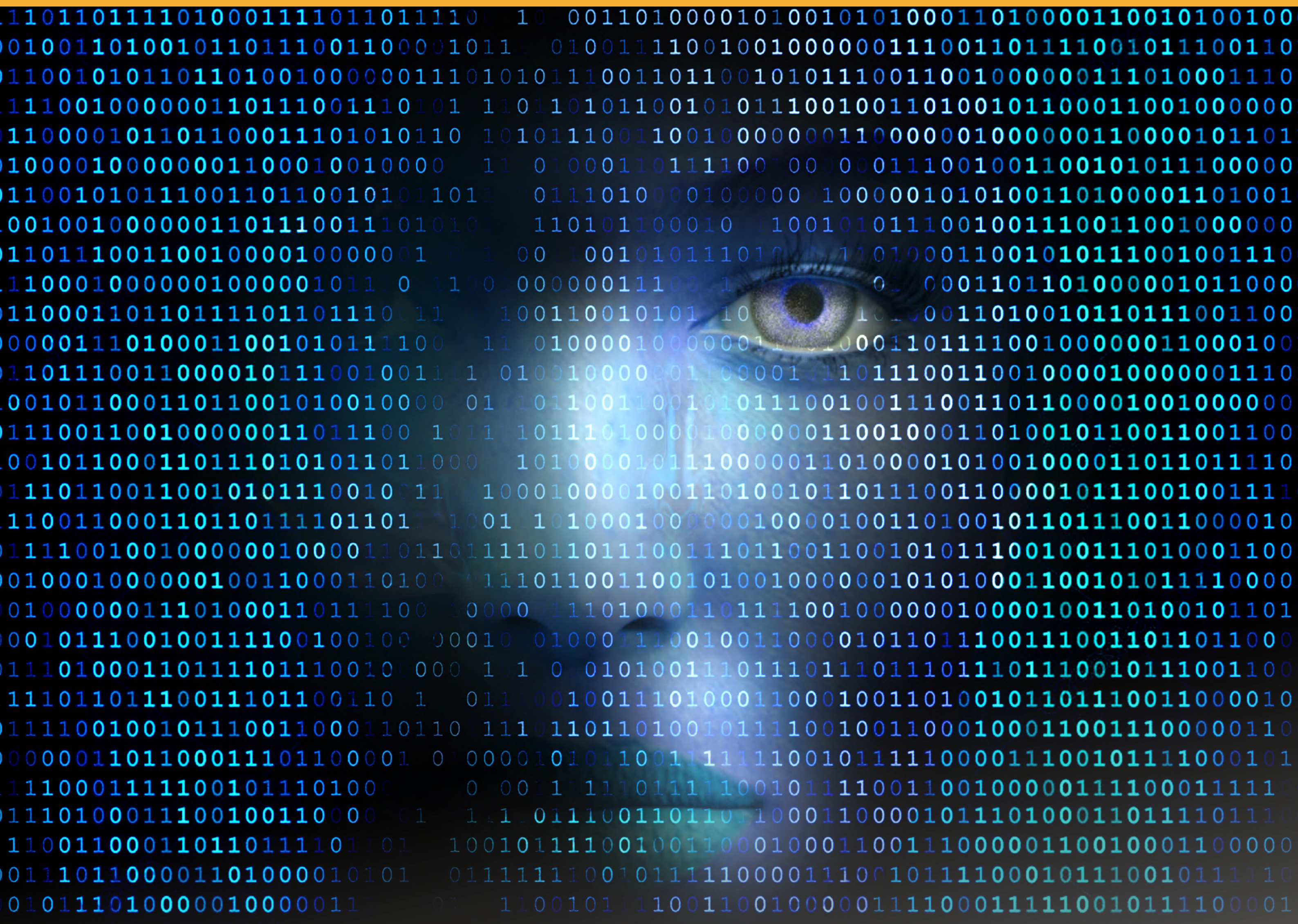
Appendices



Appendix A

Standard and/or project under the direct responsibility of iso/tc 299 secretariat (Standardization in the field of robotics, excluding toys and military applications)[1]

ISO/WD 5124 Robotics— Services provided by service robots — Safety management systems requirements

ISO 8373:2012 Robots and robotic devices — Vocabulary

ISO/DIS 8373 Robotics — Vocabulary

ISO 9283:1998 Manipulating industrial robots — Performance criteria and related test methods

ISO 9409-1:2004 Manipulating industrial robots — Mechanical interfaces — Part 1: Plates

ISO 9409-2:2002 Manipulating industrial robots — Mechanical interfaces — Part 2: Shafts

ISO 9787:2013 Robots and robotic devices — Coordinate systems and motion nomenclatures

ISO 9946:1999 Manipulating industrial robots — Presentation of characteristics

ISO 10218-1:2011 Robots and robotic devices — Safety requirements for industrial robots — Part 1: Robots

ISO/DIS 10218-1 Robotics — Safety requirements for robot systems in an industrial environment — Part 1: Robots

ISO 10218-2:2011 Robots and robotic devices — Safety requirements for industrial robots — Part 2: Robot systems and integration

ISO/CD 10218-2 Robotics — Safety requirements for robotics in an industrial environment — Part 2: Robot systems and integration

ISO 11593:1996 Manipulating industrial robots — Automatic end effector exchange systems — Vocabulary and presentation of characteristics

ISO/DIS 11593 Robots for industrial environments — Automatic end effector exchange systems — Vocabulary and presentation of characteristics

ISO/TR 13309:1995 Manipulating industrial robots — Informative guide on test equipment and metrology methods of operation for robot performance evaluation in accordance with ISO 9283

ISO 13482:2014 Robots and robotic devices — Safety requirements for personal care robots

ISO 14539:2000 Manipulating industrial robots — Object handling with grasp-type grippers — Vocabulary and presentation of characteristics

ISO/TS 15066:2016 Robots and robotic devices — Collaborative robots

ISO 18646-1:2016 Robotics — Performance criteria and related test methods for service robots — Part 1: Locomotion for wheeled robots

ISO 18646-2:2019 Robotics — Performance criteria and related test methods for service robots — Part 2: Navigation

ISO/DIS 18646-3 Robotics — Performance criteria and related test methods for service robots — Part 3: Manipulation

ISO/DIS 18646-4 Robotics — Performance criteria and related test methods for service robots — Part 4: Lower-back support robots

ISO 19649:2017 Mobile robots — Vocabulary

ISO/TR 20218-1:2018 Robotics — Safety design for industrial robot systems — Part 1: End-effectors

ISO/TR 20218-2:2017 Robotics — Safety design for industrial robot systems — Part 2: Manual load/unload stations

ISO/FDIS 22166-1 Robotics — Modularity for service robots — Part 1: General requirements

ISO/TR 23482-1:2020 Robotics — Application of ISO 13482 — Part 1: Safety-related test methods

ISO/TR 23482-2:2019 Robotics — Application of ISO 13482 — Part 2: Application guidelines

IEC/TR 60601-4-1:2017 Medical electrical equipment — Part 4-1: Guidance and interpretation — Medical electrical equipment and medical electrical systems employing a degree of autonomy

IEC 80601-2-77:2019 Medical electrical equipment — Part 2-77: Particular requirements for the basic safety and essential performance of robotically assisted surgical equipment

IEC 80601-2-78:2019 Medical electrical equipment — Part 2-78: Particular requirements for basic safety and essential performance of medical robots for rehabilitation, assessment, compensation or alleviation

Appendix B

Australia's AI ethics principles[2]

1 | **Human, social and environmental wellbeing:** Throughout their lifecycle, AI systems should benefit individuals, society and the environment.

2 | **Human-centred values:** Throughout their lifecycle, AI systems should respect human rights, diversity, and the autonomy of individuals.

3 | **Fairness:** Throughout their lifecycle, AI systems should be inclusive and accessible, and should not involve or result in unfair discrimination against individuals, communities or groups.

4 | **Privacy protection and security:** Throughout their lifecycle, AI systems should respect and uphold privacy rights and data protection, and ensure the security of data.

5 | **Reliability and safety:** Throughout their lifecycle, AI systems should reliably operate in accordance with their intended purpose.

6 | **Transparency and explainability:** There should be transparency and responsible disclosure to ensure people know when they are being significantly impacted by an AI system, and can find out when an AI system is engaging with them.

7 | **Contestability:** When an AI system significantly impacts a person, community, group or environment, there should be a timely process to allow people to challenge the use or output of the AI system.

8 | **Accountability:** Those responsible for the different phases of the AI system lifecycle should be identifiable and accountable for the outcomes of the AI systems, and human oversight of AI systems should be enabled.

Appendix C

Accredited Mechatronics Courses offered by the Australian Tertiary Sector, 2020.

Institution	Course
Australian National University	Bachelor of Engineering (Honours) (Mechatronic Systems) Bachelor of Engineering (Research and Development) (Honours) (Mechatronic Systems) Master of Engineering in Mechatronics
Central Queensland University	Bachelor of Engineering (Honours) (Mechatronics) Bachelor of Engineering (Honours) (Mechatronics) and Diploma of Professional Practice (Co-op Engineering)
Chisholm Institute of TAFE	Bachelor of Engineering Technology (Mechatronics) Advanced Diploma of Engineering Technology (National Code No 21622VIC) in Robotics and Mechatronics
Curtin University	Bachelor of Engineering (Honours) (Mechatronic Engineering)
Deakin University	Bachelor of Mechatronics Engineering (Honours)
Edith Cowan University	Bachelor of Engineering (Mechatronics) Honours Master of Engineering (Mechatronics Engineering)
Federation University	Diploma of Engineering – Technical Bachelor of Mechatronic Systems Engineering (Honours)
Flinders University	Bachelor of Engineering – Robotics (Honours)
Griffith University	Bachelor of Intelligent Digital Technologies - IoT and Robotics
Macquarie University	Bachelor of Engineering (Honours), with a major in Mechatronic Engineering
Monash University	Bachelor of Robotics and Mechatronics Engineering (Honours)
Queensland University of Technology	Bachelor of Engineering (Mechatronics) Bachelor of Engineering (Honours) (Mechatronics)
RMIT University	Bachelor of Engineering (Advanced Manufacturing and Mechatronics) (Honours) dual degree option Business Master of Engineering (Robotics and Mechatronics Engineering) Associate Degree in Engineering Technology (Advanced Manufacturing and Mechatronics) Diploma of Applied Technologies
Swinburne University of Technology	Bachelor of Laws / Bachelor of Engineering (Honours) in Robotics and Mechatronics Bachelor of Computer Science in Robotics and Mechatronics Bachelor of Engineering (Robotics and Mechatronics) Advanced Diploma of Engineering Technology – Mechatronics Engineering Design
TAFE NSW	Diploma Of Engineering - Technical (Mechatronics)
TAFE QLD	Certificate IV in Industrial Automation and Control
TAFE South West	Certificate II in Engineering Studies
TAFE WA	Integrated Technologies (Robotics Control Systems) - 22519VIC
University of Adelaide	Master of Engineering (Mechatronic) Graduate Diploma in Engineering (Mechatronic)

continued overleaf >

Appendix C — cont.

University of Canberra	Bachelor of Engineering (Honours) – Major in Robotics and Artificial Intelligence
The University of Melbourne	Master of Engineering (Mechatronics)
University of Newcastle	Bachelor of Mechatronics Engineering (Honours) Combined degree Bachelor of Mechanical Engineering (Honours) with Bachelor of Mechatronics Engineering (Honours) Combined degree Bachelor of Mechatronics Engineering (Honours) with Bachelor of Electrical and Electronic Engineering (Honours) Master of Professional Engineering (Mechatronics)
UNSW Australia	Bachelor of Engineering (Honours) (Mechatronic Engineering)
UNSW Global	Diploma In Engineering - Mechatronic Engineering
University of Queensland	Bachelor of Engineering (Honours) (Mechatronic Engineering) Bachelor of Engineering (Honours) and Master of Engineering (Mechatronic Engineering)
University of South Australia	Bachelor of Engineering (Honours) (Electrical and Mechatronic) Bachelor of Engineering (Honours) (Mechanical and Mechatronic) Bachelor of Engineering (Honours) (Mechatronic)
University of Southern Queensland	Bachelor of Engineering (Honours) (Mechatronic Engineering)
University of Sunshine Coast	Bachelor of Engineering (Mechatronic) (Honours)
University of Sydney	Bachelor of Engineering Honours (Mechatronic) Bachelor of Engineering Honours (Mechatronic) (Space)
University of Technology Sydney	Bachelor of Engineering (Honours) in Mechanical and Mechatronic Engineering Bachelor of Engineering (Honours) in Mechatronic Engineering Bachelor of Engineering (Honours) in Mechanical and Mechatronic Engineering with Diploma in Professional Engineering Practice Bachelor of Engineering (Honours) in Mechatronic Engineering with Diploma in Professional Engineering Practice
University of Western Australia	Bachelor of Automation and Robotics
University of Wollongong	Bachelor of Engineering (Honours) (Mechatronic Engineering) Master of Engineering (Mechatronics Engineering)
Victoria University	Certificate IV in Industrial Automation and Control
Western Sydney Institute of TAFE	Advanced Diploma of Engineering (MEM60112) in Mechatronics
Western Sydney University	Bachelor of Engineering Advanced (Honours) - Robotics and Mechatronics Bachelor of Engineering (Honours) - Robotics and Mechatronics Bachelor of Engineering Science (Robotics and Mechatronics) Master of Engineering (Mechatronics)

Footnotes

1 https://www.iso.org/committee/5915511/x/catalogue/

2 https://www.industry.gov.au/data-and-publications/building-australias-artificial-intelligence-capability/ai-ethics-framework/ai-ethics-principles

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