A Robotics Roadmap for Australia 2018

AUSTRALIAN CENTRE FOR ROBOTIC VISION

This National Roadmap is brought to you by the **Australian Centre for Robotic Vision**, an ARC Centre of Excellence

We are a national research centre leading the world in the new discipline of robotic vision, applying computer vision to robotics. We are funded under the Australian Research Council's Centres of Excellence Program and have a responsibility to provide national leadership for the robotics community in Australia.

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Image courtesy of Woodside Energy

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

Image courtesy of ANU

Robotics in Australia will maintain our living standards, help protect the environment, provide services to remote communities, reduce healthcare costs, provide safer more fulfilling jobs, prepare the next generation for the future, encourage investment and reshore jobs back to Australia. The Australian Centre for Robotic Vision, an ARC Centre of Excellence, has partnered with industry, researchers and government agencies across the country to develop Australia's first robotics roadmap.

This document is structured to give an overview of robotics in Australia, an overview of the issues that greater take-up creates and then a sectoral breakdown of current activity and future outlook. Each chapter is informed by participation from industry. We highlight some of the bright spots – the applications of robotics across industries, which can be an exemplar for further progress. These case studies are drawn directly from real-life experiences. And we acknowledge two important and successful paths to innovation, the use of clusters and challenges to bring together complementary skills to solve problems and develop new technologies. They're worth pursuing.

Our national consultation process was modelled on Professor Henrik Christensen's successful US Robotics Roadmap, now in its 3rd Edition [USR16]. During late 2017 and early 2018 we held a series of workshops, in different capital cities, focussing on areas of economic significance to Australia. Robotic technologies can be deployed across all sectors, and each sector has distinctive requirements that we will explore in this roadmap. We concentrate on sectors where robotics technologies can have the greatest impact either by virtue of the sheer size of the sector, the scale of transformative effect of the technologies, or the opportunity to solve Australia's unique challenges.

Over the next decade a range of new technologies will see robots that are more tactile, more capable of interacting with their physical environments, more closely working with humans and more 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 and how we can achieve gains from them across all sectors of the Australian economy. Like any roadmap, it doesn't mandate direction. But it does show the start point and the possible end points through the range of journeys Australians and our industries can take. And there are many directions and many social and economic issues to consider if we are to advance.

Underpinning this document are five key principles

Jobs matter

A robotics industry will enhance economic competitiveness to create meaningful jobs and, with the right policy settings, help adapt existing ones

Time matters

The right use of robotics eliminates workplace routine, improves efficiency and allows workers to dedicate time to interesting and more fulfilling tasks

Safety is imperative

Robotics reduces the risk of workers being placed in hazardous situations

Remote communities need to be served

Automation helps provide better and more consistent services to remote areas difficult to serve

Certainty counts

Investment decisions need clarity of understanding. The roadmap offers the means to find that clarity as well as demonstrating the current and likely future state of robotics in Australia

INDUSTRY - We must develop new high-tech firms and a vibrant robotics industry in Australia if we are to maintain our standard of living

Robotic technologies are at the heart of the fourth industrial revolution (Industry 4.0) where the physical and digital worlds converge. The potential of these technologies and the wider digital revolution is highlighted in a range of recent Australian policy statements and analyses, in part because they offer both opportunities and risks

> The missing piece holding our nation back is in the knowledge and integration space.

for Australia. Global connectivity has reduced the tyranny of distance that kept us apart from the rest of the world, but also presents the challenge of global competition. Our continued standard of living depends on us improving our productivity 2.5% every year. This is impossible to achieve through labour productivity alone, which over the five years to 2015-16 remained at 1.8%.

The productivity gap can be narrowed by robotics and automation [PC17]. A recent report by AlphaBeta [ALB17] estimates that automation can boost Australia's productivity and national income by (up to) $AU2.2 trillion by 2030. This impact would result from improved health and safety, the development of new products and services, new types of jobs and new business models. It will also rely both on how we garner and, in some cases, take a lead on the explosion of technology which will drive robotics.

The boost to Australia's national income from robot-driven productivity gains through to 2030 are $AU1 trillion from accelerating the rate of automation and $AU1.2 trillion - from transitioning our workforce to higher skilled occupations [ALB17]. By 2025 automation in manufacturing could increase employment by 6% [ALB17] while workplace injuries are set to fall by 11% as dangerous manual tasks are automated [ALB17]. Wages for non-automatable work will be 20% higher and 62% of low-skilled workers will experience increased job satisfaction [ALB17]. Consumers also expect to see robots being used more, with 58% believing that robotics will have a positive impact on society [PwC17].

As noted in Australia 2030: Prosperity through innovation (the Innovation and Science Australia (ISA) 2030 plan), Australia is leading the world in research in cyber-physical systems, computer vision, field robotics, simulation and robotic vision - but as a nation we apply robots very little. Australia ranks 18th in the world in application of industrial robots, with 50% fewer firms engaged in automation compared to leading countries [IFRIR17 ALB17]. The missing piece holding our nation back is in the knowledge and integration space. Companies keen to adopt new technologies either do not have in-house staff to assist with these adoptions or are unable to find the integration partners that they need to successfully harness the benefits of robotics and automation.

We believe Australia has a unique opportunity to take a leading role in the development of robotic technologies and in the tech sector more generally. To demonstrate Australia's existing capability and to forecast future applications, this document provides recommendations on harnessing the new and emerging technologies being developed in Australia today.

EDUCATION - We can prepare the next generation for the jobs of the future and provide education and upskilling opportunities to equip all Australians with Industry 4.0 relevant skills

While the long-term benefits of transitioning to an Industry 4.0 robot-ready economy are clear - economic growth, wealth creation, job upskilling, diverse job opportunities - short-term dislocation will impact certain occupations across all industries.

> Consultations during the development of this roadmap and its recommendations repeatedly reinforced the need to be mindful of the disruptive potential of robotics technologies.

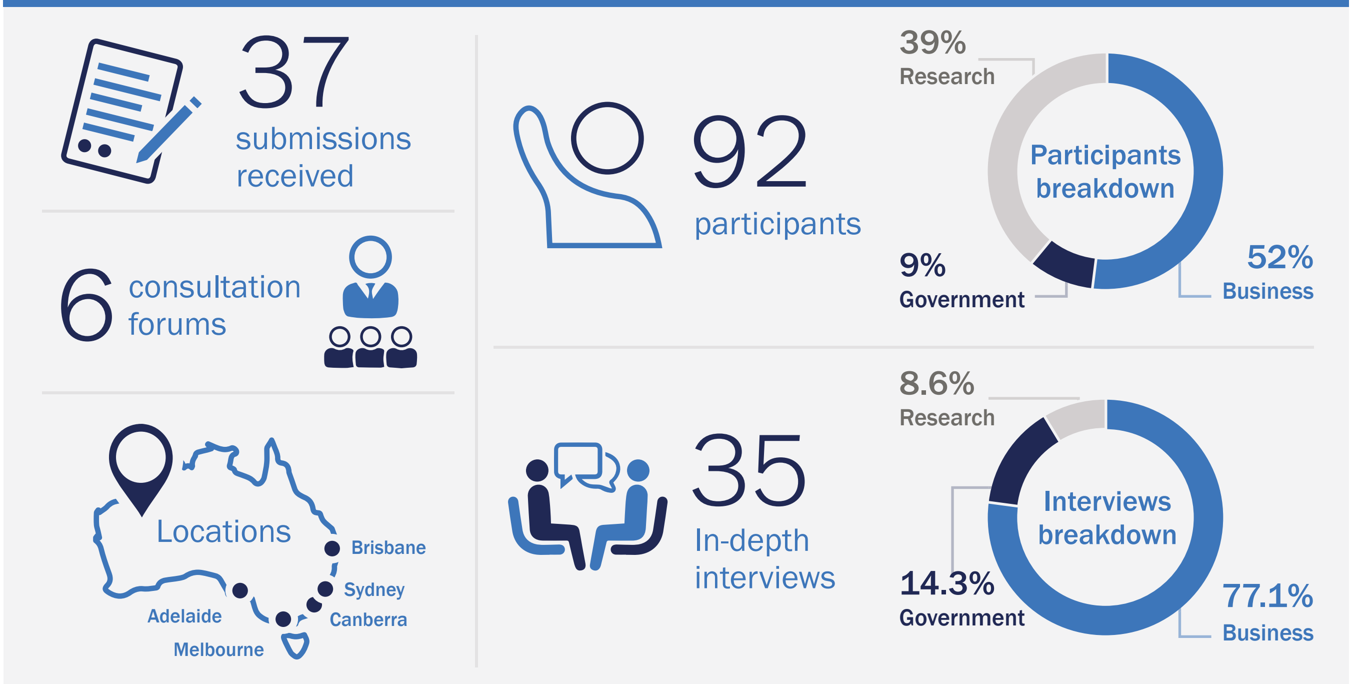
If robotic technologies follow the tenets of Moore's Law, then the cost of automation, robotics, and cognitive solutions are bound to continue falling over time, leading to a notable up-tick in adoption rates [DEL17]. One sobering statistic is that 58% of CEOs are considering automation as a way to reduce head count [PwC17]. At the same time that we embrace a robot-ready economy we must also find ways to retrain, and upskill, our workforce and to support occupations that are disrupted.

Consultations during the development of this roadmap repeatedly reinforced the need to be mindful of the disruptive potential of robotics technologies. As noted in recent Australian policy statements, including the ISA 2030 plan, these technologies have the potential to create new industries and new firms, leading to increased export opportunities, improved service delivery, and new jobs across a range of sectors - but there are already understandable concerns about their impact on existing industries and employers, and especially on their employees. These concerns are the focus of a number of the recommendations in this report, which are consistent with the findings of other recent statements – including the ISA 2030 plan, the 2016 National Research Infrastructure Roadmap, and the 2017 Australian Innovation System Report. This roadmap's recommendations can be addressed through a collaborative, multi-sector approach to the education, funding, and legislative and regulatory frameworks that underpin new industries, with a particular focus on skills and capability development - especially for those already in the workforce.

GOVERNMENT - We have the opportunity to become a testbed for robotics technology by leading the world in ethical, legal and standards frameworks

Australia is a great test-bed for robotics and automation with our vast land mass and low population density, where robots are ideally placed to take on many dirty, dull and dangerous tasks. Our unique

National consultation process



geography has led to the development of world-leading field robotics applications. In addition, many of Australia's regulatory regimes are exemplars for the rest of the world. This provides us with an opportunity to exploit these strengths by developing Australia as a test bed for new technologies taking advantage of our first mover advantage in many areas to develop a true robot economy to benefit Australia.

R&D - We can build national capability in robotics by forming research and technology clusters to develop existing talents and encourage new talent, technology and businesses

We have a significant store of talent in our robotics industry with research communities, small businesses and large corporations. When combined with the right investment, this ecosystem can build, and feed, an innovation pipeline that will realise new robotic vision products, services and businesses. Australia has an opportunity at all stages of the technology value chain, from design and build of robots through to integration and servicing of existing installations. All parts of this value chain need to be considered and supported for Australia to have a vibrant robotics industry that supports automation across all sectors of our economy.

Reducing Australia's reliance on imported technology, and know-how, to solve critical issues in training and integration are currently preventing many Australian companies from developing the new technologies required to sustain Australia's economic prosperity. We recommend expanding on Australia's core capabilities and deepening our talent pool with a concerted investment of energy and resources to develop and support Australia's fledgling tech sector through the development of technology clusters. As a country we are not big enough to tackle everything but clusters will help focus national effort on the things we are best at. Recruiting global tech giants to this cause by encouraging them to invest in research and development (R&D) and operations in Australia is critical to increase our talent pool and expand our capabilities. The results will be that Australia will create new companies in robotics, forming an important part of the supply chain in all economic sectors.

CULTURE - We must develop an entrepreneurial culture to set moon shot goals and challenges and encourage VC investment in the robotics industry

Investment in robotics start-ups in Australia is low. We need start-up founders with ambitious goals paired with sophisticated investors to develop a thriving robotics eco-system in Australia. The means of achieving this are many but this roadmap highlights two successful approaches – the use of challenges to draw together teams and technology with a specific focus and the development of regional high-tech clusters. The learnings from challenges are transferrable to other uses and we list a range of potential challenges in Appendix 14.1. The success of spinout companies and robotics technologies from some challenges is included among the case studies. The creation of regional high-technology clusters is shown to improve productivity, attract a highly skilled workforce and to attract venture capital due to the reduced risk and increased likelihood of profit to investors.

This roadmap is a living document, symbiotic with a dynamic industry. Its emphasis will shift as the industry develops but always with the intention of navigating a path to prosperity for our nation. By describing what is possible and what is desirable, the roadmap aims to create the grounds for the necessary co-operation to allow robots to help unlock human potential, modernise the economy and build national health, well-being and sustainability.

Dr Sue Keay
Roadmap Chair

What is a Robot?

Robots are autonomous machines that can move within their physical environment and manipulate objects. Robots have four main features: mobility, interactivity, communication and autonomy. In general we use the word "robotics" to encompass ALL robotics-relevant fields such as computer and machine vision, artificial intelligence and machine learning as well as automation and autonomous systems. Some of the "robots" described in the roadmap may not demonstrate all four features, such as mobility or absolute autonomy.

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). Almost 300,000 industrial robots and 7.3 million service robots were sold in 2016 manufactured by more than 700 companies worldwide.

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 an ageing population, servicing remote communities and dealing with labour shortages.

1.1 Roadmap Recommendations

Imperatives	Recommendations / Strategic opportunities for government
Industry Ensure Australia's ongoing prosperity by stimulating formation of new hi-tech firms, encouraging global tech giants to invest in Australia, and reskilling Australian workers	1 Encourage the formation of new hi-tech firms (including spin-offs (Chapter 2)) to make use of robotics technologies, as well as encouraging automation in existing firms (Chapter 10). • This should include both manufacturing and software development, and cross a wide range of industry sectors, including service industries (Chapter 7) and defence industries (Chapter 8). • The creation of new robotics firms should have a strong focus on use of Australian IP (see Recommendation 2) and on export potential (Chapter 2). 2 Encourage the expansion of local R&D and commercialisation efforts through investment by local as well as large multinational companies (Chapter 5), including incentives to invest, develop and use locally-generated IP (Chapter 9). • Lobby for tax incentives to companies that develop technologies onshore, that purchase new Australian tech and incentivise first users and early adaptors. This will help introduce new technologies within the local economy and help mitigate high capex commercialisation requirements and leverage economies of scale. 3 Facilitate the development and growth of existing and new firms by focusing on employment opportunities, skills development and training for those new to the workforce or these fields, and upskilling for existing employees. • This is a key issue and a major theme throughout the report – see further recommendations below.
Education Equip all Australians with Industry 4.0 relevant skills	4 Build national capability through education, training and research (Chapters 2-5), across all industry and education sectors (Chapter 4), and especially via collaboration (Chapter 4). • This should include a particular focus on addressing the gender imbalance in the robotics and autonomous systems research and industry workforce (Chapter 5). 5 Support the development of robotics-related microcredentials in the university and vocational education systems (Chapters 3 and 5) • The development of recognised microcredentials would offer significant advantages in upskilling and for fast, on-demand training. • The inclusion of microcredentials as part of Australian university undergraduate programs would allow Australia to leap frog ahead of other countries • Increased support for robotics challenges and competitions for undergraduate students would build interest, engagement, ideas and talent to the field (see Recommendation 18).

Imperatives	Recommendations / Strategic opportunities for government

Government

Lead the region in catalysing robotics activity by setting ethical, legal, regulatory and standards frameworks, adopting robotics in government services

6 Develop suitable ethical, legal and regulatory frameworks to enable the formation of new industries and the adoption of robotics technologies (Chapter 7).

- Create a government body to expedite the approval of new technology applications for commercial use. The body would collaborate with other government agencies, industry and unions to expedite and incentivise the path to commercialisation for Australian developed technologies.
- The frameworks should be consistent with emerging international models, for example the EU, and would encompass issues like dedicated frequencies for autonomous vehicles.
- The Australian government can set an example by being an early adopter of these technologies, for example, with government contracts to encourage consortiums to create low cost sensors and systems.

7 Invest in, develop and support the infrastructure for robotics (Chapter 7), including data and ICT networks, with the goal of ensuring wide use and benefit (Chapters 9 and 10).

8 Develop a framework for collecting and measuring data on the robotics industry and on robotic technologies, and their use, by addressing gaps in the current Australian and New Zealand Standard Industrial Classification (Chapter 2 and 7).

- This would also support the development of a national robotics strategy (see Recommendation 16) and ensure that the overall policy and funding settings are appropriate (see Recommendation 14).

9 Provide funding and policy support for upskilling and retraining (Chapters 3 and 10), as well as skilled migration (Chapters 5 and 9).

- Given the prospects for global growth in robotics, and the demand for people with the relevant skills, the overall framework to support these industries in Australia should also include measures to encourage skill retention, as well as attracting the best talent from overseas (Chapter 10).

10 Establish robotics test beds or precincts in which ‘trial and error” of new robotics initiatives can occur free from regulatory constraints, for example for autonomous vehicles (Chapter 4) or remote medicine (Chapters 6 and 9).

11 Develop appropriate operating, interoperability, risk management and safety standards for robots (Chapters 3-5, 9 and 10), aligned to international standards (Chapter 7).

- This could include developing new approaches to risk sharing and risk mitigation (Chapters 4 and 5).
- The development of new standards should be informed by pilot studies (Chapter 7) and the standards should be open by default (Chapter 9).

Imperatives	Recommendations / Strategic opportunities for government
R&D Develop clusters of robotics activity, encourage VC investment, develop pathways to commercialisation and encourage application of the social sciences	**12** Build on existing capabilities and support the development of robotics technology clusters that encourage collaboration between research and industry (Chapter 2) (see also Recommendation 16). • Improve and build on existing skills and capabilities in robotics by forming clusters (Chapters 3-5, 7, 9 and 10). • In addition to their research and development function the clusters would provide doctoral training and other forms of skills development. • The clusters should adopt open knowledge and IP frameworks as well as code and infrastructure sharing to encourage use within Australia (Chapter 4). This would also help with the development and implementation of appropriate standards – see Recommendation 14. • The clusters could include 'living labs' and technology showcases (Chapters 5 and 10). **13** Develop an appropriate funding framework to support research into, and a pathway to commercialisation for, robotics technologies – with a key goal being to make funding more accessible for new firms and emerging industries, to support automation by existing firms, and to take a human-centred design approach to technology development (Chapters 2, 5 and 7). • This could include setting up a new, multi-sector funding stream for robotics, and making the technologies more attractive to venture capital by showing the long-term investment potential. • Tackling some of the structural challenges that hinder universities from developing IP into commercial products. • Encouraging a human-centred co-design approach to ensure technologies meet user and societal requirements. **14** Develop and directly fund robotics-related industry knowledge priorities (Chapter 4) and ensure that existing and new industry and R&D programs are structured and delivered in a way that supports and encourages robotics research and industries (Chapter 2). **15** Encourage interdisciplinary research to address social and cultural issues and concerns and develop social license for robotics (Chapters 3 and 9). • There are emerging concerns and challenges regarding the ethical use of automation and autonomous systems, their impact on the workforce, and on the economic transition to Industry 4.0. Early engagement with these issues would help develop the 'social license' for robotics and automation, and provide a better way to manage their impacts.
Culture Support an entrepreneurial culture around Australia's niche robotics capability and harness the nation's imagination through aspirational goals solving Australian challenges	**16** Develop a national robotics strategy (Chapters 2 and 3) with a goal, in part, of sharing knowledge, skills and resources. • This could include the formation of a national multi-sector association or body (Chapters 5 and 7), tasked initially with the development of a national policy roadmap (Chapter 4). • A strategy based on collaboration would facilitate the development of research clusters (see Recommendation 12) and appropriate standards (see Recommendation 11). **17** Improve awareness in industry, government and the wider community of the benefits of the adoption of robotics technologies, including job creation (Chapters 3 and 10), improved service delivery in remote areas (Chapters 6 and 10), efficiency and productivity gains, and safety (see Recommendation 11). • Better awareness of the benefits of these technologies would also provide a 'social license' for their use (Chapter 3). **18** Develop and directly fund aspirational robotics-related challenges to attract interest, engagement, ideas and talent to robotics (Appendix 14.1) (see Recommendation 14).

Image courtesy of Laing O'Rourke

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The Australian Robotics Community:
The many providers of case studies of the amazing work happening in Australia and members of the academic community who contributed to a workshop in December 2017 as part of the Australian Robotics and Automation Association's annual conference, ACRA (the Australasian Conference on Robotics and Automation).

2 The robotics industry in Australia

Australia must urgently invest in robotics capability if it is to remain competitive on the world stage. Most economic peer countries are making significant national investments in robotics.

Image courtesy of UAP

2.1 Introduction

The Australian robotics industry is diverse, existing as either service businesses within major corporations or small-medium sized enterprises meeting niche market needs. The industry is supported by technological expertise across the university sector (such as the Australian Centre for Robotic Vision) and by the federal government's independent agency, the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Much of Australia's industrial robotic activity is beyond plain sight but its role is vital.

For example, vision-equipped robots are active in roles as diverse as:

- Managing environmental threats to the Great Barrier Reef where marine robots detect and exterminate the Crown of Thorns starfish
- Maintenance of vital urban infrastructure such as the Sydney Harbour Bridge where micro-robots find and manage flaws in the painted surface
- Assisting surgeons with routine medical procedures and administering drugs in remote locations
- Transporting and packing containers at export shipping terminals
- Supporting police and military personnel to understand and defuse dangerous situations.

An analysis of the strengths, weaknesses, opportunities and threats (SWOT) for the Australian robotics industry was conducted at a roadmap writing workshop involving most co-chairs. Key strengths that emerged were:

- The current advantage Australia has in niche aspects of robotics in both talent and technologies.
- How Australia's unique geography (such as vast distances and remoteness) has benefitted the development of world-leading field robotics applications.
- That many of Australia's regulatory regimes are exemplars for the rest of the world.

The Australian robotics industry has an opportunity to exploit these strengths by developing Australia as a test bed for new technologies and by further supporting the niche talent and technologies that currently exist. Capitalising on Australia's first mover advantage in many areas will enable services to continue developing a strong robotic economy to benefit Australia in the future. The risk of not doing so may see the industry fall prey to weaknesses and threats, where Australia loses niche capabilities, talent and technologies to other nations. A failure to address the current challenges that are seen to be holding Australia back including collaboration, technology commercialisation, and structural changes to support a robot economy, may indicate that Australia lacks the ambition to succeed in the new high tech industries of the future.

SWOT Analysis

STRENGTHS

TALENT/TECHNOLOGY

- top robotics researchers and access to best research networks in the field
- technologies developed here give us a first mover advantage
- Australia recognised as world leader in automation in mining
- CRCs - a competitive advantage to Australia, and also ARC Linkage industry-research grant schemes

GOVERNMENT/REGULATORY

- Australia as a source of regulatory arbitrage e.g., Civil Aviation Safety Authority (CASA) approved unmanned aerial vehicle (UAV) fly zone for Beyond Line of Sight (BLOS) operation
- Australia = trusted 3rd party, stable country with small market so not viewed as competition, therefore a good test bed with cultural similarities with large markets such as Europe and US
- Australia has topped a global index for open government data. The Global Open Data Index (GODI) – published by Open Knowledge International – Australia finished equal top with Taiwan out of 94 nations

GEOGRAPHY/CULTURE

- Australia's self-reliance due to remoteness, necessity to build critical mass in niche areas and need to solve remoteness issues such as logistics, importance of automation, more robust and reliable systems that operate in GPS denied and harsh environments
- competitive advantage applying Australian know-how to other remote countries (e.g., S America, Africa, Space etc)
- lifestyle (stability, climate, economy)
- proximity to Asia and Asian markets
- cultural diversity - Australia more globally aware than most - focus on outside due to immigration and tyranny of distance
- large land mass, low population density makes Australia an ideal test site or location for "living labs"
- due to small market size in Australia there is a need & capability to diversify, be flexible and achieve innovation on a shoestring (lean)

OPPORTUNITIES

FIRST MOVER/REPUTATION

- first mover advantage in areas such as field robotics & robotic vision
- fledgling robotics industry in Australia (chance for leadership)
- commercialise ideas in Australia (rather than ideas going overseas)
- to be known for quality and cybersecurity - idea of an "Australia inside" sticker on goods

CLUSTERS

- create integration between robotics groups through clusters
- promote more cross-sectoral collaboration
- forecast investment in technology by Defence will benefit robotics
- leverage remoteness to develop test sites or living labs
- leverage global auto industry investment in automation

ROBOT ECONOMY

- develop Australia as a robot economy
- leadership role in future-proofing business and society
- build on large scale investments in primary industries
- harness benefits of renewable energy to lead the world
- globalisation of access to capital

WEAKNESSES

SCALE

- small talent pool & relatively low wages for talent, hard to recruit
- immature industry in Australia
- need to solve problems of access to global supply chain
- small population, small market, lack of scale to do research
- small market risk/failure aversion
- foreign-owned multinationals don't always value Australian projects (e.g., closure of research labs by Alcan, Orica etc)

COLLABORATION/COMMERCIALISATION

- lack of collaboration and gap in the integration space
- lack of knowledge sharing amongst industry competitors
- limited access to large scale collaborative research grants such as EU grants
- no transfer of learnings re. innovation and entrepreneurship
- difficulty in commercialising the IP we produce, poor perceived results of Australian university commercialisation offices

STRUCTURE/REGULATION

- regulatory process around automation and robotics (no regulatory roadmap for Australia in this space)
- no overarching body that represents robotics and brings all the companies in the industry together
- visa restrictions discourage talent from coming to Australia

AMBITION

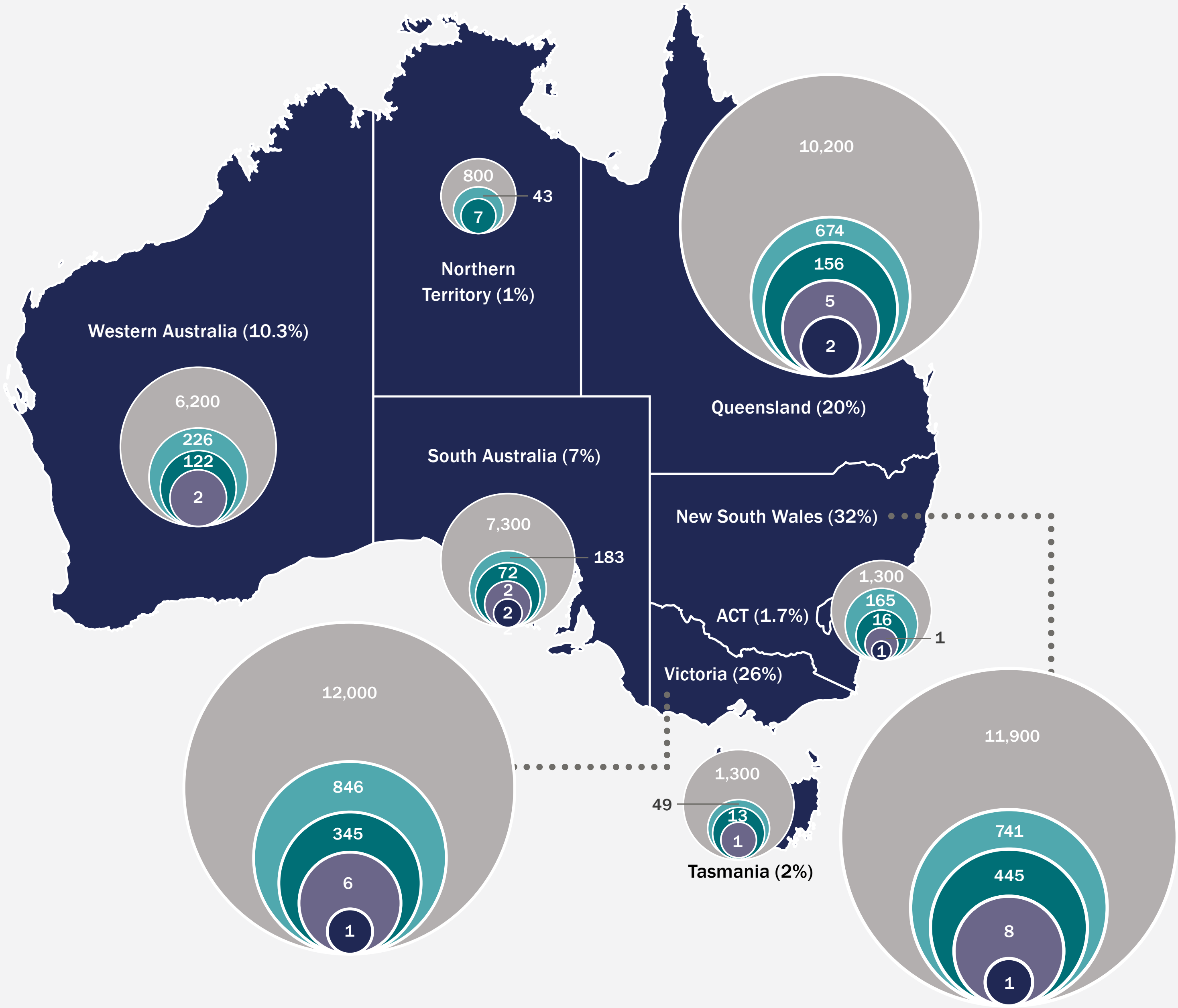
- lack of national focus on niche robotics/computer vision areas where Australia can excel
- lack of commitment to support long term audacious goals, national grand challenges (like DARPA grand challenges)
- lack of visibility of robotics within Australia and on the world stage (e.g., compared to quantum computing)
- lack of esteemed technology icons/pioneers (tall poppy syndrome) and to celebrate our intellectual successes
- lack of targeted grant schemes

THREATS

COMPETITION

- better resourced competitors
- talent poaching by tech companies (Apple, Google, Facebook etc)
- we do great stuff but exploited elsewhere
- overtaken by global robotics activity via democratisation of technology (e.g., China buys everything)

Australian Robotics Capability by State



LEGEND ▪ IICA subscribers ▪ University focus ▪ Robotics companies ▪ Mechatronics offerings ▪ Clusters

TERMINOLOGY

X% percentage of Australia's population residing in state

IICA is the Institute of Instrumentation, Control and Automation

Subscribers are the number of people in the IICA database and their location

Robotics companies are 1,177 Australian companies that broadly cover robotics and/or computer vision sourced from the proprietary Orbis database

University focus is based on the number of academics and researchers listed on university websites in fields related to robotics such as computer science, human-computer interaction, vision, control, AI, electrical and mechanical engineering

Mechatronics offerings number of institutions offering specialist qualifications in mechatronics

Clusters are centres (>30 people) with focused offerings in robotics or computer vision or related fields, including Australian Centre for Robotic Vision (Qld, SA, ACT, Vic), Australian Centre for Field Robotics (NSW), Data61 Robotics & Autonomous Systems Group (Qld), Australian Institute of Machine Learning (SA)

Source: Internal unpublished research by the Australian Centre for Robotic Vision

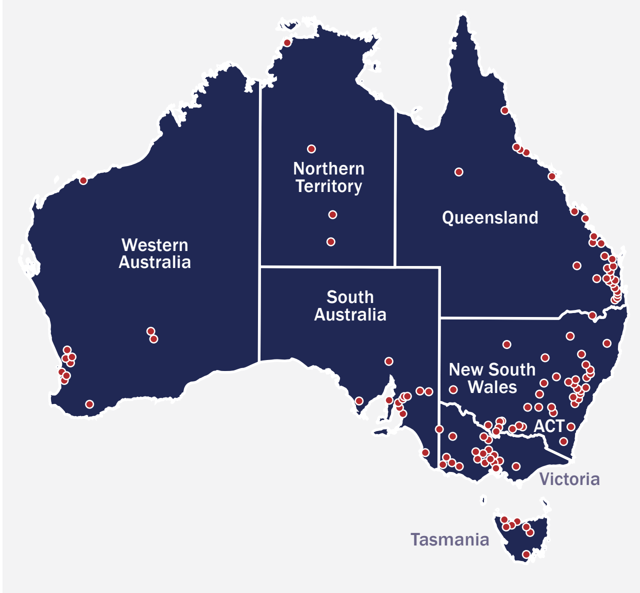
Defining Australia's robotics capability on a state-by-state basis shows that robotic capabilities closely match the population estimates, with the most populous states having the highest number of robotic companies and highest levels of robotic capability. Notable exceptions being:

- South Australia, which has a high number of Institute of Instrumentation Control and Automation (IICA) subscribers relative to population size, due to its manufacturing expertise.
- Australian Capital Territory (ACT), which has a high university focus relative to population size, due to the size of its tertiary education sector.
- New South Wales (NSW), which although the state hosts a high number of robotic companies, ranks lower in university focus and IICA subscribers than might be expected.

> Publicly available data suggests that 442 of these "robotic" companies employ almost 50,000 Australians and generate more than $AU12b revenue each year.

Image courtesy of Laing O'Rourke FreeFAB

Capability mapping of existing companies that broadly define activities in robotics



A web-based survey by the Australian Centre for Robotic Vision identified more than 1,100 companies within Australia that broadly encompass activities in robotics (see Capability map). Advances in robotics mean these companies, and others that emerge, will be important to Australia's robotic industry and will support future productivity growth and employment in Australia. Publicly available data suggests that 442 of these "robotic" companies employ almost 50,000 Australians and generate more than $AU12b revenue each year.

The identified companies cross a range of sectors including manufacturing, services, healthcare, resources, infrastructure, agriculture, the environment, space, and defence. Each of the representative sectors, their current use and the potential future uses of robotics, are explored in more detail in the body of this roadmap.

The ability to maximise the benefit of the robotics industry within Australia is approaching a crossroads, where choices must be made about the scale and direction of public and private investment. Public investment in robotics occurs through the universities system and major public sector users. Understanding the barriers and incentives to investing in the start-up arena, which houses much of the talent and fosters innovation in the technology sector, is essential. Decisions about the future of the robotics industry in Australia do not occur in isolation however, and a scan of the Australian landscape needs to be considered in the context of peer and competitor nations.

Case Study: ANCA Pty Ltd – Building Australian robots

ANCA Machine Tools, in collaboration with its project partners, aims to commercialise a proven prototype of a fully integrated robotic and digital control system, in response to customer demand. The robotic system is designed to automate existing production processes to achieve unmanned 24/7 operating environments.

The prototype robotic system has been developed on ANCA computer numerical control (CNC) machines, with the intention of commercialising the robot across multiple industries where high-pressure chemical wash-down is a required step in the production process, such as pharmaceutical and food and beverage industries. An important technical feature of the ANCA robot is the IP67 protection rating, which allows the robot to operate in difficult production environments containing high levels of dust and liquids.

A key differentiating factor of the ANCA robot is the fully integrated digital control system, developed by ANCA Motion and used on ANCA CNC machines. Most robotic systems in a factory production environment require integration of multiple hardware and software providers into a single operating solution. The ANCA robot provides a fully integrated cyber-physical product that provides end-users with an easy-to-operate universal solution.

The combination of IP67 protection rating and fully integrated digital control system fills a niche in the market as products with these features are unique, complex and not widely available.

The robot prototype has been developed to operate on ANCA CNC machines, specifically the process for loading and unloading small parts inside the ANCA machine for grinding. Sold as an optional extra, approximately 60 per cent of all ANCA customers purchase an automated loading system. As the demand for Industry 4.0 solutions increase, this feature is increasingly sought-after. ANCA Machine Tools currently import the required hardware to provide customers with a robotic option. Successful completion of this project will replace imported robotic product with an Australian manufactured robotic system. All project IP will remain in Australia.

On completion of this project, ANCA Machine Tools will have a fully functional robot and digital control system ready for commercialisation across multiple industry sectors globally, as well as for ANCA CNC machines. This project supports ANCA's business plan in transitioning from a mechanical and pneumatic based automation systems company to a more advanced and complex robotic automation solutions provider and developer of Industry 4.0 smart factory data exchange technology.

THE FUTURE OF ROBOTICS IN CNC GRINDING

ANCA CNC MACHINES

SALES FIGURES IN ROBOTS IN 2015 ARE

UP 15%

PREDICTING

DOUBLE DIGIT

PERCENTAGE GROWTH[1]

CNC GRINDERS ONLY HAVE

1.5%

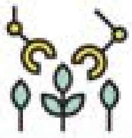
OF MACHINE TOOLS WITH ROBOTS[2]

SINCE 2014 THE NUMBER OF ANCA CUSTOMERS ORDERING CNC GRINDING MACHINES WITH ROBOT LOADERS INCREASED FROM:

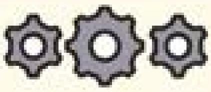
10% TO 50%

THIS IS CHANGING WITH ROBOTS BECOMING INCREASINGLY AFFORDABLE AND EASY TO PROGRAM

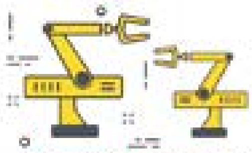
ADDING CAPABILITY
A MARKET FIRST IS ANCA'S NEW MULTI-ROBOT PRODUCTION CELL.



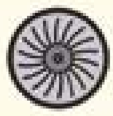
DUAL ROBOT TECHNOLOGY OPENS THE DOOR FOR UNLIMITED POSSIBILITIES FOR THE INDUSTRY, NO MATTER HOW COMPLEX.



REDUCES CAPITAL EQUIPMENT, IMPROVES PRODUCTIVITY, REDUCES WORK IN PROGRESS AND INVENTORY.

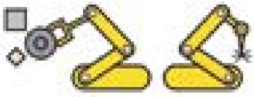


A LARGER ROBOT DEVOTED TO WHEELPACK CHANGES AND PART LOADING, WHILE A SECOND, SMALLER ROBOT IS FREE TO "MULTI-TASK" OTHER OPERATIONS WITHIN THE CELL.



BETTER CAPABILITY TO MANAGE COMPONENTS THAT ARE DIFFICULT TO HOLD, SUCH AS TURBINE BLADES AND KNEE JOINTS.

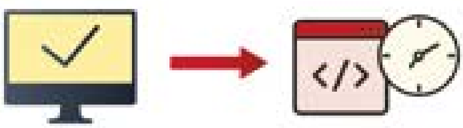
IT ENABLES TWO PROCESSES RUNNING AT THE SAME TIME. FOR EXAMPLE, THE LARGE ROBOT CAN LOAD WHEEL PACKS AND PARTS INTO THE MACHINE WHILST THE SMALLER ROBOT UNDERTAKES SECONDARY OPERATIONS SUCH AS METROLOGY, LASER ETCHING, OR PART WASHING.



USER-FRIENDLINESS MEANS GREATER USEFULNESS

IN THE PAST CUSTOMERS WERE CONCERNED ABOUT:

- THE AMOUNT OF TRAINING REQUIRED TO USE ROBOTS.
- ROBOT MAINTENANCE - HOW TO RECOVER FROM A MINOR CRASH OR CREATE A NEW PALLET.
- HOW TO INSTRUCT THE ROBOT ON CHANGING FROM ONE PART TO ANOTHER OR INSPECTING A TOOL DURING A BATCH RUN FOR EXAMPLE.



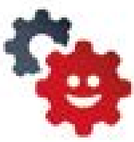
NEW PRODUCT DEVELOPMENTS MEAN SOFTWARE PACKAGES ARE NOW AVAILABLE TO SIMPLIFY COMPLEX REQUIREMENTS.

FOR EXAMPLE, ANCA'S ROBOTEACH SIMPLIFIES ROBOTIC PROGRAMMING TO SAVE HOURS OF SET UP TIME.

ROBOTICS WILL BE PART OF DAY TO DAY OPERATIONS

THE CNC MARKET HAS SEEN THAT WHAT INITIALLY SEEMS LIKE A CUTTING-EDGE PRODUCT CAPABILITY, BECOME INDUSTRY STANDARD.

AS WHEN A CNC CONTROL WAS ADDED TO A MANUAL GRINDING MACHINE, ROBOTICS ARE A SIMILAR GAME CHANGER.



EXPANDED CAPABILITIES WITHIN ROBOTICS AND INCREASINGLY USER-FRIENDLY AUTOMATION SOLUTIONS ARE MAKING THE FUTURE AN EXCITING ONE.

[1]HTTP://WWW.IFR.ORG/FILEADMIN/USER_UPLOAD/DOWNLOADS/WORLD_ROBOTICS/2016/EXECUTIVE_SUMMARY_WR_INDUSTRIAL_ROBOTS_2016.PDF
[2]HTTPS://WWW.KUKA.COM/KUKA_WP_WZM_EN.PDF

linkedin.com/company/anca

2.2 Public investment by our peers

Australia must urgently invest in robotics capability if it is to remain competitive on the world stage. Most of our economic peer countries, including the United States of America (USA), China, Korea, Europe, Singapore and Japan, are making significant national investments in robotics.

In the USA, the National Science Foundation's (NSF's) National Robotics Initiative was funded for $US100 million per year over 5 years. Version 2.0 has a similar investment split across different USA government agencies ($US40 million from the NSF and similar amounts from United States Department of Agriculture (USDA), Department of Energy (DOE), and Department of Defense (DOD)). Canada has recently invested $US125 million in a fundamental Artificial Intelligence (AI) research institute and has the stated aim of further investing in high-value, innovative, creative, ground-breaking areas such as robotics. The Chinese government is investing $US100 billion in robotics to ensure the country can supply its own industrial robots, with an aim to be producing 100,000 industrial robots per year by 2020. By the end of 2018, China will have purchased two-thirds of the world's industrial robots. Koreans are investing $US662 million in research and design in the robotics sector over the next 10 years. South Korea aims to put a robot in every South Korean household by 2020 [NGN06], and to expand the country's production of industrial robotics to be worth more than $US6 billion by 2022 [RAN18]. In the EU, 'Horizon 2020' has invested in robotics over 7 years (2014-2020) together with investments by individual European nations.

Australia has a similar opportunity as these competitors but must act swiftly to define ambitious goals, and secure and build robotics capability. Australia's National Science Statement [NSS17] supports the development of:

"national aspirations ... ambitions and goals for Australian science."

The Innovation and Science Australia 2030 plan [ISA17 - p16] notes that Australia has a head-start in many of these technologies from substantial public and private investment, and that this has resulted in geographically concentrated hubs involving both research organisations and 'tech giants' (Recommendations 2 & 12).

Image courtesy of QUT

2.3 Technology commercialisation and investment

The pathway to commercialisation in Australia

As part of the roadmap's national consultation process, extensive interviews identified the path to commercialisation as a key weakness in transitioning robotics from the R&D stage to market-ready product in Australia. While some innovations in Australian robotics have market potential, they often require significant capital to commercialise. 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 (Recommendation 2). Policy should also focus on sectors that have economic potential. Investment (of time and resources) should be focused on areas that show high potential to expand within the local market. 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 (see Chapter 10).

The start-up ecosystem in Australia

Venture capital (VC) is widely believed to be necessary to transform old industries and create new ones [VCE17]. Venture capital is central to building a highly skilled, knowledge-driven economy with 75 per cent of Australians believing the benefits of technology outweigh the risks [VCE17]. This has enabled Australian VC founders to get funded locally and also to attract top-tier overseas ventures to invest. With Australia's large super funds starting to invest in venture companies, Australia's venture capital (VC) sector raised more than $AU1 billion in 2016-17. The number of venture companies has also doubled since the start of 2016 [SUA17].

Despite this, Australia's VC funding as a proportion of gross domestic product (GDP) remains half the size of the Organisation for Economic Co-operation and Development (OECD) average. Of countries in the OECD, Australia ranks 24th, investing 0.013 per cent of GDP. Comparatively, Israel (ranked 1) invests approximately 0.38 per cent, Canada (ranked 3) invests 0.16 per cent, and New Zealand (ranked 11) invests 0.034 per cent [OECD17].

According to AVCAL CEO, Yasser El-Ansary:

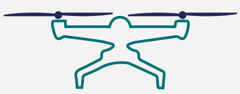
"Australia's venture capital sector is still far too small for a country with bold ambitions to be an innovation-leader."

This view may be reflected in that the Australian VC market does not provide as many opportunities as competitor markets such as the USA. For example, in the USA in 2017, $US72 billion was raised in 5,052 deals. During the same time in Australia, $AU700 million was raised in 135 deals. To be equivalent on a per capita basis, Australia would need to have raised $AU6 billion in 388 deals.

Similarly, Pitchbook identified 952 "robotics and drones" companies worldwide that have attempted to raise capital since 2008. Only nine of the companies were Australian. Of the $AU9 billion raised worldwide, only $AU6.5 million was raised in Australia. This included a combination of local and overseas (USA) investment and averaged less than $AU1 million per company (compared with a global average of $AU15 million per company). The data also showed that the Australian companies seeking funding were relatively immature, employing an average of only 11 employees. In contrast, over the same period, 46 start-ups in Canada raised capital of $AU171 million, at an average of $AU6.85 million per company with each company employing an average of 23 people.

Conversely, it is sometimes said that the Australian VC scene doesn't lack money, but it does lack 'deal flow', meaning that not many requests are made that align with the interests of investors.

Fundamental changes need to occur in the approach of Australian start-up founders and investors if Australia is to develop a thriving eco-system of robotics and related companies.



Pitchbook identifies

952 "robotics and drones" companies

worldwide that attempted to raise capital since 2008

<1%

Only nine of the companies are Australian

2.4 Talent availability - robotics skills

Australia's world-class education system, along with a good research and development base in robotic technologies, means that there is a high-quality pool of talent available to reposition Australia as a knowledge-driven robotics nation. Australia's technical expertise is well-regarded internationally, making our graduates highly valued targets for recruitment by global technology giants and overseas research institutions. Consequently, many Australian graduates and researchers with relevant capabilities leave to work overseas due to lack of local employment opportunities. Ideally, the aim is to see Australian graduates find opportunities in Australia, either joining established companies or by starting their own enterprises. The key challenge for the fledgling robotics industry is to build a path from research to commercialisation of products and services that will support the achievement of this aim.

Australia has a strong skills base, with 37 per cent of the adult population earning tertiary qualifications and 37 per cent of the labour force being employed in occupations involving science and technology. Despite concerns raised by the Productivity Commission about the quality of Australia's education system [PC17], Programme for International Student Assessment (PISA) scores in science for 15-year-olds are the fourth highest in the OECD. There are also opportunities to expand the domestic talent pool by challenging the gendered nature of the robotics and automation workforce. Currently Australia graduates 15.4 per cent female engineers [ER16] yet only 12.4 per cent of engineers in professional practice are female [EA17] and these statistics have remained static for more than a decade. It would make a significant difference if qualified women were more highly represented in robotics, or in engineering in general, in Australia.

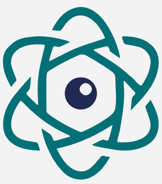
As well as creating homegrown talent to support an Australian robotics industry, there also needs to be consideration of how to become a net importer of suitable talent. Already one in three Australian workers is born overseas [II18] and Australia will continue to rely on immigration to maintain and increase the high levels of skills and capacity required to support a robotics industry. This issue was highlighted by Deloitte Access Economics and the Australian Computer Society [ADP17] who noted the importance of visa and migration arrangements that:

"ensure Australian businesses can access the necessary ICT skills to facilitate future growth, while balancing the need to build and train local talent over time."

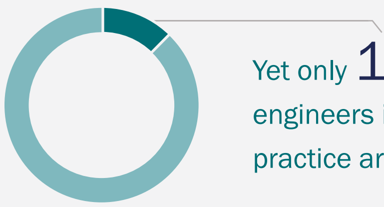
The challenges in building Australia's robotics and automation talent base through education, increasing participation by women and older workers, and migration were also discussed in the Deloitte Access Economics/Australian Computer Society report [ADP17].

37% of our adult population have tertiary qualifications

Currently Australia graduates 15.4% female engineers



37% of our labour force are employed in occupations involving science and technology



Yet only 12.4% of engineers in professional practice are female

2.5 The importance of technology clusters

Regional clusters are known to act as hothouses for generating new ideas, new applications, and the establishment of new companies to exploit these [UKR14]. Australia already has notable hotspots that have attracted talent and funding for fundamental research, higher level research training, field robotics, and specific technology development (e.g., mining automation technologies). For Australia to be internationally competitive in the areas of robotics where it excels, existing hotspots must continue to be used to grow local ecosystems of innovation, with ready access to mentoring, finance, business and marketing advice, as well as providing an opportunity to build connections across the value chain. Opportunities for new clusters must also be explored.

High-technology industries tend to be heavily concentrated in regional 'clusters' [VCA17]. According to AVCAL, regions with high-technology clusters tend to be more productive, attract a highly skilled workforce and are more likely to attract venture capital due to the reduced risk and increased profit to investors [VCA17]. The general success of clusters is attributed to a company's nearness, both in terms of location and relationships to entrepreneurs, industry experts, financial and accounting specialists, marketers, and related businesses [OM05]. Clustering also creates a hothouse environment driving rapid growth of start-up companies.

A feature of the general high-tech cluster in Silicon Valley was its genesis from well-funded military research directed toward clear national security goals [OM05]. This initial focus led to the creation of large spin-offs for civilian industry, which in turn led to the creation of an entrepreneurial culture now synonymous with the region [OM05]. Universities and industry collaborations were supported by a range of government incentives, while the favourable climate and social cohesion of California are also considered to be factors [OM05]. With the emergence of key Defence sector investments in Australia, and the growth of the Defence budget to two percent of Australia's GDP by 2020-21, it is an ideal time to look at the formation of clusters to support the development of an Australian robotics industry.

There is also a high-tech hub in Pittsburgh, USA within which a local robotics and automation cluster has flourished [PRA17]. Pittsburgh has established itself as a regional hub for small-medium sized enterprises (SMEs) with 84 businesses securing $US499 million in venture capital in 2014-15 alone. The success of the robotics and automation cluster in Pittsburgh has been analysed and found to be related to innovation and collaboration, the strong influence of a well-established robotics-focussed university (Carnegie Mellon University), investments in major technology, and collaboration with Fortune 500 companies [PRA17].

Technology clusters are not always successful and there is no guaranteed formula for success, although high-functioning networking opportunities and facilitation, a strong innovation base with supporting R&D facilities and a highly skilled and mobile local workforce are considered key [UKR14]. To this end, Australia's IT infrastructure compares well with international peers, with wide wireless broadband coverage, although the Network Readiness Index [EY17] is falling, with Australia currently ranked 18th, largely due to the costs associated with fixed broadband. Despite these shortcomings, we recommend a cluster approach for Australia to support its robotics industry.

Image courtesy of QUT

Image courtesy of QUT

2.6 Australia as a 'living lab'

Australia is a perfect test bed for new robotic technologies, as has been evidenced by the testing of drone technologies in Australia by tech giants such as Google [ABC14]. Australia has a large land mass with scattered settlements (low population density), a wealthy population of early adopters of technology, and regulators that generally work in well with industry (see Case Study – UAV outback challenge). The House of Representatives Standing Committee on Industry, Innovation, Science and Resources [PCA17], acknowledges the opportunities this offers for Australia. Their report recommended that:

"the Commonwealth Government facilitate and encourage trials of automated vehicles in Australia"

This is primarily to encourage public acceptance but is also in recognition of the associated economic and social benefits.

2.7. National Security Risk

Australia has unique skills and capability in robotics and a growing ecosystem of companies who rely on those skills. Robotic technologies are vital components of the industrial internet (Industry 4.0) used in critical infrastructure and defence applications. A lack of skills and capability in these areas poses a credible national security risk. Australia needs to develop and maintain a strong capability in robotics to protect the industry, in a similar manner to having national capability in cybersecurity to protect the information and communication technology industry.

A loss of Australia's capability in this space would mean that we would have to rely on foreign countries for expertise which can be a risky proposition. For example, in 2016 the Committee on Foreign Investment in the United States (CFIUS) agreed to the Chinese company Midea's takeover of German high-tech robotics manufacturer Kuka (which has offices in the USA) [REU16]. This decision led to changes in Germany's rules on foreign corporate takeovers where there is a risk of critical technology being lost abroad [REU17]. The change is seen as necessary to protect critical infrastructure including power grids and hospitals. Similarly, Australia blocked a tender from China's Huawei Technologies to supply to Australia's national broadband network NBN [REU12].


Image courtesy of QUT

Case Study: UAV Outback Challenge
(pushing the frontiers of drone navigation and use)

The goal of the UAV Outback Challenge is to demonstrate the utility of unmanned airborne vehicles (UAVs) for civilian applications, particularly in applications that will save the lives of people in the future. The challenge harnesses the ingenuity and passion of aero modellers, university students and high-school students around the world to develop novel and cost-effective solutions. The challenge started after a group of aerospace industry leaders and UAV experts got together to develop a plan that would allow growth in the Australian civil UAV industry, raise awareness of the potential civilian applications, and support skill development in the industry.

The UAV Challenge Outback Rescue was an unmanned aircraft search and rescue competition that ran from 2007 to 2014. It saw teams from around the world compete to save lost bushwalker Outback Joe using unmanned aircraft and deliver him a life-saving water bottle with a prize of $50,000. CanberraUAV claimed the prize in 2014.

Since 2015, the UAV Challenge Medical Express has commenced. This is an unmanned aircraft competition that demonstrates the use of robotic aircraft for medical sample retrieval and medical delivery, and is open to adult teams from around the world. This competition is focussed on the autonomy of unmanned aircraft.

The UAV Challenge inspired the development of a telemetry radio system called the RFD900. This device is now standard in the UAV industry and is manufactured by Brisbane company RF Design who have sold thousands of units around the world. Another electronic device designed to supplement commercial autopilots in such a way as to implement all the failsafe requirements is the Millswood Failsafe Device, which is also now sold as a commercial product.

The 2014 winner of the challenge, CanberraUAV, continues to develop and open source the technology they developed to compete in the challenge, including flight controller, airframe, power-propulsion and image processing algorithms. CanberraUAV contributed to Ardupilot, the most advanced, full-featured and reliable open source autopilot software available which is installed in UAVs around the world [IRA16].

Another benefit of these challenges is the close involvement of regulators. Australia's Civil Aviation Safety Authority (CASA) is internationally recognised as a leader in UAV regulation and Australia's practical approach to regulation in this space has encouraged global tech giants such as Google to test UAV delivery systems [ABC14].

2.8 Advancing technology through challenges

Challenges have been shown to increase the effectiveness of technology development and diffusion by focussed fast-tracking of aspirational goals that are currently technically impossible to achieve. A good example of this was the Defence Advanced Research Projects Agency (DARPA) Urban Challenge of 2007, which saw the first autonomous vehicle navigate a 96 kilometre course in under six hours. The collection of talent and the application of technologies to solve that challenge directly led to investment by major corporations in self-driving car technology. In the space of just over 10 years, self-driving cars are now being trialled for real-world use.

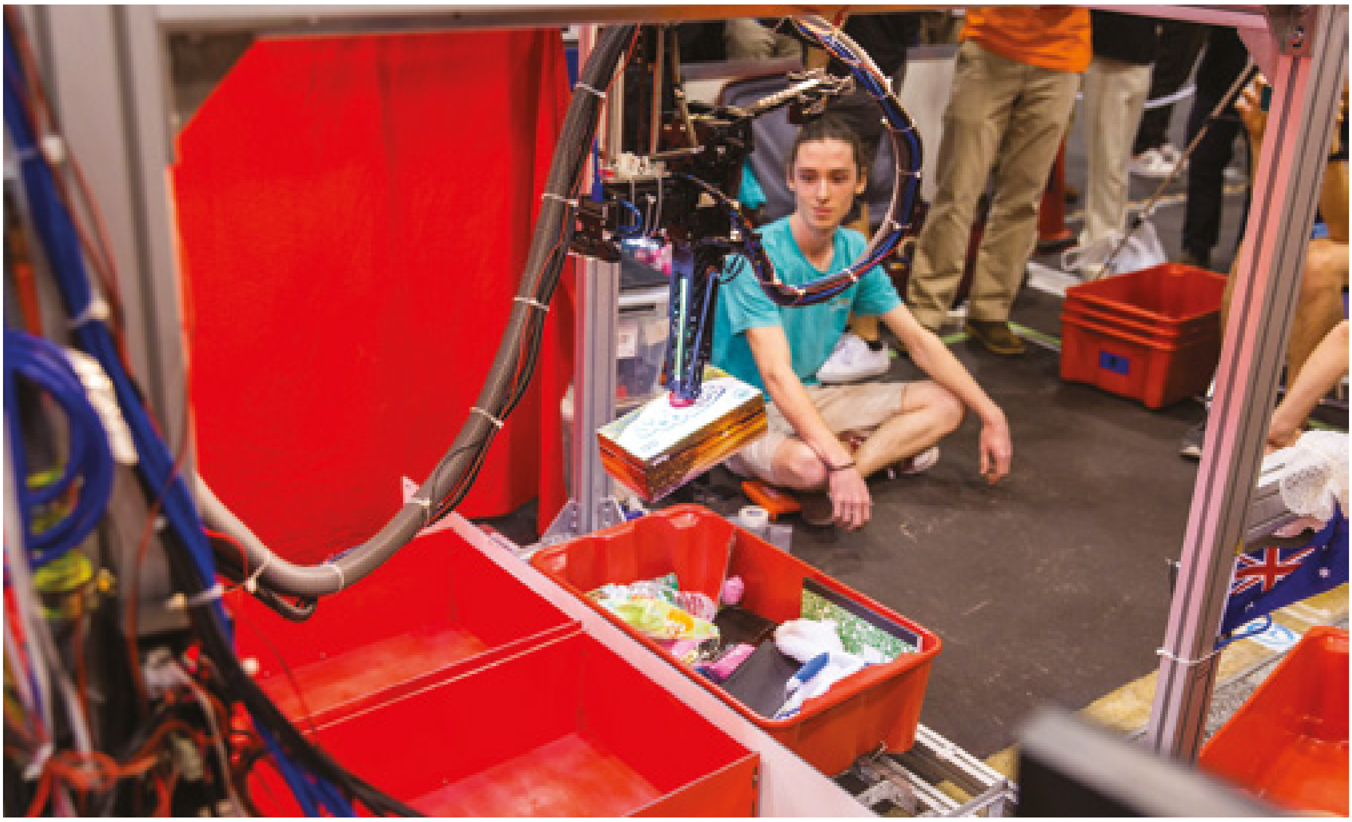
Similarly, we propose that the creation of a series of Australian challenges, to be solved by the robotics and broader communities, will fast track development of technologies. The challenges will need to focus on pressing national issues, stimulate collaboration and spark the public's imagination of the possibilities these new technologies present that are yet to be explored – a point acknowledged by Deloitte Access Economics [ADP17]. Advantages to Australia for proactively establishing challenges for international competitions include:

- the pre-commercial knowledge gained by participating Australians and Australian companies
- seeding the network of suppliers and integrators who are vital to the creation of the technological solutions
- developing the broader robotics industry value chain.

According to the United Kingdom's (UKs) Robotics and Autonomous Systems 2020 strategy [UKR14]:

"challenges need to focus on valuable societal or commercial goals: real-world problems that need solving. Success

The collection of talent and the application of technologies to solve that challenge directly led to investment by major corporations in self-driving car technology.



By involving government departments, issues around public procurement can be explored as a means of addressing national challenges.

must be hard won, and the importance of knowledge gained through failure recognised. By involving government departments, issues around public procurement can be explored as a means of addressing national challenges. Challenges also provide media and public interest stories: they educate and stimulate open awareness of RAS and showcase the industry. A new generation of engineers, technologists and entrepreneurs can be kick-started through exposure to Challenges via the media, schools and universities."

Engagement with regulators will be essential to explore how regulatory frameworks can be adapted without being a barrier to innovation [AIS17] (see Case Study UAV Outback Challenge, p. 25). The report observes that:

"Regulatory stability can encourage and incentivise innovation by setting clear quality, environmental and ethical standards, providing confidence to consumers in both domestic and foreign markets."

In this roadmap, we showcase challenges that will push the bounds of the current technology envelope for most sectors. In combination with the development of 'living labs' to test robotics technologies in different settings within Australia, future challenges will serve to widen engagement and establish regulation ahead of market penetration of both technologies and ideas.

Contributors

The discussions at the respective workshops were summarised and this chapter roadmap was prepared by:

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With additional contributions by UQ Business School MBA Consulting Practicum students: Juan Suarez, Matt Myers and Matt Cowman

3 The impact of robotics on Australia

According to the Australian Productivity Commission, the key to improving Australia's productivity lies in applying new knowledge and technologies.

Image courtesy of UAP

3.1 Introduction

Australia is one of the richest nations in the world. Living standards and educational levels are high, borrowing costs, inflation and unemployment are low, and we are living longer, and in general, healthier lives than we have in the past [PC17]. Australia's medium-sized $AU1.7 trillion economy (ranked 14th in the world) has proven resilient, thanks to the global commodities boom. Australia has also avoided recession, recording 26 straight years of economic prosperity [OCE16, II18].

Over the last few years however, wages have plateaued, despite labour productivity growing annually by 1.8% [PC17]. To maintain the current standard of living, Australia needs productivity to grow 2.5% a year, ergo reliance cannot be on current labour productivity alone. According to the Australian Productivity Commission, the key to improving Australia's productivity lies in applying new knowledge and technologies. Robotics are at the forefront of technologies that can deliver the required productivity gains. They are among the first 'new' technologies mentioned in the text of the National Research Infrastructure Roadmap [NRIR16], which notes the potential of these technologies, particularly in relation to manufacturing and natural resources.

If Australian companies embrace automation through robotics at the same rate as international peers, productivity growth can be increased by over 50% [ALB17]. Discussion of automation generates a focus on two major societal risks, unemployment and increased inequality. These risks will be discussed further in this Chapter.

Australia's $1.7 trillion economy has proven resilient, thanks to the global commodities boom

Australia has recorded 26 straight years of economic prosperity

Image courtesy of Woodside Energy

3.1. Impact on sectors of the Australian economy

Automation is set to deliver Australia a $AU2.2 trillion benefit over the next 15 years, provided that:

- Australian businesses accelerate their uptake of new technologies such as robotics, and
- workers displaced in the process are redeployed [ALB17].

As noted above, the adoption of automation is predicted to improve productivity growth by over 50% [ALB17] but this will result in changes to jobs. Some jobs will disappear while new jobs will be created, with the most impacted sectors of the economy expected to be manufacturing and services. To harness the benefits of automation, jobs must be created in other parts of the economy. An example of this shift in jobs can be seen in the computerisation of the finance sector, which has shifted work away from administrative service positions to more technologically complex areas supporting the computerisation.

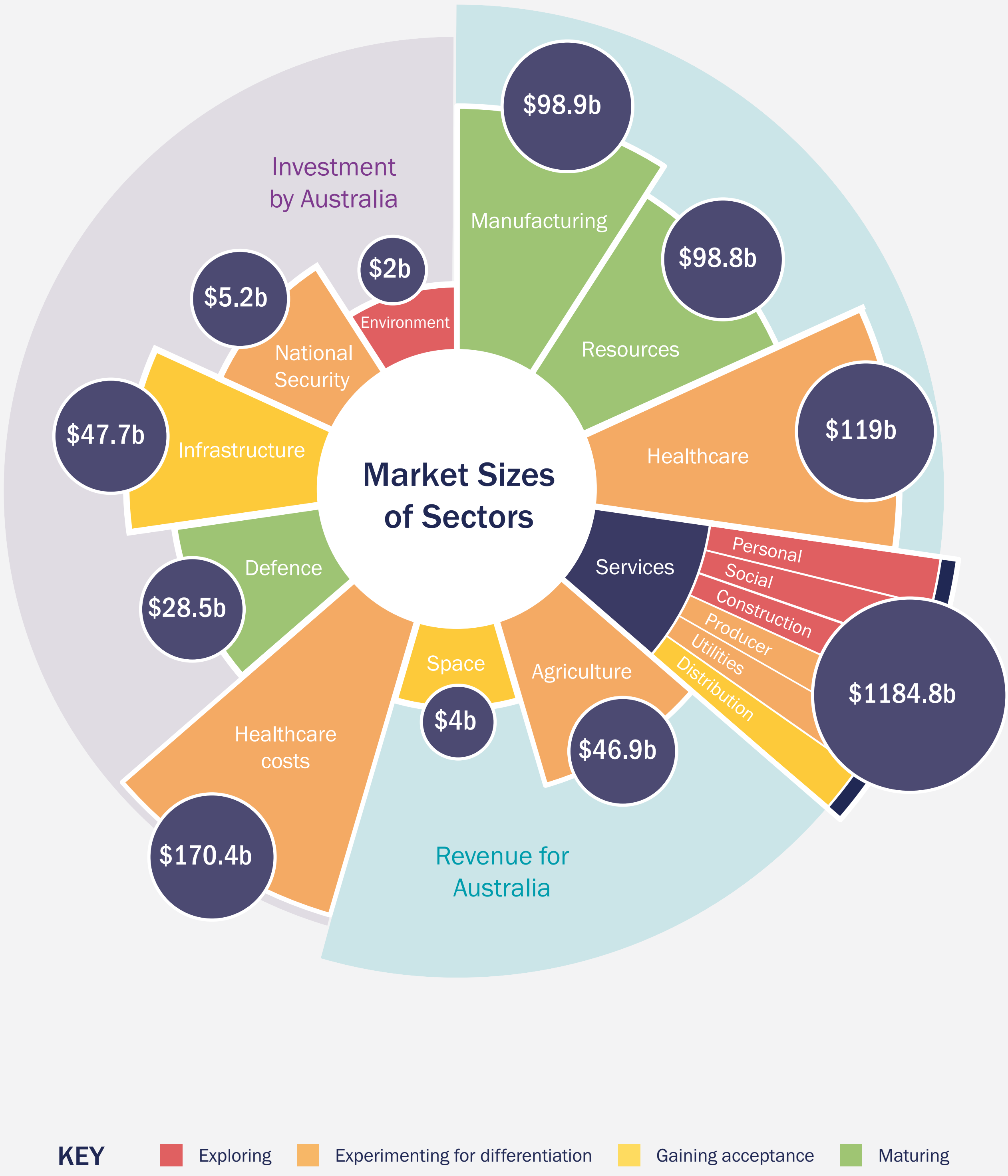
In addition to automation, robotic technologies also have the potential to make existing jobs safer, more satisfying and more creative, while at the same time reducing the dirty, dull and dangerous aspects of many occupations. This is not a new concept for Australian economic reformers. Over the past 30 years, numerous areas of the economy have been transformed, such as industries impacted by the loss of tariff protection, including steel manufacturing, textiles, motor vehicles and shipbuilding. Appropriate planning and development of alternate career paths for displaced workers can minimise the impact on workers, resulting in more productive industries and newly reskilled workers deployed elsewhere.

In this roadmap, the focus is on the sectors of the Australian economy expected to be most impacted by new robotic, automation, and computer vision technologies. Major sectors are discussed separately within the following chapters.

Some of these sectors have been exposed to automation over an extended period. For example, manufacturing has seen robotic technology implemented since the 1950s. Others, such as hospitality, are relatively new to the robotics and automation scene.

Therefore, contrast exists between industries that are mature in the adoption of robotics versus those that are still in more exploratory stages. The least mature market sectors are expected to be the ones that will see the most disruptive changes. As part of the roadmap process, we have calculated a 4-point maturity score for select sectors of the Australian economy, as shown in the diagram on p. 31. This highlights the contrast between various sectors and shows those that have the most potential for future gains.

Market size and robot maturity of sectors of the Australian economy



3.2 Workforce and skills

As companies seek greater automation, an increasing concern is echoed: "When will robots take our jobs?" There is no question that robotics and automation will lead to job losses in some areas of the economy. Reports of the loss of 6,000 jobs at NAB recently due to the application of artificial intelligence is one such example. The bank is, however, also committed to hiring 2,000 people with technology skills to support this [NAB17], making it important to recognise the net change in jobs over time. Policy has an important role to play in ensuring that the economic advantages of robotics are shared equally in our society – a point acknowledged in the Innovation and Science Australia 2030 plan [ISA17].

It is known that most CEOs considering the adoption of these technologies do so with the aim of reducing headcount [PwC17]. Economists refer to this as "substitution", where new processes cause job shedding and changes to the nature of work. Conversely, the benefits of technological change can also create wealth and jobs, producing an "income" effect. These two major economic forces normally work in opposite directions.

For automation and robotics, short-term job loss and disruption will be most keenly felt by those employed within the Services sector. In the long run, income effects are likely to comfortably outweigh substitution effects and produce economic growth and gains in employment. To buffer the short-term substitution effects and take advantage of the long-term income effects requires careful consideration of the sectors of the economy most likely to benefit or be disrupted by these new technologies and concentrated programs that support and, where necessary, reskill workers who initially lose their jobs.

As Australia enters the age of Industry 4.0, the fourth industrial revolution, lessons need to be learnt from the past. After the first industrial revolution, economic conditions for the working class fell for several decades until economic and social measures were put in place to make a fairer system. Those measures and the fairness they support are an important part of the Australian labour market which has continued to reform with the times. The past 40 years have seen a decline in union membership and more opportunities for businesses to command flexible working conditions from employees. During this period, there has been a rise in part-time and casual work, and some workforce restructuring has been due to technology and a greater take-up of automation and robots. Despite this, the measure of income equality used by the OECD and the Australian Bureau of Statistics, the Gini CoEfficient, has remained largely stable this century.

> As companies seek greater automation, an increasing concern is echoed: "When will robots take our jobs?"

Future advancements in the application of robotics and automation will continue to give rise to further concern about inequality, with productivity gains harnessed by robot owners at the expense of workers. While many people will benefit from robotic technologies, the risk to social cohesion if those benefits are not evenly shared justifies an urgent focus of social policymakers. Good policy planning is required to protect individuals from bearing the brunt of change which will deliver broader societal benefits.

This debate is not unique to Australia. It has been shaped by a series of international studies which, with increasing sophistication, have sought to map the impact of automation on current employment. The dominant reference has been the Frey/Osborne study of 2013 [FO13] which determined that 47 per cent of North American and British jobs were at risk from technology. A study by the Committee for Economic Development of Australia (CEDA) achieved a similar outcome in 2015.

More recent northern hemisphere work by Frey and Osborne [FO13] looked in greater detail at other societal impacts on employment and concluded the vulnerable category of jobs was closer to 20 per cent over the next decade. Importantly, it nominated another 10 per cent of current jobs that would grow and concluded that the impact on approximately 70 per cent of jobs was impossible to predict.

The World Economic Forum and Boston Consulting Group have started to map which skills might be transferrable from jobs currently thought to be vulnerable. This work indicates that careful career planning involving individuals, corporations and governments can create more valuable alternative roles for those at risk. There are, however, associated issues that influence this outcome, including inflexibility of ageing workers and educational levels that may prevent some workers easily shifting from their current mode to working with technology.

Attempts to address such issues have given rise to discussion around the need for a universal basic income to ease the transition for those potentially pushed from the workforce through technological advancements. This is an ongoing discussion and is subject to trial in some northern European countries. An associated issue is the rise of the so-called ‘gig economy’ of freelance workers competing internationally for digitally based work. While there is concern at its impact on employee conditions, the Australian Productivity Commission notes there is not yet substantial evidence of the rise of a gig economy in Australia [PC17].

Skills required for a robot economy

How do we educate our children for the jobs of the future? How can we help the current workforce adapt? What are the skills needed for a new robot economy? Some of the most common skills required are generalist, creativity, adaptability and resilience. While there is an increased focus on science, technology, engineering, and mathematics (STEM) education at all levels in Australia, will this be enough to prepare people for jobs that have not yet been created? Like all new technologies, integrated skills encompassing the social sciences, law, economics, the arts, and design are necessary to ensure acceptance by society.

How do you rapidly reskill people for a dynamic job market? What will the guaranteed jobs of the future look like aside from robotics engineers and robot handlers? Does Australia have mechanisms in place to cope with the structural adjustment and the speed of workforce change that is likely to take place, where micro-credentials (validated learning of specific skills in a concentrated timeframe) will become increasingly important.

There are concerns that Australia is not yet well-positioned to meet these skills challenges. *Australia 2030: Prosperity through innovation* (the *Innovation and Science Australia 2030* plan) [ISA17] recommends a review of the nation’s vocational education and training systems and, subsequently, the development of *“a strategy to make the sector increasingly responsive to new priorities presented by innovation, automation and new technologies”* (see Recommendation 4).


Image courtesy of UVD Robots

3.3 Ethics

The consensus from the national workshops held to develop this roadmap was that ethics deserved immediate attention. The World Commission on the Ethics of Scientific Knowledge and Technology (COMEST) released a report on robotics ethics in 2017 that acts as a good starting point [CRE17]. Many participants pondered the question of whether, just because we can develop new technologies in robotics, should we, and to what extent? Some examples given of the dilemmas facing the developers of new technologies include:

> As robots increasingly impact on daily lives, consideration must be given to how humans design, construct, use and treat robots, and other AI.

- On a fully automated farm, is it okay for robots to terminate livestock?
- In pest control, who decides which pests it is okay to control?
- In a fatal accident involving an autonomous vehicle, who is deemed responsible – the robot?
- In aged care, is it okay to have a robot perform duties that involve direct contact with a person such as massage?

A set of national guidelines or a charter that considers the policy implications are urgently required. These ethical considerations must be translated into guidelines, regulation and legislation, an area where government will play a crucial role, as acknowledged in an Australian Government consultation paper, released in September 2017 as part of the development of a new digital economy strategy [DE17]. The paper notes the need to “consider the social and ethical implications of our regulations relating to emerging technologies, such as AI and autonomous systems” – especially when they are involved in making decisions. Some of the broader ethical issues relating to autonomous vehicles were canvassed by the House of Representatives Standing Committee on Industry, Innovation, Science and Resources report on the ‘Social issues relating to land-based automated vehicles in Australia’ [PCA17].

As robots increasingly impact on daily lives, consideration must be given to how humans design, construct, use and treat robots, and other AI [NAT16]. These ethical considerations or “roboethics” [RE16] are human-centric. The term “machine ethics” is used to describe the behaviours of robots and whether they are considered artificial moral agents with their own rights.

Roboethics is concerned with developing tools and frameworks to promote and encourage the development of robotics for the advancement of human society and the individual, and to prevent its misuse. Using roboethics, the EU has devised a general ethical framework for robotics to protect humanity from robots [EU16], based on the following principles:

- Protecting humans from harm caused by robots
- Respecting the refusal of care given by a robot
- Protecting human liberty in the face of robots
- Protecting humanity against privacy breaches committed by a robot
- Managing personal data processed by robots
- Protecting humanity against the risk of manipulation by robots
- Avoiding the dissolution of social ties
- Equal access to progress in robotics
- Restricting human access to enhancement technologies.

Australia needs to consider its own set of roboethical principles, suitable for the Australian context, that can be used to guide in the development and application of new robotic technologies. It has been more than 10 years since South Korea announced plans to create the world’s first roboethics charter [NS07], to prevent the social ills that might arise from having inadequate legal measures in place to deal with robots in society. South Korea has the world’s highest population density of industrial robots, 631 robots per 10,000 people compared to Australia’s 84 robots per 10,000 people [IFRIR17]. The charter details the responsibilities of manufacturers, the rights and responsibilities of users, and the rights and responsibilities of robots. Some robot rights are written into Korean law, affording robots the following fundamental rights: to exist without fear of injury or death and to live an existence free from systematic abuse. In Korea it is illegal to deliberately damage or destroy a robot, or to treat a robot in a way which may be construed as deliberately and inordinately abusive.

3.4 Design

A movement towards ethical design of technology has seen researchers and companies deploying frameworks for new technologies. This includes value sensitive design or 'responsible innovation' to help identify likely stakeholders and their values. One weakness of such frameworks is that they are often deployed on the assumption that a system will be built. The role of designers, policymakers and society should be to decide whether a system should be built at all, before being unleashed on important public infrastructure such as hospitals or courtrooms. Developers of new robotic technologies should apply these principles, which typically rely on focus groups or other techniques, to establish stakeholder views on a range of issues such as data privacy, which can then be incorporated into technology design.

Advances in autonomous robotics, and especially in the use of robotic vision systems, will make autonomous robotic systems increasingly available to non-specialist users. Although their autonomy is increasing, this does not mean an end to the need for human-robot interaction. For instance, autonomous agricultural robots will need to be maintained by farmers and instructed on which weeds to remove, which crops to harvest and which seeds to plant; autonomous scientific platforms will need human input on what types of data to gather, from where, and will need to make that data available in forms that human collaborators can make sense of. Robotic autonomy will bring a need for new kinds of interaction and new knowledge about how to design interactions so they make sense for a wide range of non-specialist users [JD17].

Non-specialist users present significant design challenges for any interactive technology, but particularly for autonomous robotics systems, which lack established conventions of use (see 3.3 Ethics). Previous research has uncovered some of the factors that contribute to intuitive use in existing product categories [BPM03], however, there is currently little known about what contributes to intuitive use of autonomous robotic systems. Social uptake of these new technologies will be strongly dependent on how people experience the use of the technology. The development of intuitive user interfaces will be key and can make these technologies accessible to more people and therefore have a greater positive impact on the world [JD17].

The EU mandates that robot design should incorporate the following considerations across all robot types:

Safety

Design of all robots must include provisions for control of the robot's autonomy. Operators should be able to limit robot's autonomy in scenarios in which the robot's behaviour cannot be guaranteed.

Security

Design of all robots must include, as a minimum standard, the hardware and software keys to avoid illegal use of the robot.

Traceability

Design of all robots must include provisions for the complete traceability of the robots' actions, similar to an air craft's 'black-box' system.

Identifiability

All robots must be designed with protected serial and identification numbers.

Privacy

Design of all robots potentially dealing with sensitive personal information must be equipped with hardware and software systems to encrypt and securely store this private data [EU06].

3.5 Safety and Standards

Robots should be safer than humans at achieving the same tasks, such as driving, because they are engineered systems not burdened by human fallibility (except in their conception). Traditionally, robots have operated in interlocked cells, isolated from people to ensure human safety. However, modern robotic systems are increasingly allowing more collaborative applications and it is no longer always practical to keep them physically separate from people. Many robots must operate in public spaces, such as retail robots or robotic vacuum cleaners (see Chapter 7). For this reason, ensuring that robots can operate safely in public, unconstrained environments, where required, is becoming critically important.

Who is responsible for ensuring robots, including imported robots (which account for most of the Australian robot population) are safe? The answer is multi-faceted. The manufacturer (if Australian), the importer, the supplier, the integrator, the designer, the retailer and the employer (where it is a workplace robot) all bear equal responsibility.

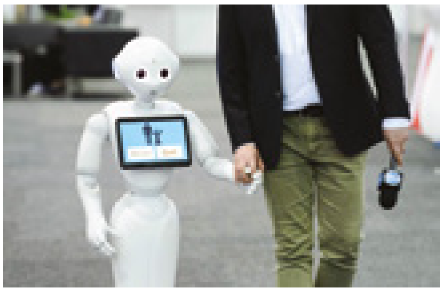
Australia has well established standards for industrial robots to minimise risk in industrial settings. The expanding population of service and personal care robots is less well-regulated, however, as these robots are often deployed in a home setting rather than a workplace. For this reason, it is important that Australia has standards for the use of service and personal care robots. There are some international standards for these robots that may be adopted in Australia in the future (for example, ISO 22166-1 *Modularity for service robots*; ISO 13482:2014 *Safety requirements for Personal Care robots*). As the demand for robots increases, and new robots become available in the market, there will be a need for new, relevant standards. The development and application of suitable standards is being considered as part of the Australian Government's work towards a new digital economy strategy [DE17].

Who is responsible for ensuring robots, including imported robots (which account for most of the Australian robot population) are safe?

Industrial robots have their own machine specific standards due to their potential strength, speed, and complexity of operation. For example, a person may not be able to predict what a robot will do next as its programming may be complicated, plus the robot utilises multiple sensors which have a probability of dangerous failure. The robot standards define the integrity of safety control systems that are required and the 'best way' for ensuring safety of personnel in all modes of operation.

Interoperability is a challenge facing the adoption of automation and robotics, and is a mixture of technological, commercial and regulatory challenges. The Institute of Electrical and Electronics Engineers' (IEEE) Robotics and Automation Society Standing Committee on Standards Activities is experimenting with standards that allow robots to interact and communicate with other robots, but these standards are not enforceable. Standards for interoperability of autonomous systems should be urgently addressed.

Standards for the safety of vision systems is also an area of concern. Presently, it is not clear when a vision system can be deemed 'safe', for example, what level of recognition is required? 100 per cent recognition of people under any weather and lighting conditions? What levels of redundancy are required?



Images courtesy of CSIRO Data 61

3.6 Legal Frameworks

As part of a national roadmap for the adoption of robotic technologies in Australia, Australian policy-makers need to develop a well-adapted regulatory framework for robotics at a federal, state, and territory level. In-depth interviews as part of the roadmap's national consultation process suggest that government and industry regulatory and compliance laws are a barrier to the development of a robotics industry in Australia. New technologies (automated construction, drones, and similar) are received well by, and would often benefit, companies operating in Australia, but their uptake is hindered by government and industry regulations designed for other purposes. For instance, a surveying company may want to use a drone for onsite surveillance, but they are hindered by airspace regulations.

While there have been parliamentary inquiries on the implementation of some robotic technologies (for example, autonomous vehicles [APH17]), there needs to be a more systematic effort to develop a co-ordinated national response on the regulation of robotics. This will both enhance Australia's prospects and opportunities in the field, establish public trust and community acceptance, and deal with risk and liability in an appropriate fashion. The Australian Productivity Commission could play a useful investigatory role in respect of providing expert advice on the adoption of robotic technologies. Australia needs to develop laws in respect of robotics, which are adaptable, efficient, effective, and accountable.

In the United States, lawyers and scholars have sought to develop a larger jurisprudence in respect of robotics law and policy. This framework has sought to engage in the legal classification of robotics, and bring together a wide range of fields of regulation - including intellectual property law; privacy law; employment law and occupational health and safety; liability; crime and justice; and military law.

The European Parliament issued a resolution in 2017 on robotics law and ethics [EU17]. As well as articulating general principles, the resolution focuses upon research and innovation, education and training, liability, intellectual property, data, standardisation, security, and safety. Moreover, the resolution has a special focus upon autonomous means of transportation - looking at autonomous vehicles and drones. The resolution also notes some special considerations associated with public health care robots, medical robots, and human repair and enhancement. The resolution discusses larger issues about environmental impact. The European Parliament has also made suggestions in terms of developing codes of ethics for the inventors and users of robots. There is a strong focus upon the protection of fundamental human rights in the resolution.

At an international level, there have been several developments in respect of robotics law and policy. A recent 2015 World Intellectual Property Organization report highlights the competition in respect of patents in this field. If Australia is going to be competitive in the field of robotics, it needs to provide for good pathways for research, development, and commercialisation of intellectual property in the area (see Section 2.3).

Contributors

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4 Resources

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

Image courtesy of Rio Tinto

4.1 Australia’s resources sector

Resource operations produce 40% of Australia's exports and are often located in remote and regional areas of Australia, which cover 85% of the Australian land mass (see also Agriculture, Chapter 10). However, the vast distances present numerous challenges in service delivery, freight distribution and telecommunications, many of which can be solved via the application of robotic technologies – a point acknowledged by the Minister for Resources and Northern Australia, Senator the Hon Matt Canavan. In his speech at the National Press Club 28 March 2018, he said that automation “fundamentally changes the geography of mining” [RE18]. As noted in Australia 2030: Prosperity through innovation (the Innovation and Science Australia 2030 plan, p18) [ISA17], Australia leads the world in mining automation technologies. This allows the Australian resources sector to operate safely and more efficiently in remote and harsh conditions (AT17).

Mineral, oil and energy resources are still vital to sustaining Australia’s ongoing economic prosperity, directly contributing more than 8 per cent of Australia’s GDP. The Resources sector dominates Australia’s export income, leading 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. In 2017, the resources sector employed more than 200,000 people and generated $AU205 billion in export revenue – 40 per cent of the nation’s export earnings. The sector has made significant improvements in health and safety over the past decade, reducing the incidence of both fatal and serious injuries. Worker fatalities have decreased 65 per cent from 12.4 worker fatalities per 100,000 workers in 2003, to 4.4 in 2015. However, the sector still has one of the highest fatality rates of any industry with an average of 9 workers dying each year. In addition to direct-mining activities, Australia’s Mining Equipment and Technology Services (METS) sector (the backbone of the resource supply chain) employs 386,000 people and delivers $AU90 billion to the Australian economy. However, over the past 20 years, half of Australia’s share of global exploration investment has moved offshore to countries where the technical risk of exploration is considered lower [AM17].

Australia’s METS sector is diverse and mainly comprised of SMEs (1-199 people) that provide specialised products and solutions for mineral exploration, extraction, and mining supply chains. This includes equipment manufacturers, engineering services, mine software products and other related equipment, services and technologies, where the primary function of the division, department, or specialty company is to support the mining and mineral extraction industries. METS companies derive most of their revenue from products and

Snapshot: Resources Industry

A long-term contributor to Australia's growth and prosperity.

$205b exports

217,600 people employed

Sector Definition

Resources - includes minerals and energy exploration, extraction and processing.

Key activities include

extracting naturally occurring mineral solids, such as coal and ores; liquid minerals, such as crude petroleum; and gases, such as natural gas; underground or open cut mining; dredging; quarrying; well operations or evaporation pans; recovery from ore dumps or tailings as well as beneficiation activities (i.e. preparing, including crushing, screening, washing and flotation) and other preparation work customarily performed at the mine site, or as a part of mining activity

Challenges/Opportunities

- Safety
- Labour costs
- Social License to operate
- Remote operations (FIFO)
- Regional development and infrastructure
- High exploration costs as easily exploited (shallow) resources are exhausted

Key Robotic Technologies for the sector

- advanced computer vision
- machine learning
- AI capabilities

services supplied to the mining sector and, consequently, there is a mutually beneficial relationship between the METS and mining sectors. METS companies focus on developing solutions and providing services to mining companies, both domestically and globally. They are innovative and have a deserved reputation for developing cutting edge technologies. The partnership of both METS and mining companies with publicly funded research organisations (PFROs) has resulted in world-class outcomes, which have been deployed not only within the mining industry, but also in adjacent industries including the defence, automotive and manufacturing sectors.

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).

Australia is a secure source of 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 Atlas Copco (Epiroc) see Australia as the ideal testbed for advanced autonomous mining equipment.

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. The impact on the METS sector will directly relate to how well it adapts and develops automation and robotics capacity to meet this need, both on a local and international scale. However, greater automation may reduce jobs, or at least will change the types of jobs available. Over the five years to November 2020, employment in the mining industry is projected to decrease by 14.1 per cent nationally [DE16]. In his speech on 28 March 2018, Minister Canavan announced the establishment of a taskforce to lead development of a new resources statement, for release later in 2018 [RE18]. The work of the taskforce will encompass new ideas, new technologies, and policies to *"attract investment, contribute to regional economic progress, build community support, simplify business, find new minerals, and ensure that Australia gets best use of its mineral resources before they are exported."* There is a clear role for robotics and automation in achieving all this, and the robotics industry welcomes the opportunity to engage with the taskforce by connecting contributors.

4.2 Robotics and the resources sector today

Australia's mining innovation efforts to date have resulted in the country being recognised as a low-cost producer in iron ore, and Rio Tinto becoming the world leader in mining automation. The economics of autonomous haulage systems (AHS) show gains achieved via: reduction in fuel consumption (~10%), maintenance costs (14%), tyre wear (12%), labour cost (5-10%), and truck life time (12%). Autonomous fleets outperform manned fleets by an average of 12 per cent, primarily by eliminating required breaks, absenteeism, and shift changes. Over the past eight years, Rio Tinto has spent about $AU1.5 billion on technology programs in iron ore, including its automation efforts and an Operations Centre in Perth. This is no small sum when placed in the context of the federal government's recent announcement to spend around $AU1.1 billion over four years on economy-wide innovation efforts. Rio Tinto's actions and expenditure demonstrate the central role that the private sector must play in developing and adopting new ideas and converting them into real productivity improvements [BAE16].

The nature and scale of activities in the resources sector sets it apart from other sectors.

The nature and scale of activities in the resources sector sets it apart from other sectors. While the average life expectancy for Fortune 500 companies is only 15 years [BBC12], just the production phase from a mine site can continue for 40 years or more [AM17]. The resources sector also draws upon significant financial, human and natural resources due to the nature and scale of its activities. The impact on the resources sector from global megatrends identified by the CSIRO, will be partially addressed by robotic technologies [CS17].

The relevant megatrends are:

Higher global primary energy demand

Demand for primary energy is predicted to grow due to population growth, increased urbanisation and expansion of the middle class. Global population is expected to increase from 7.6 to 9.8 billion people by 2050.

Rapid technology shifts

New digital technologies and systems (including data, sensors, and hardware) will improve and be adopted but they may initially lack integration and interoperability thus limiting potential benefits.

Increased costs and complexity

Large reserves of minerals, oil and gas have been largely exploited. New reserves will be deeper, and more difficult to extract.

Heightened engagement

Social license to operate has become more important within the resource sector with a growing need for resource companies to undertake greater community engagement and purchase locally. This includes an imperative to engage over contentious issues such as robotics in the workforce.

4.3 The future of robotics in the resources sector

The resources sector has a great opportunity to lead other sectors of the Australian economy and improve the overall low rates of automation and adoption in Australia. While the resources sector is by far the most advanced sector in terms of adopting automation, there are still areas where robotics can lead to further advances. The greatest ongoing impact for robotics in mining is between exploration and the mineral processing function. This phase encompasses mine planning, the actual mining process (drill / blast / load / haul) and comminution (breaking of rocks).

> The greatest ongoing impact for robotics in mining is between exploration and the mineral processing function.

Benefits of future application of robotics to mining [MZ15] include:

- Changing the mining process into more precise and predictable operations as evident in manufacturing – for example, creating ‘a rock factory’,
- The possibility of undertaking mining in geographic areas that would otherwise be unviable due to hazards and/or remoteness,
- Miner safety and improvements to mining logistics and planning.

The mining industry is starting to embrace mobile automation in the form of haulage in open pits and loading in underground operations. This is already having a positive impact on production and safety for long-life bulk commodity mines. In the future, these benefits may be seen in shorter term specialist mining operations once autonomous equipment becomes cheaper, increases in functionality and flexibility, and encompasses greater interoperability.

The goal for resource companies is true automation whereby mining or resource extraction becomes non-entry, that is, human-less. Non-entry mining allows different (and sometimes more economical) geotechnical approaches to ground support and slope angles, increasing productivity and allowing access to previously sub-economic ore bodies. True automation of the mining process would also require the automation of the ancillary tasks, including geology, geotechnical, surveying and sampling. Non-entry resource extraction also allows mines to act more as warehouses, with the possibility of mining on-demand or just-in-time extraction of resources as they are required.

Second order value for mining companies is also bringing short interval control to the mining process. This is a well-established function in mineral processing and in oil and gas, but has remained elusive in the extraction sector due to its complexity and variability. This process requires the digital conversion and virtualisation of complex tasks, such as geology and geotechnical functions. This would require a significant effort in advanced computer vision, machine learning and AI capabilities. The Innovation and Science Australia 2030 plan [ISA17], suggests that the forthcoming Digital Economy Strategy should prioritise *“the development of advanced capability in artificial intelligence and machine learning in the medium - to long-term to ensure growth of the cyber–physical economy.”*

These changes require specific research and development in key areas that can play to Australia’s core strengths. Australia has the greatest latent domain knowledge in mining consulting services as well as being the leader in mining software. This reservoir of skills and knowledge in conjunction with our strength in computer vision provides Australia with a clear advantage in developing the complex blend of computer vision, machine learning and AI products.

New sensing and communication technologies will drive improved safety and productivity and enable greater automation and remote control. Australia is already a world leader in the development and export of integrated systems technology. Breakthroughs in automation, data analysis, modelling and resource processing have changed the nature of mining work. The rise in connectivity and remote sensing technologies is enabling the development of new remote monitoring and analytics solutions. This has allowed some METS companies to alter their business model from providing products, processes and services to

> The rise in connectivity and remote sensing technologies is enabling the development of new remote monitoring and analytics solutions.

working with producers to provide end-to-end services internationally, such as remotely monitoring mining operations.

Interoperability is one of the issues facing industries and companies seeking greater automation and application of robotics. Interoperability can pose a combination of technical, commercial and regulatory challenges. Most mine sites use a mix of equipment and fleet suppliers whose solutions do not communicate due to the sometimes significantly different network, safety, and control system related requirements of the robotic systems of each original equipment manufacturer (OEM). This challenge is being partially overcome. For example, OEMs like Caterpillar have recognised the need for interoperability and will, by 2019, have a substantial fleet (>20) of competitive trucks in blended autonomous operation.

Standards for interoperability for minerals and energy applications should be addressed. Who is accountable for safe operation of a blended/integrated system? Which element of the system will make decisions that will influence safe operation, e.g., speed limits? Who is responsible for validating new systems for safety and operational performance when new software releases impact across multiple providers? Many of these issues are currently being worked through for self-driving cars.

In the future, complete autonomy will be needed, which will include:

- Optimised and decentralised cooperative robotics systems that can be independently aware, meaning less reliance on a control room.
- Strategic, tactical and adaptive path planning and machine control, object detection and classification systems to ensure optimised collision-free navigation.
- Cycle determination and segmentation for productivity monitoring.
- Robust perception - when operating in unknown, complex and/or dangerous environments, a robot relies on its sensors and interpretation algorithms (perceptual systems). More work in sensor fusion, machine learning and AI needs to be done to make these systems robust.
- Robust and accurate positioning and localisation that does not rely on global positioning systems (GPS).
- Robust robots for working deep underground under high temperatures and pressures.
- Small-scale ‘nano’ robots to do in-situ extraction of resources, on-demand.
- Robots that can self-create - for space mining this would mean being built on location.
- 3D printing of mine infrastructure.

4.4 Main findings for robotics in the resources sector

The resources sector has an important role to play in sharing knowledge of world-leading automation with other sectors of the Australian economy. Important drivers for robotics in the resources sector include safety, productivity and overcoming the challenges of operating in remote and harsh conditions at scale. The provision of remote services is an area where Australia can arguably lead the world and can have important spill-over effects into areas such as the delivery of medical services to remote and disadvantaged Australian communities. A focus on robotics in the future will see the resources and related METS sector continue to advance, with Australia acting as an ideal testbed for advanced autonomous mining equipment. Key opportunities in the future are the reduced price and scale of robotic solutions aiming towards on-demand and in-situ human-less mining and mineral processing.

Image courtesy of Rio Tinto

Case Study: Rio Tinto Mining Automation

Rio Tinto's fleet of autonomous haul trucks have moved more than 1 billion tonnes of material to date. Since commencing trial operations in 2008, haul trucks fitted with autonomous haulage system (AHS) technology have now moved both ore and waste material across five sites in the Pilbara, including the newly commissioned Silvergrass mine. Last year, Rio Tinto's autonomous fleet accounted for the movement of about a quarter of the total material moved across Pilbara mines. On average, each autonomous truck was estimated to have operated about 700 hours more than conventional haul trucks during 2017, with around 15 per cent lower load and haul unit costs. Importantly, there have been zero injuries attributed to autonomous haul trucks since deployment, highlighting their significant safety advantages [RT18].

Autonomous haulage systems used in mining are in high demand. The typical approach is to enhance existing mining trucks by integrating them with robust autonomous sub-systems. As an example, Komatsu introduced its FrontRunner® autonomous haulage system (codeveloped with Modular Mining Systems, USA) for use at Rio Tinto's Pilbara iron ore operations in Western Australia. Meanwhile, at the Rio Tinto Pilbara mining site, about 100 autonomous trucks are operated. The trucks navigate the complex mining environment to deliver payloads of overburden and ore without drivers. This is revolutionising productivity and mine operations, especially at mines where it is difficult to secure sufficient labour, owing to their remote locations.

Images courtesy of Woodside Energy

Case Study: 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 Robonaut 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.

Further trials are planned at Woodside's onshore and offshore facilities throughout 2018.

Contributors

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5 Manufacturing

Manufacturing in Australia has been declining since the 1970s, when one in four Australian workers were employed in the sector. However, there are signs of recovery, with strong growth in 2018, particularly in food production.

Image courtesy of Laing O'Rourke

5.1 Australia's manufacturing sector

Australia leads the world in niche manufacturing for several high-value industries, including medical technology and aerospace, but needs to adapt to the fourth industrial revolution (Industry 4.0). The "smart factory" of Industry 4.0 has robots connected remotely to computer systems equipped with machine learning algorithms that can learn and then control the robots with little human input [FO18]. Industry 4.0 promises a new era of manufacturing where mass customisation and decentralised production are normal.

Despite its increasingly high-tech nature, modern manufacturing in Australia has an image problem. While the majority of Australians (82.5 per cent) believe the manufacturing sector should be supported, few people want to work in it [SMH17]. The sector is characterised by an ageing workforce and poor gender diversity (men outnumber women by almost 3 to 1) [WGEA16]. The manufacturing industry also has a high number of work-related fatalities, injuries and illnesses, with approximately 18 workers killed each year. Another concerning statistic in the industry is that young workers (those aged between 15–24 years) recorded an injury rate 44 per cent higher than young workers in the Australian workforce as a whole [SWA18].

Manufacturing employs many skilled and unskilled workers. For example, it is estimated that about 40 per cent of engineers are employed in manufacturing and related consulting industries [EA17]. 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 [AMWU16].

Manufacturing in Australia has been declining since the 1970s, when one in four Australian workers were employed in the sector. The downturn has gathered pace since the global financial crisis and the loss of Australia's automotive industry, and now only one in 13 Australians are employed in manufacturing. However, there are signs of recovery, with strong growth in 2018, particularly in food production [CS16].

Currently, about 80 per cent of the value of Australian manufacturing comes from four major sub-sectors: Food, beverage and tobacco products (27%), petroleum, coal, chemical and rubber products (19%), machinery and equipment (18%) and metal products (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 64 per cent of jobs in the sector. The remaining 36 per cent of employment is created by large enterprises with more than 200 employees [ABS16].

5.2 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 deploy 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 10 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.

To maintain and grow standards of living, Australia will have to increase productivity. Automation is a key to this and automation in manufacturing, which makes up six per cent of Australian GDP, will be a major contributor to the national well-being, as determined by living standards. In manufacturing, 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.

However, in Australian manufacturing, robotics numbers have flat-lined at around 7,500 installed units, growing only 1% over the 2011-16 period, while the number of robots installed worldwide has grown from 1,147,000 to 1,785,000, a 56% increase. A record 285,100 units were installed in 2016 alone [IFRIR16]. The following data demonstrates why Australia is ranked 18th in the world in robot density in the manufacturing industry [IFRIR17]:

In Australia, there are

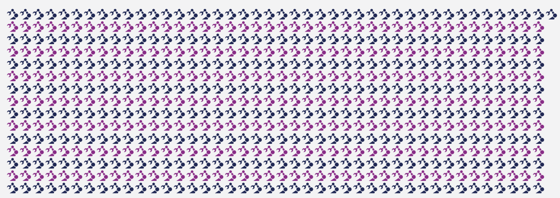
83 robots per 10,000 employees

The world average is

74 robots per 10,000 employees

In South Korea, ranked 1st in robot density for manufacturing, there are

631 robots per 10,000 employees



> Automation in manufacturing must evolve to support small manufacturers with a diverse range of needs and capital constraints.

Growth in Australia's use of industrial robots has been tempered by the demise of the automotive industry (2017), which had a large density of robots per worker. This has magnified the fact that 64 per cent of Australian manufacturing companies are SMEs (between 1-199 employees) with a relatively high ratio of highly-skilled persons to low-skilled labour [PM12]. 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. Full automation of unskilled jobs can be purchased, and Australia needs to develop specific technology to support reskilling and redeployment of the existing workforce.

Automation in manufacturing must evolve to support small manufacturers with a diverse range of needs and capital constraints. Australian manufacturing is not large enough to support the creation of the appropriate tools to deliver these needs alone. However, by investing appropriately and sharing people, data, and solutions across sectors, Australia can grow a national capability to support and expand its niches and compete in the rapidly changing manufacturing world.

Another considerable opportunity is the blurring boundary between manufacturing and other industry sectors, which were once considered discrete. For example, construction is moving towards pre-fabrication 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 are taking place onsite. This is an opportunity for two discrete and non-competitive sectors who have a shared driving need in the core capabilities robotics offers.

Snapshot › Manufacturing Industry

World class niche applications with strong public support to make things in Australia.

$99b output

$96.1b exports

838,000 people employed (6.7% total Australian employment)

Sector Definition

Manufacturing is making chemical, mechanical, physical material transformations, substances, and components into consumer and industrial goods.

Key activities include

- Food
- Beverage and tobacco manufacturing
- Metal products manufacturing
- Petroleum
- Chemical and rubber products manufacturing

Challenges/Opportunities

- Ageing workforce and skills shortages
- Safety
- Lack of diversity
- Labour costs
- Accelerating and the disruptive impact of technology
- Changing skill requirements
- Small volumes

Key Robotic Technologies for the sector

- Collaborative robots
- Learning and adaptation
- Human/Robot interaction
- Perception
- Explainable AI
- Certified vision for safety

5.3 The future of robotics in the manufacturing sector

Robotics in large manufacturing companies has been widely deployed across a variety of tasks. This includes material handling (73%), welding (4%), assembly (drilling, fastening, fitting, riveting - 2.4%), processing (gluing, painting, polishing, routing - 1.2%), packaging (<1%) and inspection (including clean room – 9.4%) [IFRIR17]. Take-up of robotics by Australian organisations, however, is producing low volumes, and customised or complex products have been limited due to inflexibility and the high barriers of entry to existing robot systems.

> SMEs typically lack the resources to have dedicated automation engineers on staff.

The opportunity to apply new robotic technology in the manufacturing sector is two-fold: to enable seamless and safe co-operation between robots and people, and to allow rapid adaptability of robots to new tasks without requiring a deep automation skillset 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.

Adding a robot to a production system yields improved quality, safety, and productivity. The productivity of person-robot teams is greater than either person teams or robot teams alone. The deployment of a collaborative 'assistant' robot that can communicate and work safely with people in manufacturing environments would unlock latent productivity and augment Australia's world-class talent pool.

SMEs typically lack the resources to have dedicated automation engineers on staff. This limits the uptake of robots into low volume, or highly customized, production lines, as the programming cost can overwhelm the productivity improvements. Using AI and vision to build robots that can learn skills from experience or demonstration, and share those skills across industries or organisations, will further allow robots to be added to Australian factories at low cost and without requiring highly skilled programmers to be on staff.

Low volume, custom manufacturing relies on high quality to be cost efficient. Without the repetition and structure of a high volume standardised manufacturing line, "blind" robots can cause defects or pass on incomplete work. Equipping robots with integrated vision and other sensors enhances the information gathered during the manufacturing process. This allows robots to assess the job to be done, make any required modifications to ensure process quality, and record the outcome for auditing.

SMEs may not be able to easily quantify the impact of adding robotics to their manufacturing lines. High fidelity simulation enabling virtual prototyping, design, and commissioning of automation will allow manufacturers to reduce risk. Benefits can be validated before significant money is invested in hardware, and improved speed of deployment can be achieved once the design is finalised.

Achieving this step change is not a technology challenge alone. The Australian robotics supply chain 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 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 and 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.

5.4 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.

> 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.

Image courtesy of Laing O'Rourke


Image courtesy of Boeing

Case Study: Boeing Australia - Where humans and automation work together

Since the 2008 establishment of Boeing's advanced research and development unit in Australia, Boeing researchers have pushed the limits of what collaborative robots ('co-bots') might achieve in various facets of industry, including assembly, fabrication and repair.

New machines are targeted to work in areas that are repetitive and strenuous to team members. A recent example is the 737 component production system at Boeing's facility in Fishermans Bend, Melbourne.

Many 737 components have hundreds of rivets that need machining to a nominal height upon installation. It is time-consuming work that could lead to repetitive strain on human operators. Additionally, there is the risk of damage to the components, as manually-operated shavers can slip, leading to costly rework.

Integrating new technology can be a challenge because factory layouts are already configured, operators are experienced and skilled in existing processes, and there is often limited capital available for system change. Implementing a new robot cell needs to be low cost, cause minimal disruption, and deliver rapid payback of value to an already streamlined production system.

The Boeing team spent considerable effort designing a system that is lightweight, unobtrusive and contains redundant safety measures, both with respect to the co-bot and the shaver tool it applies.

Since the introduction of the low-cost, low-disturbance system in 2017, the co-bot has saved hundreds of hours of ergonomically-difficult human labour. This demonstrates that robots can be a mechanism to reduce human risk even as they work side-by-side with people. As an unanticipated tangible benefit, machining cutter consumption also decreased through efficient manipulation only possible by an automated solution.

This implementation by Boeing in Melbourne represents human-robot collaboration and a vision of the future for factories.

Case Study: Laing O'Rourke - Lifting frontline job satisfaction

Laing O'Rourke is a $AU6 billion international operation with 50 years of involvement in Australian construction and infrastructure. It prides itself on advancing off-site construction and, as a result, has embraced many fundamental manufacturing principles, as well as establishing significant scale manufacturing plants. *"Our perspective is that construction is the epitome of mass-customisation - we manufacture very large scale, expensive, intricate, and complex one-off units which some call buildings,"* Laing O'Rourke explains.

This philosophy is more than words. In 2011, Laing O'Rourke established a well-funded futures innovation group; the Engineering Excellence Group (EnExG) in Sydney, Australia to research, develop, deliver, and strive to lead innovations in the sector while also aiming to disrupt the industry.

One focus area for EnExG has been on exploring the deep-integration of robotics systems and capabilities into frontline work flows, environments, and machines of Laing O'Rourke operations. Recently, this workforce-need centred approach was applied to its Austrak rail sector manufacturing facility.

The result is a robot with sensing and perception capabilities that sees, understands, assesses and identifies potential issues such as manufacturing faults, needs for rework or rejection, forthcoming safety incidents, or a gambit of line issues (see picture). This creates the possibility for manufacturing machines and lines to intelligently act without worker involvement and present viable units, along with inherent recommendations to frontline workers. The disembodied robot seamlessly contributes to and is welcomed by the team.

With the line configured in this way, frontline workers are freed from the burden of routine work and can focus their expertise where they will contribute most.

Although this type of robotics implementation is notoriously difficult to measure with tangibles over a short time frame, the lift in frontline job satisfaction, engagement, and performance, along with the increased flexibility of these lines, is a demonstrable step towards operations of the future. If the robot is performing well and operations run smoothly and without incident it can, however, create the paradox of measuring the absence of negatives.

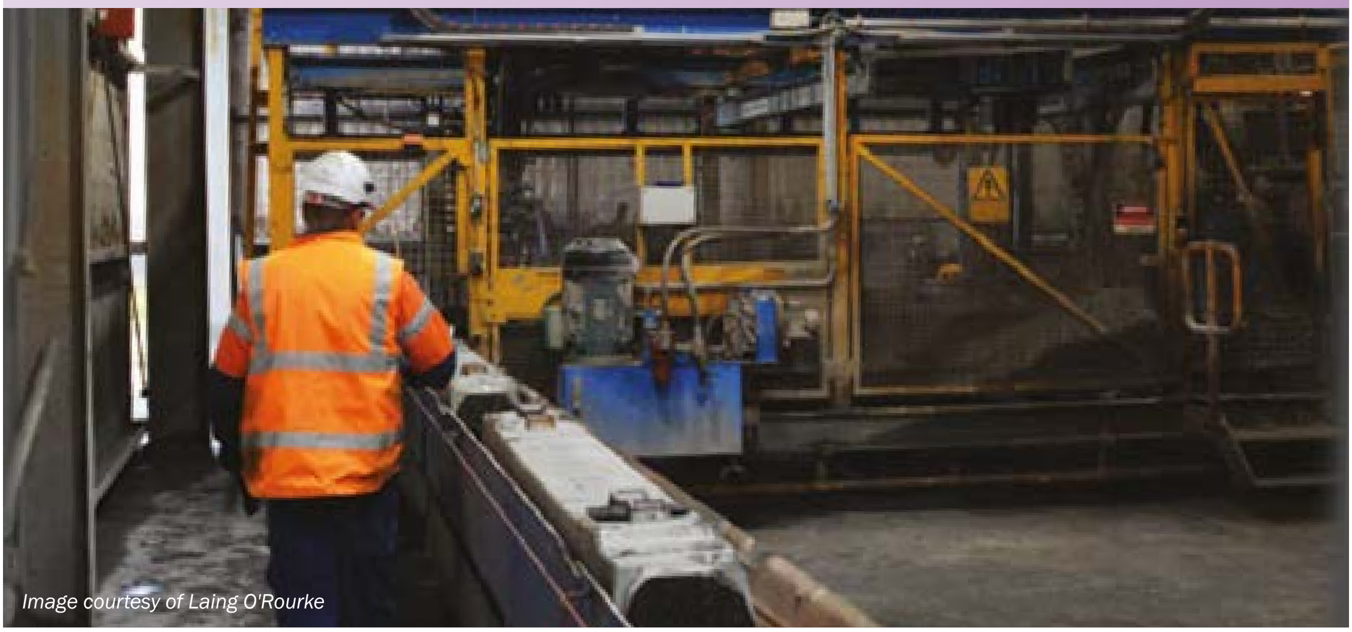


Image courtesy of Laing O'Rourke

Case Study: IR4 - Mass customisation via robotic automation

IR4 is an early revenue technology company that is setting global benchmarks in flexibility for the application of automation solutions. By utilising 3D model data as the single key input to system automation and control, solutions become viable in manufacturing environments characterised by:

- low volume
- significant product and environmental variability
- large numbers of product variants.

Once a 3D model is imported, the system simply requires raw stock and consumables to be maintained to automatically manufacture the specified products. When the design / product changes, the system automatically reprograms itself with an upload of the revised 3D model.

IR4 licenses their technology to another Australian company, SSS Manufacturing, to fabricate structural steel. At SSS Manufacturing, the real-time automation solution uses the system's artificial intelligence to calculate the most efficient way to process steel sections presented for fabrication. Processing includes all functions required to fabricate a steel section, being handling, blasting, scanning, cutting, coping, holing, welding, and painting. By using the 3D model, SSS Manufacturing has realised a reduction of more than 75 per cent in the labour content required to fabricate steel sections, despite incorporating innumerable variations, with 100% accuracy. This translates to significant customer benefits that include cost, quality, traceability, scheduling and ease of implementation of design changes.

IR4 is now working towards delivering extended capability and industry technology transfers. Additional capabilities being developed include:

- human machine collaboration
- solutions derived directly from 3D scanning data devoid of any 3D model data.

Image courtesy of IR4

Images courtesy of ANCA

Case Study: ANCA - Australia's largest user of industrial robots

ANCA is an Australian company, founded in Melbourne in 1974, now with offices around the globe. ANCA is the market leader of a high quality CNC (Computer Numerical Control) tool and cutter grinders supplying the aerospace, automotive, electronic, medical and other technologically advanced industries. The company has a sophisticated machine tool factory and employs highly skilled and specialised staff. Forming ANCA Motion in 2008, the company also produces CNC Control Systems, IO Devices, Servo drives and motors suitable for machine tool and motion control applications.

Until recently, machine tool users have not benefited greatly from robotics, with most applications dominated by manual tending. CNC grinders only have 1.5% of machine tools automated with robots. As robots become more affordable and easier to program, this trend is shifting.

Since 2014, the number of ANCA customers ordering CNC Grinding Machines with robot loaders has increased from 10% to 50% of machines sold. In response to this demand, ANCA has developed an innovative new multi-robot production cell. It works by having a larger robot devoted to wheel pack changes and part loading. A second, smaller robot is then free to 'multi-task' other operations within the cell. This opens a whole range of machining possibilities as one CNC grinder can essentially become a flexible manufacturing cell. Customers have found the cell has a better capability to manage components that are difficult to hold, such as turbine blades and knee joints. The approach has the added benefit of allowing two processes to run simultaneously. For example, the large robot can load wheel packs and parts into the machine while the smaller robot completes operations such as metrology, laser etching, or part washing. The dual robot technology reduces capital equipment costs, improves productivity, and reduces work-in-progress and inventory.

ANCA's world-first system is provided as a turnkey solution to several global customers. To build the dual robot technology, the company purchases between 35-40 robots per month but has plans to develop its own robotic manufacturing capability (see Case Study p. 18).

Image courtesy of Rotacastor

Case Study: Rotacastor - Newcastle company manufacturing robotic wheels

Australia Post used ball transfer tables for manual sorting of bulky international mailbags weighing up to 35 kilograms. This required substantial, repetitive manual effort by operators to push, pull and rotate the bags, exposing the operators to potential musculoskeletal injury. To address this issue, Australia Post looked for alternative solutions that would substantially reduce operator input and exposure to risk of injury. With a targeted push/pull force of 50N (5kg) for a 35kg bag, it was acknowledged that this target would most likely require a powered solution, adding to operating and maintenance costs.

The Rotacaster Solution: Rotacaster proposed a manual transfer solution utilising their 48mm Rotacasters combined with polyacetal (POM) spacer rollers. The roller's smaller diameter was designed to provide support for the soft packaging, while minimising friction and reducing the number of Rotacaster wheels required. Australia Post and Rotacaster collaborated on the design and construction of the transfer table. Trials were successfully undertaken at an Australia Post gateway.

Outcome: The solution resulted in a significant reduction of push/pull forces to between 40 and 70N (4-7kg) in all directions on the table. Australia Post considered this a remarkable achievement in the absence of any powered assistance.

Additional Advantages: In addition to reducing the push/pull forces required, without the cost, noise, and maintenance associated with a powered solution, the polymer surfaces of the Rotacasters and spacer rollers have demonstrated a lower affinity to adhesion of labels and stickers from packages, further reducing downtime and maintenance costs.

Case Study: Paddock to Plate

Meat & Livestock Australia (MLA) is currently driving an extensive $AU60 million program of advanced 2D and 3D imaging technologies, encompassing the full ‘paddock to plate’ red meat value chain. MLA has key strategic partnerships with leading domestic and global technology provider organisations, for example: hyperspectral imaging (US), dual energy xray (NZ), airline baggage CT (US), including both 2D and 3D modalities.

The imaging technologies are being developed for application: on-farm for livestock and pasture management with autonomous vehicles, in processing plants for livestock scanning for health diagnosis, in-plant for carcass robotic between-bone cutting lines, in-plant for robotic separation of meat from bones ‘robotic surgery’, and in-plant for robotic meat cut recognition with pick and packing into export cartons. Each has the objective of increasing value chain production and labour efficiencies.

MLA views the key opportunities of vision-assisted robotics as: the use of on-farm autonomous devices to conduct arduous or repetitive or time-consuming tasks, adding value to meat products through precise cutting and delivering high value-added products to selected markets, providing valuable process and product data to the value chain, and the ability to re-allocate valuable labour from arduous and repetitive processing tasks to value adding complex activities more suited to people.

Images courtesy of MLA

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6 Healthcare and Wellness

Health dominates public expenditure and employment. We spend more than 10% of our GDP ($170.4b) on health, making it a prime candidate for innovation to both reduce costs and improve outcomes.

Image courtesy of Go.Robot

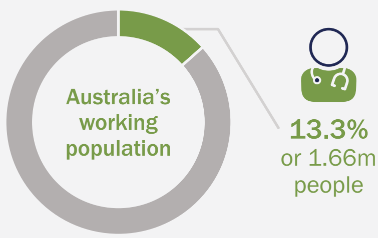
6.1 Healthcare and wellness in Australia

Australia has an ageing population and enjoys one of the highest life expectancies in the world (80.3 years for men and 84.4 years for women). Yet, more than one in two Australians suffer from a chronic condition, making wellness – freedom from disease – an important consideration.

Good health is not shared evenly across the Australian population. Indigenous Australians (3% of the population), those living in regional (32%) and remote (2.3%) locations, and 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 are especially affected by lack of medical advice, with health outcomes consistently below average [NSH16]. This is a pressing issue given that the rate per capita of medical specialists in Australia is 1 per 1,000, and 10 per cent of Australians travel for more than one hour to consult a general practitioner (GP).

Health also dominates public expenditure and employment. Australia spends more than 10 per cent of GDP ($AU170.4 billion) on health, 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 13.3 percent of the working population, or 1.66 million people [ABS17-1, LM18]. It also accounted for 16 per cent of serious workers' compensation claims in 2014-15, totalling 17,565 claims [SWA18]. 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 [SWA18]. They have one of the highest rates of work related injuries and illnesses, predominantly due to regular people handling.

The healthcare (and social assistance) industry is Australia's largest employer



6.2 Robotics, healthcare and wellness today

Healthcare and social assistance workers may work in designated facilities such as healthcare and residential facilities or within people's homes. These variable workplace environments, along with the fact that client services staff often work alone, can increase the risk to worker health and safety. Trends indicate that patients are getting older, sicker and heavier while workers are also getting older. More patients will need lift assistance, raising the risk for workers suffering from musculoskeletal disorders caused by the increased demand of hazardous manual tasks. Workers in aged care have a higher than average chance of being seriously injured at work due to hazardous manual tasks or slips, trips and falls [SWA18].

Robotic technologies can be applied to both medical treatment and to the provision of medical services, with benefits to both patients and healthcare workers. Robotics in treatment include medical interventions such as prevention and health promotion, treatment and care, and rehabilitation. Robotics in service provision impacts on resources applied to healthcare and wellness including human resources, logistics, material handling, research, monitoring, surveillance, and technology. Robotics applied to the medical environment provides an opportunity for significant benefits to the safety and well-being of healthcare workers.

The use of robotics technologies in healthcare and wellness has already produced new products and services and created new markets. The impact of medical robotics on clinical practice includes:

- 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 times and the number of subsequent treatments
- Enhancing the cost-effectiveness of patient care
- Enabling the delivery of services to remote areas
- Improving the training and education of medical personnel by using simulators
- Promoting the use of information in diagnosis and therapy [IFRSR17].

The healthcare and wellness sector has the potential to benefit from automation of parts of its workflow. However, despite

Broad areas where robotics could benefit healthcare include:

- Surgical robotics
- Vital signs monitoring and sample taking (e.g., blood)
- Remote or teleremote medicine
- Bionics, exoskeletons and lifting assistants
- Hospital services (e.g., food and medicine delivery)
- Pharmabots
- Manufacturing of medical devices
- Simulated environments for training medical staff
- Companions focused on health (particularly for the elderly).

more than 1.7 million robotics procedures worldwide (to 2013), the use of surgical robotics has not delivered on its early promise. Some equipment has been made more expensive and studies are divided on the overall health benefits related to the use of surgical robots. Between January 2000 and December 2013 there were 144 deaths, 1,391 patient injuries, and 8,061 device malfunctions associated with robotic systems used in minimally invasive surgery (MIS) [PLOS16]. Conversely, the use of robots in non-surgical areas is delivering undisputed benefits [IFRSR17]. Following is a description of some of the current common applications of robotics in the healthcare and wellness sector.

Diagnostic Systems

Diagnostic robots may come in the form of robot arms/manipulators that guide diagnostic equipment outside the human body or guide the body relative to a diagnostic instrument, or microrobots that carry diagnostic instruments inside the body. The most established procedures in this field are for radiology and biopsy where the robots can operate in potentially dangerous radiological environments [IFRSR17].

Logistics robots

Simple mobile robots transport material such as food, pathology samples, linen, and medical equipment around hospitals or between buildings on a hospital campus. This practice is becoming common at new hospitals in Australia, when the robots are planned for as the hospital is being built (see Case Study p. 64). Disinfectant robots are also being trialed [IFRSR17].

Pharmaceutical robots

Robotic pharmacists can be used in conjunction with electronic health records to dispense medicine and are increasingly used in some pharmacies.

Surgical robots

Australia is seen as a follower in the uptake of surgical robots, although the practice is rapidly increasing (see Case Study p. 65). Most common are teleoperated robots that allow surgeons from different locations to advise or operate on patients. The main uses are as surgical assistants (holding tools), tele-surgeons, image-guided surgery, and activation of motions such as drilling [IFRSR17]. The current motivation for using surgical robots is usually to increase precision rather than to increase efficiency (e.g., the use of the Da Vinci robot in urology to remove prostate cancer – robotic prostatectomy). More work needs to be done to improve

Snapshot: Healthcare and Wellness Industry

A costly industry with high potential for the introduction of robotics and automation to improve levels of care and services to remote communities.

$170.4b investment

1.66m people employed and predicted to grow

Sector Definition

Provision of medical services, manufacture medical equipment or drugs, provide medical insurance or otherwise facilitate the provision of healthcare or wellness services.

Key activities include

Hospitals | GPs | Pharmacies | Radiology | Pathology | Social assistance - aged and child care

Challenges/Opportunities

Safety | Labour costs | Workplace injuries

Key Robotic Technologies for the sector

Manipulation | Human-robot interaction | Deep learning | Simulation the accessibility, intelligence and accuracy of operations to reduce individual surgery time, making more treatments possible and reducing surgical waiting lists.

Vital signs monitoring and sample taking

Nurses regularly make and record measurements of vital signs and take samples from patients (mainly blood samples). Automated vital signs monitors have been developed but are not yet common. There are known issues with automatically recording the data that largely relate to IT systems and a lack of electronic health records. Inexpensive, non-contact, computer vision-based vital signs monitors would have significant impact. Automated machines for blood taking have been demonstrated, however they are not yet commercially available.

Remote or telemote medicine

Current mobile telemedicine is essentially a video chat session on a robot, but there is future potential to have the ability to either point or interact with the remote physical environment [ABC18]. Imagine a National Telemedicine Network (NTeN) in which a surgeon from Perth can help with a trauma case in Brisbane. This represents a good opportunity for Australia due to its significant proportion of rural and remote locations and known issues with the availability of suitable healthcare workers in such areas. The Australian Defence department also has a strong interest in this area, with some systems already used for remote ward rounds.

Rehabilitation and physical therapy robots

Rehabilitation robots assist people with a disability to complete necessary activities or provide therapy with the aim of improving the patient's physical or cognitive functions. The aim is to increase the training intensity for improved functional rehabilitation compared to using a human therapist's assistance. Physical therapy robots stimulate body movements, helping the patient to learn control of mobility functions (gait and balance, arm and hand) by controlled repetitive movements for neurological rehabilitation. As physical therapy is labour-intensive and strenuous for therapists, it is well-suited for automation [IFRSR17].

Bionics, exoskeletons and lifting assistants

By definition, these robots are likely to interface directly with humans. The military has been a significant funder of prosthetic limb and exoskeleton development. South Korea and Japan have focused on lifting assistance robots. Open-source bionics is becoming a significant activity world-wide.

Manufacture of medical devices

A significant proportion of medical devices must be custom-made for a patient (e.g., stents to replace heart valves). Consequently, some medical devices that may be presumed to be mass produced are in fact hand-made. The medical device industry has the potential to significantly benefit from the latest manufacturing techniques that utilise robotics (see Chapter 5).

Robot training for medical interventions

There is greater use of simulation in health care education to improve patient safety and quality of care. This includes the adoption of more realistic simulation-based teaching methodologies, which serve as a bridge between the acquisition and application of clinical skills, knowledge, and attributes, and increasing use of robotic simulators [IFRSR17].

Companion robots

Companion robots are becoming more common, particularly for the elderly or people with disabilities. These robots can replace or augment companion animals, providing a level of comfort and care, and increased mobility. Robots can also be used to remind elderly people living independently to take their medication or to help perform regular medical checks, such as taking blood pressure. Such robots have been trialled all over the world, including Japan, where *"around 5,000 nursing-care homes across the country [Japan] are testing robots"* [EC17]. Companion robots may be in the form of a humanoid or wheeled robot, and tend to resemble something 'cute' (e.g., cats, dogs, seals, or other furry creatures). The "Paro" robot provides a good example (see Case Study p. 67).

Social robots

Social robots are designed to interact with humans. Companion robots are a type of social robot but social robots have broader applications than companionship. Social robots are being trialled for use as concierge robots, delivering information and public health education to reduce the workload of healthcare professionals in these repetitive tasks. Social robots can be used to deliver interventions such as therapy or to monitor patient health and well-being.

6.3 The future of robotics in healthcare and wellness

New products and services related to robotics will continue to enter the existing market and create new markets in the healthcare and wellness sector. For example, Deloitte Access Economics and the Australian Computer Society recently considered how robotics and remote systems can alleviate health workforce shortages and enhance service provision in regional areas [ADP17].

The application of computer vision to medicine is being revolutionised by deep learning, a special branch of machine learning. It relies on 'so called' artificial deep neural networks to extract meaningful patterns in training data. This is then used to learn to detect and recognise objects in images, understand spoken language, or control robots. Deep learning has the potential to completely revolutionise the way doctors diagnose and treat diseases in the future.

A crucial prerequisite to train deep neural networks is the availability of training data. More data, and supplementary diverse data, leads to better outcomes. At the moment, the availability of anonymised pathological data (such as CT or MRI scans and radiographs) is very limited, and controlled by hospitals and individual medical practitioners. Access to such anonymised medical data can progress global advances in the detection, diagnosis, treatment, and management of diseases. This would allow remote, and early, diagnosis of conditions such as skin cancer, macular degeneration or diabetic retinopathy. Such advancement could have a major impact in reducing future medical costs. By working towards greater availability and collaborative use of anonymised patients' tests and histories to build deep learning powered smart devices, Australia can become a global leader in this area.

A crucial prerequisite to train deep neural networks is the availability of training data. More data, and supplementary diverse data, leads to better outcomes.

Due to the vast remoteness of Australia, there is not always a constant local supply of medication for acute and chronic conditions, especially if access requires consultation with a pharmacist. There is a clear need for a modern, transparent and sustainable solution. Remote pharmacies can fill this gap as well as provide a solution to certain emergency situations, such as to aid in disaster response and to support the Defence sector (see Case Study p. 66). The Australian Productivity Commission advocates robotic dispensing of routine medicine and a commensurate reduction in trained pharmacists. A similar opportunity exists for remote medical imaging, where patients are scanned remotely and diagnosed online by a combination of trained clinicians and artificial intelligence (see Case Study p. 68).

Australia has research strengths in biomechanical modelling and the development of simulation and training for both medical practitioners and for training robotic systems before deployment in real-life situations. Transfer learning is the transfer of control knowledge from one robotic system to another. When the source domain is a simulation, transfer learning is less costly and more practical than using a real robotic system in terms of energy, risk, wear and tear, and patient or operator safety, and has the added advantage of being able to be used multiple times. Simulation environments and transfer learning are important in any field where large or expensive machinery is used, and needs to be thoroughly tested.

The future includes the availability of AI-powered smart mobile devices that are trained on available medical data, reducing the pressure on clinical and outpatient services, freeing up doctors' time to attend and treat more critical cases. It includes logistics robots performing manual tasks such as linen and food distribution in the back-of-house, and greater use of social robots in front-of-house concierge roles, providing public health education, companionship to patients, and assisting medical professionals to do their jobs effectively.

6.4 Main findings for robotics in healthcare and wellness

Australia is a wealthy nation with enviable healthcare, yet providing services to remote and disadvantaged communities is challenging, and more than 50 per cent of the population suffers from at least one chronic disease. Advances in robotics (including AI) can assist with the provision of medical, pharmaceutical and imaging services to remote communities and can aid in the detection, diagnosis, treatment, and management of diseases. Health dominates public expenditure and the health sector is Australia's largest employer. However, working in the health 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 Study: Lamson Concepts – Hospital logistics robots

The Sunshine Coast University Hospital (SCUH) currently has 450 beds, with plans to grow to 738 beds by 2021. The Lamson Automated Guided Vehicle (AGV) system, Transcar, automatically transports meals, laundry, waste and supplies throughout the hospital. Sixteen Transcar vehicles make more than 900 journeys every day to transport ~500 trolleys to 124 drop-off stations around the hospital. The AGVs can transport up to 500kg and travel along 2.3 kilometres of pre-determined track.

Automated transport of goods reduces injury to hospital staff, and wear and tear on hospital infrastructure. It also enables just-in-time delivery and full transparency and control of the delivery processes. This frees hospital staff to concentrate on patient care and higher-skilled activities. Lamson Concepts supplies a range of autonomous solutions for use in hospitals.

Images courtesy of Lamson Concepts


Image courtesy of Wesley Hospital


Image courtesy of Intuitive Surgical

Case Study: Australia's first Centre of Excellence in Robotic Surgery

The Wesley Hospital in Queensland has two DaVinci® surgical robotic systems and hosts Australia's largest robotic program. Over the last eight years, surgeons at the hospital have performed 4,500 robotic surgeries, using a computer to control surgical instruments attached to robotic arms while performing minimally invasive surgery. Robotic surgery enables surgeons to perform precise and delicate procedures with only small incisions and is increasingly being used in urology, gynaecology, colorectal, thoracic, cardiac and gastro-intestinal surgery.

The DaVinci® robot, from Intuitive Surgical Solutions (USA), is a versatile surgical robot system that follows the master-slave operation principle. The robot has found worldwide acceptance in advanced surgery and is reported to have achieved an installation number close to 3,745 (as of June 2016) across more than 2,000 hospitals.

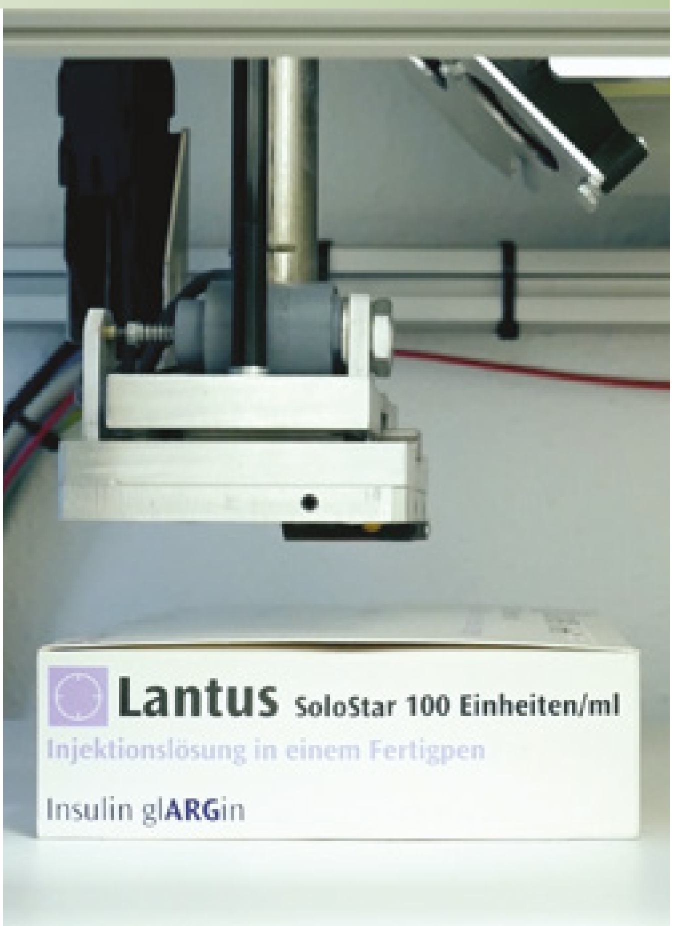
At the Wesley Hospital, nine specialist surgeons perform robotics surgery using the robot, with additional surgeons undertaking training to enable future use.

Case Study: Go.Robot – remote pharmacies

Go.Robot is an Australian company that distributes and configures robotic solutions for inventory management and blister pack production in the pharmacy sector, and has also developed a solution for remote medical dispensing. Remote pharmacies are necessary to improve health outcomes for people living in regions such as the Torres Strait, the Northern Territory, and remote areas of Victoria and South Australia.

Using Go.Robot's solution, pharmacists consult with patients via video-chat and remotely dispense medication from secure cabinets in a controlled process. Supervision by a local clinic or remote identification via iris or fingerprint recognition ensures that medication is being dispensed to the correct patient. Stock levels can be monitored in real time by funding agencies and pharmacists alike, with deliveries automatically triggered.

Go.Robot supplies a sturdy cabinet that can hold up to 1,500 trays of medication. It can be used as a 24/7 standalone pick-up for medication or it can be combined with an external terminal. There is also a bigger solution to act as a full-sized remote pharmacy with internal fridge, thousands of stock items, external label printer, and card function, supported by video consulting and remote dispensing by a qualified pharmacist.



Images courtesy of Go.Robot

Image courtesy of Prof. Wendy Moyle

Case Study:
Dementia – Paro robot trials in Australia

Paro is an advanced interactive robot in the form of a soft toy, shaped like a baby seal. Paro is a social robot and responds to people and its environment as if it were alive, moving its head and legs and making sounds. A study by Australian researcher, Professor Wendy Moyle of Griffith University, looked at the benefits of using the social robot for people with dementia. The study involved 415 residents of 28 residential care facilities in South East Queensland. The research focus was on whether the introduction of the robot helped to reduce anxiety and if it decreased the tendency of dementia patients to wander. The findings showed a modest effect on agitation, which is one of the hardest symptoms of dementia to reduce.

Compared to a soft toy, the Paro social robot produced better connection and engagement. While the robot is not suitable for mass interventions and should not be a substitute for human contact, it can be effectively used to reduce anxiety in people with dementia.

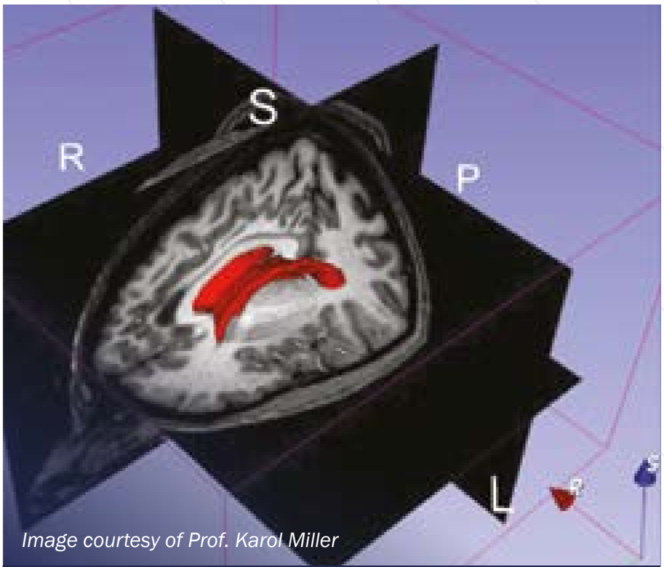


Image courtesy of Prof. Karol Miller

Case Study:
Surgical simulation for neuronavigation in epilepsy surgery

The Intelligent Systems for Medicine Laboratory at the University of Western Australia has entered a research collaboration agreement with Computational Radiology Laboratory of Boston Children's Hospital to develop a surgical-simulation based approach to epilepsy treatment. The project will demonstrate the benefit of this new approach for accurately identifying the placement of surgically implanted invasive electrode arrays and epileptic seizure onset zones identified by them, relative to brain anatomy. The technique employs a unique non-linear biomechanical model of the brain and has the potential to dramatically increase the number of epilepsy patients benefiting from precisely targeted surgery – the only curative treatment for epilepsy.

3D magnetic resonance image presented as a tri-planar cross-section. Public domain software 3DSlicer, developed by collaborators at Harvard and MIT, was used to generate the image.

Case Study: Maxwell Plus – personalised healthcare solutions

As experts in Artificial Intelligence (AI) and MRI technology, Maxwell Plus believe the future of healthcare firmly lies within this technology. Established in 2016, this Brisbane-based start-up is passionate about driving change towards personalised healthcare solutions.

Working towards a vision of post scarcity health care, Maxwell Plus is rethinking the identification, detection and diagnosis of diseases such as cancer. By combining machine learning with medical imaging, Maxwell Plus are working to make cancer diagnosis faster, more affordable and more accurate.

Due to the nature of cancer, there are cases every year, whether it be prostate, lung or breast, where early diagnosis is missed (false negatives) resulting in later diagnosis, and harsher treatments. There are also cases where individuals are misdiagnosed (false positives) and undergo unnecessary treatment which negatively impacts them through treatment side effects, out-of-pocket expenses, and reduced opportunity to work.

By training machine learning algorithms to read thousands of medical cases consisting of imaging, genetics, and histopathology, Maxwell's AI can provide insights into personalised risk assessments and health monitoring. This aids in reducing the incidence of false negatives and false positives through improved accuracy in cancer detection.

Maxwell Plus is working to apply AI through Maxwell Plus Cloud to help clinicians diagnose disease and make health data and insights available to individuals with Maxwell Plus Health.

Maxwell Plus is also working with a number of global partners including University College London (United Kingdom), St Vincent's/Garven (Australia) and Veterans Affairs (United State of America).


Image courtesy of Exaptec

Case Study: Companion Robots

Australian company, Exaptec, distributes a range of social robots including the new family companion social robot, Buddy. The open-source, connected robot was designed as a modular platform and can be expanded with different accessories, such as arms. Buddy uses facial recognition to remind family members of important events and to identify potential dangers inside and outside the home. Buddy can communicate wirelessly with other devices via Bluetooth and Wi-Fi. Unlike Siri, Google Home or Amazon Echo, Buddy is mobile and proactively interacts with its surroundings.

Buddy is being used as the social robot platform for senior assistance solutions in an innovative project aiming to improve the everyday lives of the elderly. Funded by the European Commission, the Agile CoCreation of Robots for Ageing (ACCRA) project (www.accra-project.org) is a collaboration between European and Japanese universities. The goal of the ACCRA project is to develop robotic applications to improve the daily lives of the elderly.

Contributors

This chapter was based on submissions and a workshop held on 28th November 2017 in Melbourne, VIC, with contributions from the individuals listed below:

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7 Services

Service robots have a key role to play in addressing societal challenges such as demographic change, health and well-being, transport and security.

Image courtesy of Ambrogio

7.1 Services Overview

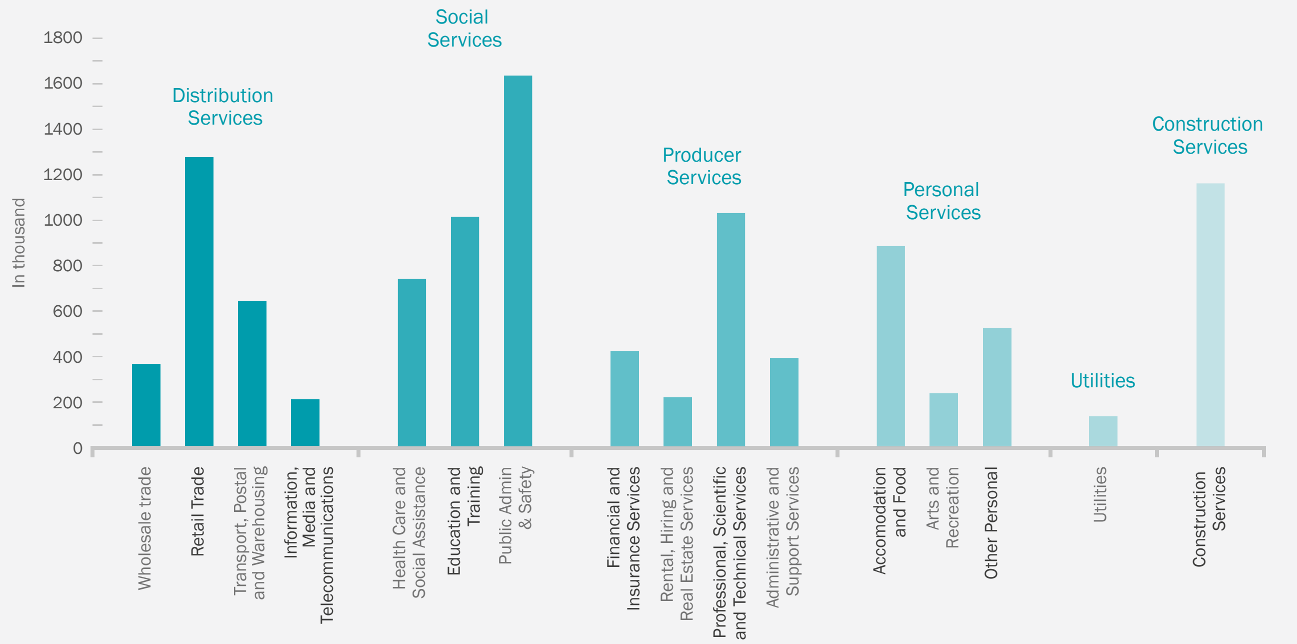
7.1.1 Australia's services sector

Australia's services sector is critical to its overall economy. The term 'services' applies to all activity in the Australian economy not directed at the production of 'goods'. It covers a diverse range of utilities that is increasing in importance for our future wellbeing. In 2017, services represented 70 per cent of Australia's gross domestic product (GDP), equating to an output of $AU1,184 billion [TR17]. Services also play an increasingly important role in our international trade, with services exports growing an average of 3.2 per cent per annum from 2010-2015, equating to 20 per cent of Australia's total exports [DFAT16]. If the value of intermediate services is captured, services contribute 40 per cent of our value-added export earnings.

Services exports grew strongly in 2015–16, with Australia's top service export — international education — growing by 9.4 per cent to be worth $AU19.8 billion [AIR16]. Most importantly, nine out of 10 Australian workers are employed in a services industry, accounting for more than 11 million people (88 per cent). Most of the increase in employment in Australia over the last fifty years (more than 7 million jobs) has been in the services sector [ASS00, POA06].

While primary (agriculture, mining) and secondary (manufacturing) economic sectors remain important to the Australian economy, the tertiary sector (services) is growing as Australia, like many developed nations, moves towards a knowledge-based economy. As the services sector grows, it has also contributed to more than half of Australia's annual aggregate labour productivity growth [TR17]. Services provide essential inputs into virtually all goods and services that Australia produces. Therefore, the performance of the services sector has an important influence on the overall performance of the Australian economy, together with the international competitiveness of our industries. Further improvements to productivity in the services sector, by implementation of robotic and vision technologies for example, will have a major influence on our economy.

Services employment (as of November 2017)

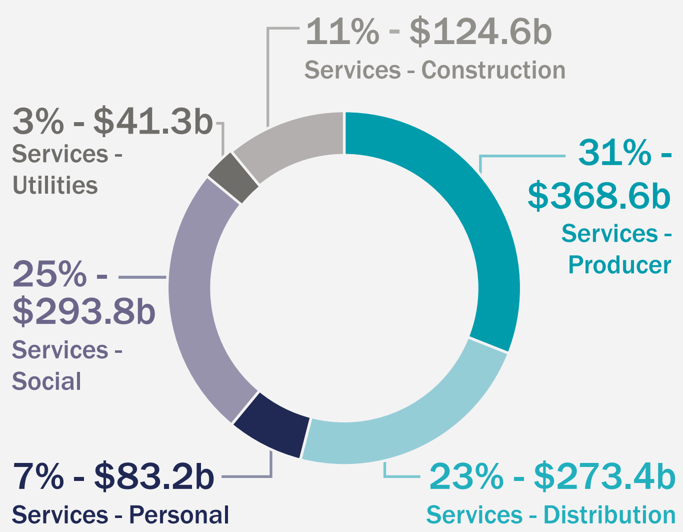


Source: Cat No 5204.0, Australian Bureau of Statistics

A key risk for services is the impact automation will have on employment. Over 85 per cent of Australia's casual employees work in the services sector, which employs more than three-quarters of all low-skilled workers in Australia. In 2001, 91 per cent of low-skilled white collar workers, and 58 per cent of low-skilled blue collar workers, were employed in the services sector. While high-skilled workers predominate, the absolute size of the services sector means that it is also a major employer of low-skilled workers [ASS00]. Services were also responsible for all growth in low-skilled employment over the period 1986 to 2001 — an increase of about 7.5 per cent, or around 149 000 low-skilled jobs.

Although service jobs are concentrated in Australia's capital cities, accounting for 85 per cent of the metropolitan workforce, service workers also dominate (75 per cent) employment in non-metropolitan regions [ASS00]. This suggests that any impacts on services jobs will have a widespread impact on the Australian community [DOJ17].

Value of the different services sectors to the Australian economy



7.1.2 Future outlook for the services sector in Australia

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 (logistics). 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 larger 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 [CE17].

7.1.3 What industries are service industries?

Distribution services

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

Social services

health and community services*, education, emergency services (police, ambulance, firefighters and state emergency services), government administration and defence**

Producer 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 Chapter 6 **see Chapter 8

Different services have a varying level of impact on the Australian economy (see facing page). The next sections, look at how robotic technologies have already infiltrated Australia's services sector and what might be expected in the future. To do this, Australia's services sector is divided into clusters of similar activities [ASS00] as above.

Definitions

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. Robots are often broadly termed either 'industrial' or 'service' robots. 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, and yet their numbers are now far outstripping those of industrial robots (International Federation of Robotics 2017 [IFRSR17]). Service robots may be distinguished according to the scale at which they are used. Service robots that help individuals or households are called 'domestic' or '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.

Snapshot

The Australian services sector

Dominates the Australian economy and is growing in importance.

$1,184b output

11m people employed

Key activities include

Transport | Logistics | Waste Management | Financial Services (banking, insurance) | Education | Professional Services (incl Law) | Retail | Tourism | Entertainment | Construction | Utilities | Security | Property services | Social services | Maintenance

Key Robotic Technologies for the sector

- Autonomous Vehicles (for transport of people and goods)
- Inspection robots (construction, utilities, retail)
- Visual verification technologies
- Integration between robotic technologies and built environment technologies (e.g., elevators, doors, dock levellers)

Challenges/ Opportunities

- Ageing population
- Reduced size of working population *(if no changes to immigration policy)*
- Adaptation to more highly skilled workforce
- Competition from emerging knowledge economies

Image courtesy of QUT

7.2 Distribution Services

7.2.1 Australia's distribution services sector

Distribution services is a broad sector encompassing retail and wholesale trade, transport, logistics, IT, and communications. The sector is worth a total of $AU273 billion to the Australian economy (16 per cent of GDP) and employs 2.5 million people [ABS18]. Alone, the Australian logistics industry was estimated to employ 1.2 million people and to have added $AU131.6 million to Australia's economy (8.6 per cent of GDP) in 2013, with this expected to rise to $AU187 million by 2021. Retail trade is the largest employer within distribution services, employing over 1.2 million people in 2017 [ABS18], and having the largest concentration of the lowest paid service jobs (75 per cent of the national average [ASS00]).

The total size of the sector belies its influence on other parts of the Australian economy, and the enormous disruptive changes the sector will soon face as such services are transformed by robotic technologies. In logistics alone, the volume of service robots being produced globally is rising rapidly, with 25,400 systems known to be installed in 2016 – 34 per cent more than the 19,000 installed in 2015 – accounting for 43 per cent of all the world's professional service robots [IFRRS17]. The value of worldwide sales of logistic robots is estimated to be $US992 million, and is forecast to grow six-fold, to $US5.8 billion by 2020 [IFRRS17].

The advent of self-driving cars, and their impact on the economy, is worthy of its own roadmap, with international predictions suggesting consumers will be able to buy self-driving cars as early as 2020 [RA15]. Successful operation of driverless cars in Australia's unique environment and remote areas is likely to require adaptation of existing technologies. Despite the lack of an automotive manufacturing industry in Australia, there are a range of enabling technologies required, which Australia will be well-placed to develop and export. Many of these technologies are enablers for the introduction of robotics technologies in the entire services sector, and therefore, multiple benefits are likely.

The impact on the Australian economy from reduced transportation costs, which will be realised by the introduction of autonomous vehicles, is significant. Transportation inputs produce the strongest proportionate benefits to GDP (at 0.17), with labour cost reductions thought to promote job growth, although the range of impacts is wide [AIR16].

7.2.2 Robotics and distribution services today

Multiple factors will lead to the distribution services sector adopting robotic technologies. They include:

- An ageing workforce, unable to sustain current practices – 25 per cent of transport, postal, and warehousing workers are aged 55 years, or over.
- Long distances between major centres put human drivers at risk (speed versus duration of journey). Tired drivers put other people, and infrastructure, at risk.
- A younger workforce, who are less likely to want to do direct manual labour, but view working with robots as more exciting.
- More online purchasing increases the number of discrete orders, adding complexity to current warehouse, fulfilment, and transport infrastructure.
- Smaller regional centres are often serviced less than major centres. Robotics could make more frequent servicing of these towns viable.

7.2.3 The future of robotics in distribution services

Transport

The application of robotic technologies in distribution services has the potential to hugely influence all sectors of the Australian economy. Examples include enabling reduced infrastructure costs, benefit to all other industries, reduced costs of transporting goods (both within Australia and to export), provision of goods (and services) to remote communities, improved safety, less accidents, fewer cars/trucks as more efficient, but also, widespread job loss.

Given the lack of an automotive manufacturing industry, Australia's primary role in preparing for connected and autonomous vehicles lies in supporting infrastructure, regulations and technological advancements. In Queensland alone, the Department of Transport and Main Roads estimates that 20 per cent of the state's fleet will be autonomous between 2034 and 2045, increasing to 100 per cent between 2048 and 2057, with similar benefits expected for all Australian states. Globally, the development of a new passenger economy is predicted to be worth more than $US7 trillion by 2050 [SA17]. This figure is based on the development of new services, such as provision of self-driving car services (transportation, delivery) to consumers and businesses, as well as the development of new applications and services, and the social benefits of creating a time surplus.

> Economic and social benefits of connected and autonomous vehicles include increased road safety, reduced traffic congestion, increased driver freedom, and increased productivity.

Increased road safety

Each year, road accidents kill approximately 1,400 Australians, and hospitalise another 32,500 [NRS11]. The annual economic cost of road accidents in Australia is estimated at $AU27 billion per annum [ABC17]. Between 2003-2015, there were 583 work-related fatalities in the road transport industry, with 92 per cent (535) occurring in the road freight transport industry [SWA18]. The World Health Organisation estimates that governments spend 3% of GDP on costs related to traffic accidents (approximately $US2.3 trillion) [WHO15].

Platooning and higher speeds to reduce congestion

The economic cost of avoidable congestion in Australia was estimated at $AU16.5 billion for the 2015 financial year [ASoE16]. The introduction of self-driving vehicles will allow transportation at higher speeds, and the use of strategies, such as platooning, to lower fuel costs and reduce congestion on the country's roads.

Increased driver freedom

Most commuters spend more than 30 minutes in a car every work day, equating to at least 60 billion hours driving per year, which could be applied to other activities [SA17].

Increased productivity

Self-driving vehicles will be able to make deliveries 24 hours a day, seven days a week, resulting in improved productivity for transportation companies. The role of a driver will be redefined, and might include inventory and supply chain management, and customer service.

Self-driving cars in Australia

Self-driving vehicles are thought to provide a $AU95 billon economic opportunity to Australia, saving $AU80 billion from road safety and congestion, and creating 16,000 direct and indirect jobs. They also develop high-tech research and design capabilities in Australia's workforce [ADVI16]. Australia has already conducted the southern hemisphere's first on-road trial of driverless cars. After the initial demonstration trial and awareness raising, the Australia and New Zealand Driverless Vehicle Initiative (ADVI) is pushing for full-scale industry field operational tests. These will inform local policy and legal frameworks before the staged introduction of driverless vehicles onto the private and public road networks. The infographic on p. 78 shows the activity in Australia supporting the deployment of driverless cars.

Snapshot — Distribution services sector

A crucial sector for maintaining connections between businesses and people.

$273b output

16% GDP

2.5m people employed

Sector Definition

Distribution services includes retail and wholesale trade, transport, logistics, IT and communications.

Key activities include

- Retail trade
- Transport services
- Logistics
- Wholesale trade
- IT and Communications

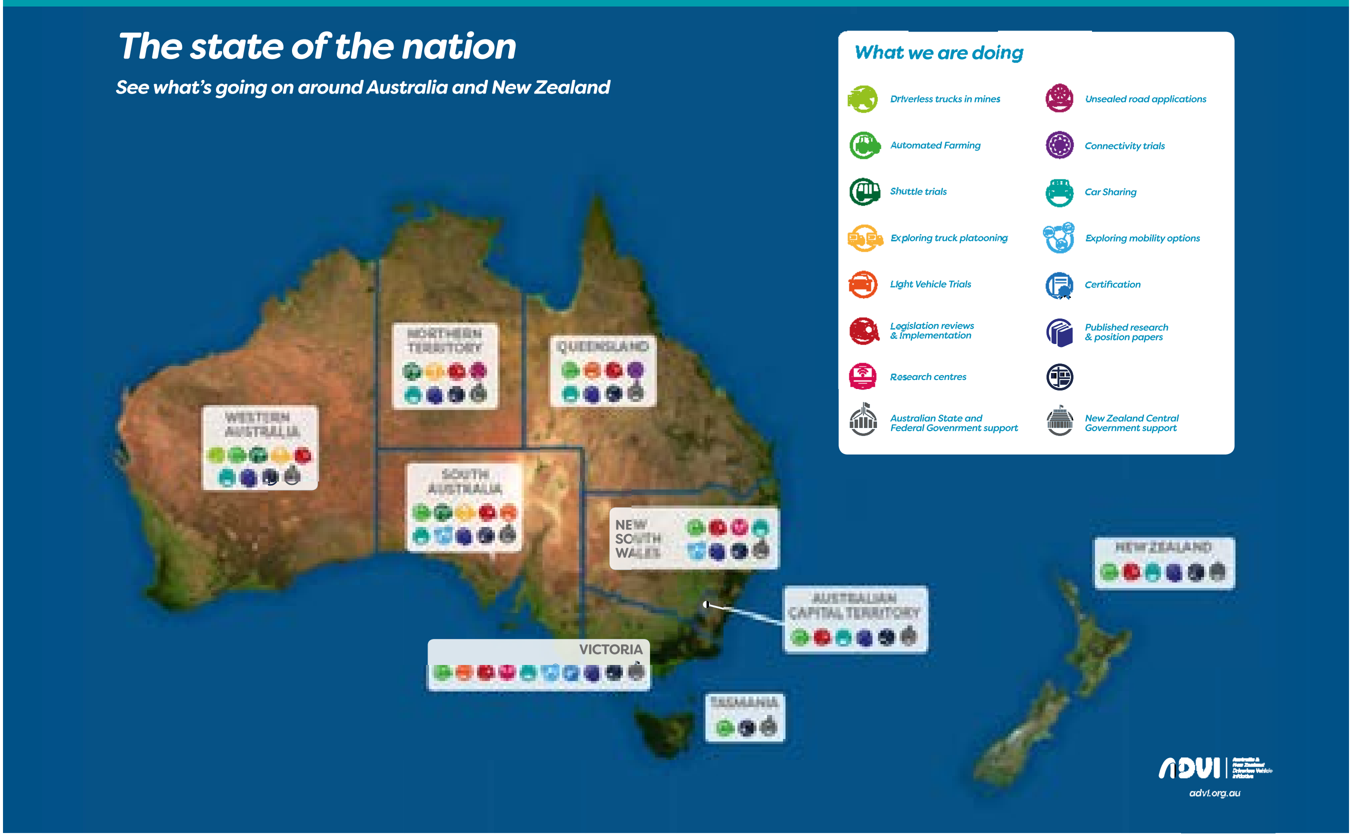
Challenges/Opportunities

- Expertise and facilities to provide certification of autonomous vehicles meet Australian legal frameworks and standards
- Threat of widespread job losses

Key Robotic Technologies for the sector

- Navigation
- Precise position control (mobile robotics in logistics applications)
- Recognition of changing environments (models of transient vs permanent elements)

Activity in Australia supporting the deployment of driverless cars



Source: Australia and New Zealand Driverless Car Initiative (ADVI)

Logistics

Australia was an early adopter of automation in the storage, picking, and packing of goods, with many warehouses containing some level of automated equipment since the early 1990s. While this was not robotic equipment, it sets the scene for robotics to become more common as these automated sites reach the end of their existence. Robots, and automation, in logistics is becoming ubiquitous in Australia, particularly with Amazon (one of the largest robot companies in the world) moving into the Australian market. An example of this is the number of Autostore systems in use in distribution centres. Autostores are mobile robots, on a framework, that operate above stacks of crates and totes.

Retail

The Australian retail market is relatively small, with large distances between consumers, and low growth in population. This requires economies of scale for national retailers to deliver items to consumers across that market in a consistent manner. As retail accounts for some of the lowest paid unskilled jobs in the services sector, it is likely to be strongly disrupted by automation. Robots will soon be used for shelf scanning, to eliminate stock runouts and items in wrong location, shelf-filling and dynamic shelving, and moving of unit load devices (pallets, trolleys, roll-cages) from transport to display.

Customer-facing robots in retail are extremely rare in Australia, however, in countries such as Japan they are becoming commonplace and it is likely that Australia will follow this trend. With digital sales set to double over the next 10 years, reaching an average of 20 to 25 per cent, stores can no longer restrict themselves to a solely transactional role, and need to refocus on in-store experience [ROL16]. Worldwide growth in retail, or 'public relation' robots, was expected to increase by 37 per cent in 2017, with sales of Softbank's social robot 'Pepper' believed to have exceeded 20,000 units [IFRSR17]. These robots are increasingly used in public environments to offer services, attract customer attention, and promote sales. Working with IBM to jointly develop their Watson artificial intelligence technology for the Japanese market, Softbank has applied AI to the Pepper robot, processing customer dialogues, and operating in more than 1,000 independent retail outlets [IFRSR17]. Preliminary studies suggest that a combination of retail robots can produce a 10 to 30 percent increase in periodic store traffic, as well as reduced staff costs, and the creation of a positive, and efficient shopping experience [ROL16].

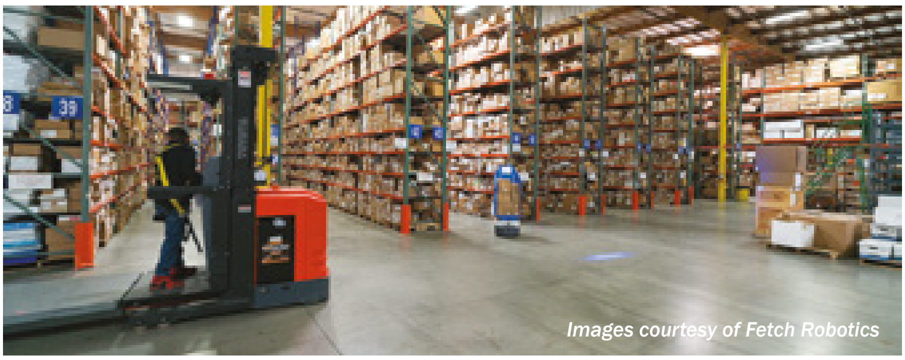
Robots in retail must create new customer experiences, optimise customer pathways by providing real-time data and analytics, increase the fluidity of in-store procedures, and perform a high number of low value tasks [RR16]. Opportunities to apply robots in both front-of-house and back-of-house retail activities include:

- goods management (e.g., inventory robots, stock control robots, surveillance)
- front office and customer experience (e.g., customer greeting and entertainment, product information and demonstration, promotion, augmented virtual reality)
- customer services merchandise (e.g., product picking, automatic payment, virtual queue, product delivery)
- customer path analysis (e.g., customer count, trajectory analysis, behaviour and emotion analysis) [ROL16].

Most robots in customer-facing roles in retail are stationary, which reduces their effectiveness. Technologies are required that allow these robots to cope with stairs, doorways, kerbs and similar, as well as potentially unsealed floors/roads in rural retail applications.

IT and communications

IT and communications are the foundation industries for Australia to successfully deploy robotic technologies, therefore Australia needs a strong technology sector. In general, Australia needs better communications networks to deliver remote services. While networks currently have an IoT focus, robots are the ultimate IoT device. More focus in the future will be on connecting individuals within the Australian population rather than providing services based on geography. The geographic approach leaves large portions of primary production land, and interconnecting highways, without adequate coverage for autonomous vehicles, or other communication for robotics.



Images courtesy of Fetch Robotics

7.2.4 Main findings for robotics in distribution services

Distribution services have a strong influence on other parts of the Australian economy and will face significant disruption, particularly in logistics, with the advent of new technologies such as self-driving cars. Lowering transportation costs will directly raise productivity in Australia while enabling increased provision of services to remote communities. The sector has an ageing workforce, and retail and logistics are becoming more complex, requiring robotic solutions. The needs of this sector are diverse. Warehousing, transport, and customer-facing retail all have different needs, and all face disruption to established business models.

Case Study: Kalmar: AutoStrad Terminal Solution

"Within the next 10-15 years many of the major stevedores will automate and the AutoStrad will be an attractive proposition for many of these operators" says Matt Hollamby, Brisbane Manager, Terminals Division, Patrick Corporation.

Kalmar's automated straddle carrier terminal is a proven, modular, scalable and flexible automation platform that uses state-of-the-art vehicle navigation systems, combined with the advanced terminal logistic system (TLS) for equipment control.

At the heart of the solution is the automated straddle carrier (AutoStrad): a driverless straddle carrier that can automatically pick, transport, and place containers, providing free-ranging horizontal transport at speeds of up to 30 kilometres an hour. The straddle supports ISO 20, 40 and 45-foot dry containers and reefers, provides twin forming and lifting, and interchanges with quayside operations, truck, automated stacking cranes, rail mounted gantries, and manned reach-stackers.

In 2005, the first fully-automated AutoStrad container terminal was opened by Patrick Stevedores in Fisherman Island, Brisbane. This was a collaboration between Patrick Technology and Systems, and Kalmar. In 2012, the Asciano AutoStrad solution was transferred to Kalmar, and the current AutoStrad and AutoShuttle solutions have been developed by teams both in Sydney, Australia and Tampere, Finland. AutoStrad terminals now operate in Patricks' Botany Terminal, Australia (2015), TraPac LA Terminal, USA (2016) and, VICT Melbourne Terminal, Australia (2017).

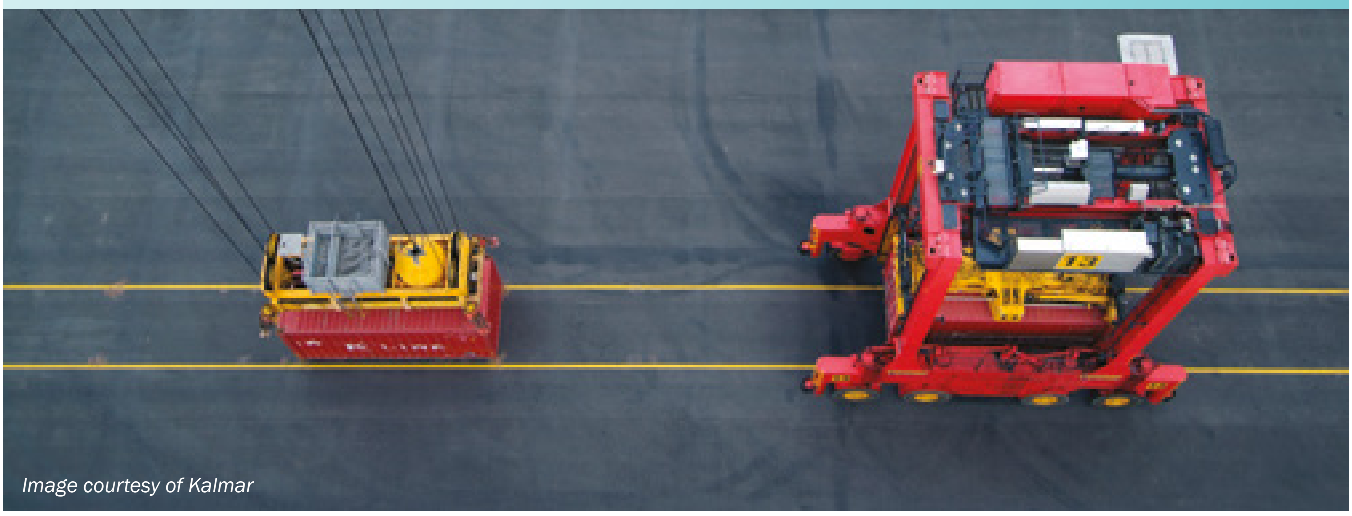


Image courtesy of Kalmar

Image courtesy of Marathon Robotics

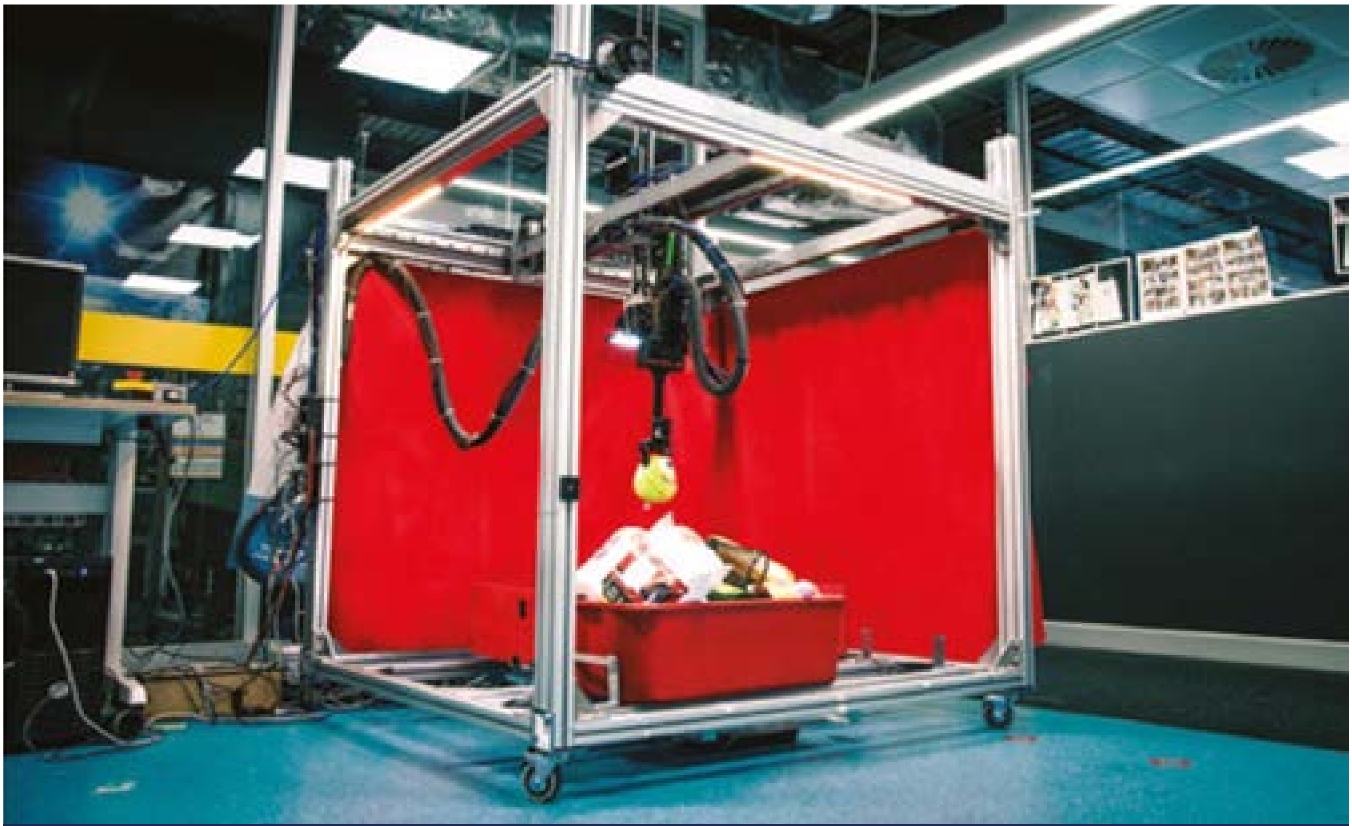
Case Study: Last-mile delivery using robots on the footpath

Marathon Robotics, a Sydney-based company with a focus on ground autonomy, has partnered with Australia Post to conduct trials in robotic sidewalk delivery.

The last mile of a delivery is often the least efficient and most expensive part of the supply chain of goods. The e-commerce market is expanding rapidly and consumer appetite for on-demand delivery keeps increasing. Besides packages, consumers are getting used to ordering food and groceries directly to their doorstep. Robotic sidewalk delivery addresses a portion of the last-mile delivery problem.

Marathon and Australia Post conducted a trial of after-hour on-demand delivery of packages in New Farm, Brisbane, in late 2017. Consumers were able to sign up for their packages to be delivered between 6 p.m. and midnight, if they had missed the delivery during the day. Over 100 packages were successfully delivered during the one-month trial.

To conduct the trial, Marathon built a semi-autonomous robot based on its field-proven robotic technology. The robot was able to build a map of the entire suburb of New Farm including all sidewalks, planning paths from the post office to the consumer's door, and autonomously navigating and avoiding fixed obstacles and pedestrians on the way. Consumers were notified via SMS of the approaching delivery and were able to unlock the compartment by sending a reply.



Case Study: Australia wins the Amazon Robotics Challenge

In 2017, a team from Australia won the Amazon Robotics Challenge to build an automated robot, including hardware and software, to successfully pick, and stow items in a warehouse. Amazon is one of the largest robotics companies in the world and requires the technology to quickly package and ship millions of items to customers from their global network of fulfilment centres. The commercial technologies to solve automated picking in unstructured environments are still being developed.

Using an in-house cartesian robot (Cartman) built for only $AU10,000, the team from the Australian Centre for Robotic Vision applied a novel few-shot learning algorithm to place first in the competition. The challenge combined object recognition, pose recognition, grasp planning, compliant manipulation, motion planning, task planning, task execution, error detection, and error recovery. The robots were scored by how many items they successfully picked, and stowed, in a fixed amount of time. They were also challenged by being given 16 unseen items just 45 minutes before the competition began.

Cartman can move along three axes at right angles to each other, like a gantry crane, and featured a rotating gripper that allowed the robot to pick up items using either suction or a simple two-finger grip. Cartman's vision system was the result of hours of training data, and training time, but the team also had to create a robust vision system to cope with the unseen items. One feature of the vision system was that it worked off a very small amount of hand annotated training data. Cartman needed just seven images of each unseen item to be able to reliably detect them.

The robot was only unpacked and reassembled out of suitcases a few days before the event, and broke a wrist during the competition, which had to be quickly re-engineered and a replacement part 3D printed.

Case Study: Pegasus Alpha - Flying Car

In the back streets of Brisbane, two brothers with a passion for the automotive industry had a feeling that the future is vertical. NXG3N Robotics is a small Queensland company that has developed some amazing technologies in the fields of agriculture, urban habitats, and now mobility.

Their latest venture is Pegasus Alpha, a flying car.

At the recent Uber Elevate Conference, it was quoted that there are 75 known eVTOL (and related) technologies being worked on globally. NXG3N's view is that Australia can be either a consumer or a contributor, and they want to be a contributor. Largely, the technology already exists, it is more a matter of the entrepreneurial will to make this happen.

This crazy idea was a total of 8 weeks from conception to full-scale prototype. As depicted in the images below, there now exists a 1/9th scale fully functioning prototype, utilising 3D design, 3D printing, CNC mills, vacuum forming, fast tracked manufacturing and existing drone technology to prove the concept. NXG3N knew this was not enough to gain national attention and push this mobility agenda, and so with only four weeks to the ICRA2018 Conference, they chose to create a full-scale flying prototype, of which the first uav-test-flights will be conducted by the end of June 2018.

The next stage for this is to connect with appropriate partners and explore the further development of advanced composite materials for the airframe, flight control systems, batteries and other fuel sources.

To date this project has been supported by MTAiQ Innovation Hub (Brisbane), who are historically key players in the automotive training industry, and they know that the future of training is fundamentally different with a need to focus on eLandVehicles, and eVTOLs.

This has further been driven by Tony Wheeler of ImagineX (Brisbane), an entrepreneur and tech-startup advisor, who drove the challenge of 'let’s go full scale’, and believes that connected hardware and software systems design and integration is key for the future.

The key here is the connection of technical research and entrepreneurial ability, to get things done! Australia has a unique advantage in this space, but it may be lost, yet again, unless we challenge our culture of funding and commercialisation at the deepest level. Many small companies, such as NXG3N will just disappear unless we get this right. Creating easier funding pathways for non-university based research, or simplifying the process and culture of private-university partnerships is essential to supporting this type of development in Australia.


Images courtesy of NXG3N Robotics

7.3 Social Services

7.3.1 Australia's social services sector

Social services are non-market services - either provided free of charge, or with significant price reductions, due to heavy subsidies. Social services include health and community services, education, government administration and defence. Details of applications in healthcare, defence and social infrastructure are included in separate sections of this roadmap. The social services sector is worth a total of $AU293 billion to the Australian economy (17 per cent of GDP), and employed 3.4 million people in 2016 [ABS17]. In 2015-2016 non-market services represented 16.9 per cent of GDP [AIR16]. In 2015-2016, non-market services grew more strongly than market services for both output (4.2 per cent compared to 2.8 per cent), and employment (4.1 per cent compared to 1.8 per cent). Employment growth in non-market services was also stronger in regional areas (6.4 per cent compared to 2.3 per cent in capital cities) and is likely to support regional employment [AIR16].

Social service workers — including teachers, scientists, doctors, nurses, defence personnel, police, and other public servants — are the most highly educated group in the Australian economy. In 2000-2001, over two-thirds of these workers were in high-skilled occupations, over 40 per cent had completed either a bachelor, or higher degree, and just under 60 per cent were employed by the public sector [ASS00]. Gender differences are notable in social services, where women outnumber men by a ratio of two to one, increasing to three to one in health and community services, with education above the average for the services sector. It is worth noting that 23 per cent of workers in education and training are aged over 55 years.

7.3.2 Robotics and social services today

There are many emerging applications for robotic technologies in the social services sector. 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 for behavioural and therapeutic interventions that can benefit social workers, teachers and police. Surveillance robots are being trialled in a range of settings and could be used in challenging operations, like prison security, or, to monitor OH&S in government workplaces. Robots are being trialled as teaching assistants and automation is predicted to free up more than 8 hours a week of teacher time in marking assignments and other repetitive tasks [ALB17]. Korea is trialling robots that will assist with teaching English, especially in regional areas which may not have access to native teachers at school. Healthcare and defence applications are covered separately in Chapters 6 and 8.

Image courtesy of EMYS

Image courtesy of QUT

7.3.3 The future of robotics in social services

There is low infiltration of robotics in many of the social services, except for healthcare and defence, which are treated separately in Chapters 6 and 8 respectively. An exception would be the use of tEODor, an explosive ordnance (bomb) disposal and observation robot by the Australian police service. This robot has been used in bomb disposal, and to enter buildings in hostile situations, to gather intel for officers outside when it may be dangerous for them to enter the building. If Australia follows the lead of other countries, then robot ballistic shields to protect our emergency services personnel, crowd control robots, traffic control and enforcement robots, and greater use of drone technology for surveillance, crime prevention and evidence collection, are all more likely. In the UK, drones are fitted with long range acoustic devices (LRAD) to deliver a deafening boom of sound to deter people about to commit crimes.

7.3.4 Main findings for robotics in social services

Social services are non-market services that are free or heavily subsidised. The sector is an important employer of highly educated people, and those located in regional areas, including teachers, scientists, doctors, nurses, defence personnel, police and other public servants. As with many sectors, social services have an ageing workforce, with 23 per cent of workers in education and training aged over 55 years. The most sophisticated application of robotics in social services is in defence and the emergency services. Police use robotics for surveillance and intelligence-gathering to protect people from dangerous situations. Robotics is not implemented at scale in the sector, although robotic technologies can act as a force multiplier in under-resourced areas, where they might significantly free up worker time, for example, in teaching. Robots are also being trialled for behavioural and therapeutic interventions, traffic control, and enforcement. The full-range of possible applications of robotics in social services has hardly been explored, suggesting that there could be many opportunities in the sector.

Snapshot | **Social services sector**

Employs the most people of any of Australia's services sectors.

$294b	3.4m	17%
output	people employed	GDP

Key activities include

Education · Welfare · Not-for-profits · Government · Postal Services · Healthcare* · Defence ** · Miscellaneous Professional and Social Services

Sector Definition

Social services includes health and community services, education, government administration and defence.

Key Robotic Technologies for the sector

manipulation · deep learning · human-robot interaction

Challenges/ Opportunities

- Adaptation to more highly skilled workforce
- Competition from emerging knowledge economies

*see Chapter 6 **see Chapter 8

Images courtesy of UQ

Case Study: Robots in education

The Humanoid Robot Research project is a collaboration between The Association of Independent Schools in South Australia (AISSA), Swinburne University, The University of Queensland (UQ), and Queensland University of Technology (QUT).

The project aim is to understand what impact humanoid robots may have on students' learning, and how humanoid robots can be integrated into the Australian Curriculum.

Over three years, two humanoid robots were placed at 12 different primary and high schools in South Australia. Each school was encouraged to explore how to integrate the robots into teaching and learning. The schools had one robot on loan, for one to three school terms, and a number of teachers and classes in each school integrated the robot into classroom learning.

The teachers and students at each school learned how to program the humanoid robots to speak and walk. Some schools had students exploring facial recognition, and programming dance routines to music. The students could try their program first on the virtual robot, before running it on the real robot. Students could program using a visual drag-and-drop language, or timelines with Choregraphe, or Python, a general-purpose programming language. The two robots were very popular and became a part of the learning community. At one school, the robot was programmed by the students in Years 1- 4 to speak Narungga, the Aboriginal language of Yorke Peninsula in South Australia.

The project has found that humanoid robots have a positive impact on school students from preparatory level up to Year 10 level and could easily be integrated into the Australian Curriculum, across a range of learning areas, in authentic ways. The teachers found the students became more deeply engaged in their learning, because it was a humanoid robot they were working with, and because of this enthusiasm, students often led their own learning with the aim to solve challenges they had set themselves.

The Humanoid Robot Research project was recognised by the Australian Computer Society (ACS), and won The Digital Disruptors Team Award for Service Transformation for the Digital Consumer (NFP) in November 2017. The project was also highlighted in the Reconciliation Australia Practices (RAP) Impact Measure Report, 2017.

Image courtesy of UQ

Case Study:
Co-designing a robot for Indigenous Australian language revival

Opie the Robot is a technology deployed in classrooms in the southeast Arnhem Land community of Ngukurr, to help teach heritage languages including Rembarrnga, Marra, Ngandi, and Wubuy, using Kriol as the interface language. The robot was co-developed by the Ngukurr Language Centre and the University of Queensland (UQ), to teach languages that are among the oldest in the world. Opie uses recordings from some of the last known language speakers from the Roper River region to develop children's language skills using fun, interactive language activities and memory games. The robot is an important support tool for teachers who typically only get one hour per week in each classroom to teach those heritage languages to children in the community. Opie has two tablets, one with expressive eyes for social engagement, and another for interactive activities. Opie can be flat-packed for transport, and assembled within remote communities.

Case Study: Ocular Robotics

Ocular Robotics patented technology platform, RobotEye, directs the view of sensors with high speed and precision, exceeding the capabilities of alternatives by up to two orders of magnitude. Simultaneous high-speed movement and localisation is a key enabling capability for many security and defence applications.

RobotEye can be adapted to different sizes and its robust structure has the advantage of high immunity to shock and vibration. The size, weight and power (SWAP) advantages and simplified environmental protection make RobotEye well-suited to mobile applications.

RobotEye does not rely solely on vision and integrates different types of sensors with product categories in vision, 3D LiDAR, thermal and hyperspectral. Ocular Robotics' sensor fusion approach can often significantly simplify solutions and the RobotEye platform's precision enables the straightforward co-registration of heterogeneous datasets. Further, the directing/scanning of non-vision sensors by the RobotEye often delivers a very efficient implementation of these sensing modes, making their use feasible where it otherwise would be too costly. Ocular Robotics' RobotEye sensing products have been applied in areas including robotics, automation, security, defence, structural fatigue analysis, industrial safety, and monitoring and agriculture, with the number of application areas growing continually.

Images courtesy of Ocular Robotics

Case Study: Case Study: BIA5 Innovation Robotics and customers

BIA5 Pty Ltd is a start-up company that specialises in designing, manufacturing and supplying cutting edge robotics systems to enhance the capability of military, law enforcement and private security agencies.

BIA5's advanced technological solutions offer operational solutions and reliably expand methods of response to a range of contemporary scenarios.

The robotic solutions provided by BIA5 have been designed in partnership with Deakin University's, Institute for Intelligent Systems Research and Innovation (IISRI). To date BIA5 has played a key role in bringing robotics into a tactical context within Australian policing. BIA5 provides a unique mix of operational experience and technical knowledge in the development and application of ground robotics as a command tool during high-risk situations. BIA5’s robotics systems have been used within Australia and shown impressive operational success through aiding in the execution of operational tasking without placing lives at risk. Being in a position to work alongside specialised police officers resulted in the OzBot Titan Force Entry robot. This robot showcases the balance of using reliable and proven technologies alongside force and power to gain a formidable tactical advantage. This innovative approach to the development of tactical robotics systems allows a point of difference from the traditional finesse offered by EOD robots.

BIA5’s management team continues to look for opportunities to partner with other Australian business and universities. These partnerships will focus on cutting-edge design, engineering, manufacturing, installation and maintenance of robotics as well as command and control information technology solutions. Their mission is to work with and alongside end users to convert technology ideas into industry and first responder capability; bridging the capability gap and increasing both operational effectiveness and personnel safety. BIA5 aims to deliver this in the Australian market to alleviate the gap regarding a locally designed, manufactured and supported robotics system.

Looking ahead, BIA5 is seeking opportunities and partnerships within the agricultural industry, where their knowledge of practical robotic design and engineering can be applied to improve efficiency. The current system designs have proven to be adaptable to suit various industries and tasks through their prowess off road and modifiable size.

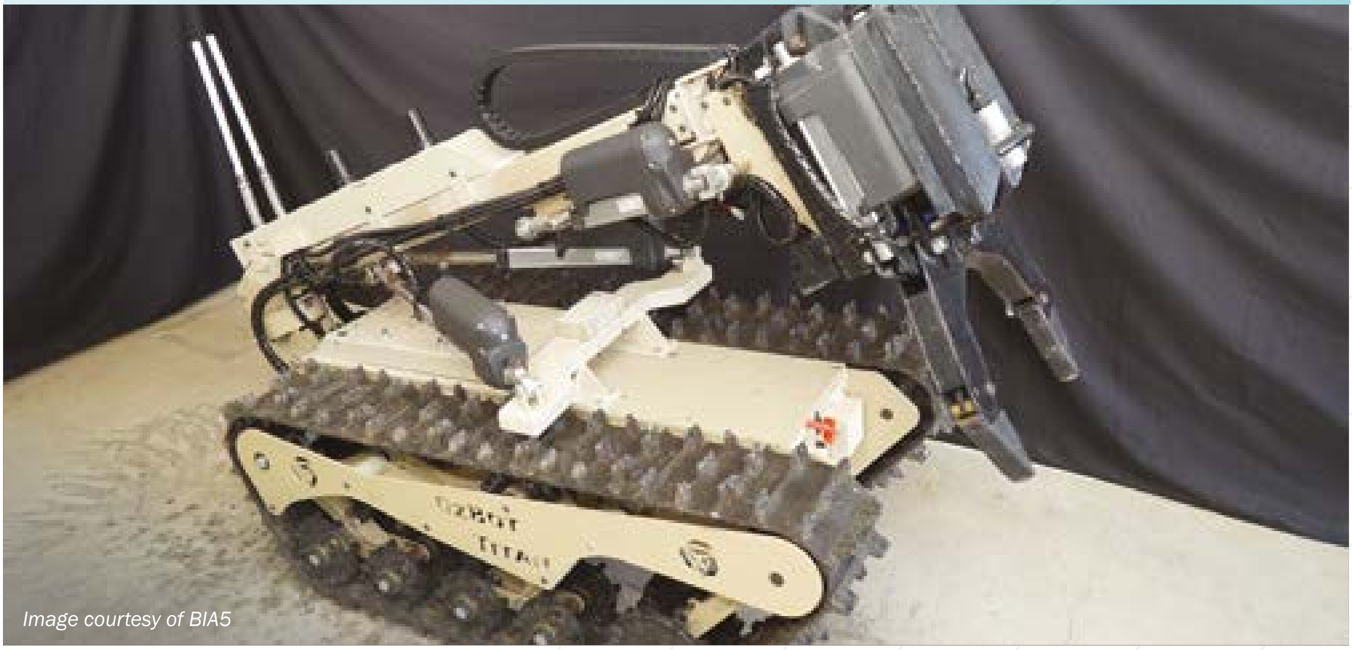


Image courtesy of BIA5

Image courtesy of Marathon Robotics

Case Study: Autonomous robotic targets - from University startup to global market leader

Marathon Robotics 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 can build a map, localise within the map, plan paths, and avoid 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, the Middle East, and Europe.

7.4 Producer Services

7.4.1 Australia’s producer services

Introduction

Producer services are the most valuable of Australia’s services, worth $AU369 billion of Australia’s GDP in 2016, the largest contributor to the national economy [ABS18]. Overall, producer services in Australia was worth 22 percent of GDP, employing more than 2 million people, and is expected to continue to be a core sector of Australia’s economy in the future [ABS18].

Australia’s four major banks are among the world’s largest banks by market capitalisation, and all rank in the top 25 globally for safest banks. They are also some of the most profitable in the world [AICFS18]. The strength of Australia’s financial services is underpinned by a mandated retirement savings scheme (superannuation), highly skilled and multilingual workforce, and advanced business infrastructure. Deep and liquid financial markets and regional leadership in investment management make Australia one of the major centres of capital markets activity in Asia. Underpinning much of Australia’s financial services strength is the growth of its investment funds sector. Australia has one of the largest pools of contestable funds under management globally, valued at approximately $AU1.3 trillion ($US850 billion) [AICFS18]. It is estimated 14.1 million Australians have a financial stake in the property industry through their superannuation funds [PCA15].

Snapshot — **Producer services sector**

Dominates output in the Australian services sector and is a leader in FinTech in the Asia-Pacific region.

$369b output

2.086m people employed

22% GDP

Key activities include

- property & business services (accounting, consulting, legal)
- financial services and insurance
- also incorporates corporate services, like industrial cleaning, etc

Sector Definition

Producer services includes our banks and financial institutions, insurers, and corporate services such as property (real estate) and business (accounting, consulting, law).

Key Robotic Technologies for the sector

- artificial intelligence
- location and environment mapping

Challenges/ Opportunities

- Adaptation to more highly skilled workforce
- Rapid adoption of new technologies by customers
- Competition from emerging knowledge economies

7.4.2 Robotics and producer services today

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 producer services are structured, delivered and consumed. This trend is evident in Australia and is more apparent in other countries in the Asia-Pacific region [AICFS18]. Technology has made an enormous change to the way Australians engage with their banks — with the once ubiquitous in-branch interactions now predominately replaced by ATMs, online transactions, and mobile services [AICFS18]. Worldwide in 2017, investors deployed $US16.6 billion across 1,128 deals to venture capital-backed FinTech companies [CBI17]. With developments in financial technology, robotics is set to deliver new services, with the potential to generate new types of jobs.

> When robots are enabled with cognitive computing, AI, and machine learning capabilities, they can operate autonomously, learn on the job, and can interact and conduct seemingly intelligent conversations with customers.

Not all indicators are positive however, with a recent analysis finding that 34 per cent of a bank worker's job is susceptible to automation. One of Australia's banks recently announced the loss of 6,000 current jobs, to be replaced by 2,000 new jobs requiring different skills, mainly in the area of data science [ABC171]. In general, there is a burgeoning trend for customers to move away from big banks to smaller organisations and start-ups that provide the same services [TAB17]. Millennials have high digital expectations of banks. This demographic is likely to be more willing to engage with robots for financial transactions, and to trust them with complex activities [CIO16].

Australia's producer services sector has been quick to take up robotic process automation (RPA), machine learning, AI, and computer vision techniques. For example, ANZ is using RPA in processing payroll, accounts payable, mortgage procession, and human resource (HR) functions. The ICICI Bank uses RPA to perform over one million banking transactions in back-end operations per day, reducing response time by 60 per cent, together with improving accuracy. These software robots are deployed in over 200 business process functions of the bank, across retail banking, agri-banking, trade and forex, treasury, and HR. These processes include addressing change requests, automatic teller machines (ATM) query resolution, and verifying know-your-customer compliance [TFB]. While robotics hardware has found increasing industrial applications over the last few years, its entry into the services sector, especially financial services, is quite recent. This technology is now touted to bring fundamental changes to the way banks operate, heralding a new era in self-service banking.

To meet these expectations, banks are using virtual robots in multiple processes via RPA. Processes that are high volume, manually intensive, and prone to risk and human error are prime candidates for RPA. Such applications, like chatbots and robo-advisers, are virtual robots that do not physically interact with the world and have not traditionally been viewed as part of "robotics" - although they rely on machine learning and AI. Such distinctions are blurring however, with RPA deployed alongside humanoid robots to provide customer service at bank branches. When robots are enabled with cognitive computing, AI, and machine learning capabilities, they can operate autonomously, learn on the job, and can interact and conduct seemingly intelligent conversations with customers. Already, Roboadvisory company Betterment, is reportedly managing over $US5 billion assets, with KPMG estimating that by 2020, robo-advisers will manage $US2.2 trillion in the USA alone [KPMG17]. The market for robotic technologies in the financial sector will be significant. Less is known about how these technologies will influence the property market, but similar significant change is likely.

> Processes that are high volume, manually intensive, and prone to risk and human error are prime candidates for robotic process automation.

7.4.3 The future of robotics in producer services

The use of ‘real’ robots in producer services in Australia is in its very early stages and is following the trends of other countries towards providing customer services by embodied technologies. For example, Japan’s Bank of Tokyo is using Aldebaran’s Nao robots as customer service agents. The robots are equipped with a camera and microphone, use visual and speech recognition, can respond to 19 spoken languages, interact and communicate with customers, and provide structured responses to queries. Australia’s Commonwealth Bank is looking at introducing similar methods, and have been trialling customer reactions to the Chip robot (see Case Study p. 93).

7.4.4 Main findings for robotics in the producer services

Producer services are Australia’s most valuable services worth 22 per cent of GDP, and the industry is already undergoing significant change due to robotics. Australia is one of the major centres of capital markets activity in Asia, with one of the world’s largest pools of contestable funds under management, and a property industry that attracts strong investment. The sector has been disrupted by the advent of mobile technologies, with the internet replacing many front-line service roles in the sector, and the dominance of Australia’s ‘big four’ banks, challenged by small, nimble competitors. Investment in technology has mainly focussed on non-robotic automation, such as the application of artificial intelligence to call centres, high-volume transactions, trading, and financial advice. Consumers expect to access the latest technologies, and social robots are entering the sector, providing concierge and advisory services. The full extent of opportunities that may be provided to the sector is yet to be explored.


Image courtesy of CommBank

Case Study: Social robot services

"The opportunity to experiment with a robot-like Chip in a real-world environment such as Sydney Airport is unique, even on a global scale. It is also incredibly valuable, as it allows both corporates and academics to contribute to the growing field of research in social robotics and ensures that both CommBank and Air New Zealand remain at the forefront of disruptive technologies.” – Tiziana Bianco, General Manager Innovation Labs, Commonwealth Bank

The University of Technology Sydney (UTS) has a research partnership with the Commonwealth Bank of Australia (CBA) that helps industry uncover and create new opportunities to design engaging customer experiences with social robots. The Social Robotics Research team in the UTS Magic Lab work with the CBA Innovation Lab in Sydney to design social robot behaviours that solve complex problems for organisations and help to generate competitive advantage.

The social robotics market is expected to be over $US20 billion by 2025.

This unique academic-industry partnership has built a new high-performance world-leading university-industry collaborative capability. This can assist Australian businesses prepare for, and take advantage of, social robotics, with a game-changing disruptive technology poised to disturb trillion-dollar value pools in the global economy.

Social robots will change lives, transform business, and impact every Australian industry. An important area of focus for the partnership is the exploration of safe and secure human-robot interaction using industry-based experiments.

In July 2016, a state-of-the-art, 300-pound security robot at the Stanford Shopping Centre knocked down and ran over the leg of a 16-month-old boy. Knightscope, the company that made the security robot, explained that the robot veered to the left to avoid the child, but he ran backwards, directly in the front of the machine, and fell. It is imperative that people can safely and securely interact with social robots offering services in agile manufacturing, healthcare and transport.

7.5 Personal services

7.5.1 Australia's personal services

Personal services are those consumed mainly by individuals and households. They include services in tourism, hotels and restaurants, recreation, entertainment, and personal services such as hair and beauty treatments [ASS00]. Also included are domestic or personal robots that people purchase and use in their own homes to provide personal services.

The personal services sector is worth a total of $AU83 billion to the Australian economy (5 per cent of GDP), employs 1.7 million people, and contributes strongly to Australia's total services exports [ABS18]. The personal services sector is expected to grow, due to increased outsourcing of household services by cash-rich and time-poor households [ASS00]. Households are increasingly applying their own robotic solutions to solve personal chores such as lawn mowing, pool, and floor cleaning. In 2015-2016, personal travel, worth $AU16.5 billion, was Australia's second largest services export after education, growing 16.9 per cent per year [AIR16]. Tourism set new records, with 7.7 million tourists visiting Australia in the twelve months to March 2016, and values for tourism-related services growing by 11.2 per cent in 2015–16 to $AU43.6 billion [AIR16]. This suggests that Australia has remained an attractive destination for international tourists, likely supported by a lower Australian dollar.

The incidence of part-time work is highest in personal services. In 2000-01, part-time work accounted for almost 40 per cent of the workforce [ASS00]. The workforce is generally low skilled and paid 90 per cent below average services sector wages. Low skilled work tends to be the easiest to automate, so robotics could potentially have a large impact on the workforce, taking away mundane work and leading to upskilling of the sector. Employment in this group grew at more than double the national average rate and contributed to 20 per cent of Australia's new jobs [ASS00]. Accommodation and food services has the highest proportion of workers aged 15-24 years (43 per cent), almost three times higher than the rest of the Australian workforce [SWA18].

Snapshot — **Personal services sector**

Cash-rich and time-poor Australian households are increasingly outsourcing many chores.

$83b output

1.7m people employed

Key activities include

- tourism
- hotels and restaurants
- recreation
- entertainment
- domestic services
- other personal services (e.g., hairdressing)
- domestic or personal robots that people purchase and use in their own homes

Sector Definition

Personal services are those consumed mainly by individuals and households, and include tourism, hotels and restaurants, recreation, entertainment, and personal services such as hair and beauty treatments

Key Robotic Technologies for the sector

- natural language processing
- human-robot interaction

Challenges/ Opportunities

- Adaptation to more highly skilled workforce
- Move to gig economy (workers employed on tasks rather than jobs) undermines traditional business models

7.5.2 Robotics and personal services today

Robotic technologies can be applied in two ways in personal services: firstly, to reduce labour costs by assisting or replacing human workers, and secondly, to increase product or services sales by using social robots to interact with and influence customers. Both options will be controversial in discussions about robotics and automation in the sector. While personal services robots can assist human workers, relieving them of mundane tasks and allowing them to concentrate on more creative or complex tasks, there is also a high risk that some workers will be replaced by robots. One of the main drivers for companies to adopt robotics is to reduce headcount and decrease labour costs [PwC17]. While the use of customer-facing social robots in personal services is limited in Australia, it will be similarly controversial in the future. 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.

> In 2016, the total number of service robots for personal and domestic use increased by 24 per cent to approximately 6.7 million units.

In economic and labour terms, industrial cleaning represents one of the most dynamic areas where robots (as opposed to home robotic vacuum cleaners) can be applied. In Europe, more than 176,900 cleaning contractors employ 3.32 million employees generating a turnover of $AU66 billion. The sector's steady and sustainable growth (over 9 per cent annually), can be explained mainly by the evolution of the market penetration of cleaning companies and the continuous outsourcing of services. The adoption of robotics is driven by labour costs, which comprise 70 to 80 per cent of costs, with floor cleaning representing 60 per cent of the cleaning task. Cleaning robots eliminate certain types of cleaning work, which frees employees to do more skilled tasks. Potential labour cost savings can vary from 20 to 50 per cent. For this reason, there is high potential for an increase in the use of personal service robots such as floor-cleaning robots [IFRSR17].

In 2016, the total number of service robots for personal and domestic use increased by 24 per cent to approximately 6.7 million units. Worldwide value was up by 15 per cent to $US2.6 billion. Service robots for personal and domestic use are recorded separately, as their unit value is generally only a fraction of the many types of service robots for professional use. So far, service robots for personal and domestic use are mainly used in the areas of domestic (household) robots, which include vacuum and floor cleaning, lawn-mowing robots, and entertainment and leisure robots [IFRSR17].

Images courtesy of iRobot

7.5.3 The future of robotics in personal services

Service robots in everyday environments or public settings are still a novelty in Australia but they have significant potential. Typically, these applications must be well designed to surprise or impress the public and invite further interaction and consumption. Installations usually rely on vision-enabled robots, for example, museums use camera-equipped robots that can navigate and can be used for people to remotely visit the attraction and show themselves around.

As the sector is developing quickly, some major application areas have developed, such as robotics in hotels and restaurants, in public environments for guidance and information outlets, in stores or other public environments to promote sales or services, or as robot attractions such as joy rides.

Tourism, hotels and restaurants

As in retail, robots are used as concierge services, can help with translation for foreign nationals, and in the future, will most likely conduct tours using autonomous vehicles.

In hotels, robots can perform the tasks of carrying suitcases to rooms, delivering room service, transporting laundry, and double as security robots when not on active delivery duty. In restaurants, they can be used in the preparation of food. Robots are mostly used as an attraction, to prepare or serve food and drinks, or act as shelves for returning trays. A growing sector is public relations robots. In 2016, almost 7,400 units were sold, 139 per cent more than in 2015. Most of these robots were telepresence robots, for mobile guidance and information, with a sales volume of 7,200 units in 2016, up from 3,100 units in 2015. The total value of public relation robots increased by 126 per cent to $AU159m. By 2020, sales are expected to grow from $AU159 million to $AU5.8 billion (a 37-fold increase). This is higher than any other form of professional service robot [IFRSR17].

Recreation

Robots could be used to maintain sporting grounds, monitor health of public pools and other public spaces, and answer queries from the public as a concierge robot.

Entertainment

Robots (or UAVs) are increasingly being used in cinematography (see XM2 case study p. 97). There are also performance robots used for theatrical performance, and as a replacement for animatronics. Advantages include camera position and repeatability, and replacement for steadicam (mobile robot and/or UAVs). Robotic animatronic use in movies has been largely superseded due to advances in digital animation that have removed the need for physical representation of characters.

> Companion robots are becoming more common, particularly for elderly or people with disabilities, as they can replace or augment companion animals, providing a level of comfort and care and increased mobility.

Robots at home (domestic services)

The hugely popular small humanoid robot called 'Pepper' was originally created for use by SoftBank Mobile's retail stores in Japan, and was released in 2014. Pepper is a social robot that can talk with humans, recognise and react to emotions, move, and live autonomously. During interactions, Pepper analyses facial expressions, body language and verbal cues, honing responses, and offering a dynamic and surprisingly natural conversation partner. Within advanced IoT architectures, there is large potential to make the robot a versatile and customisable platform for human machine interaction (e.g., using the Watson dialogue service - see case study p. 98).

The market for household robots was worth $US1.234 million in 2016. It is forecast to grow by a factor of 10 to reach $US11.278 million by 2020 [IFRSR17].

Other personal services (e.g., hairdressing, beauty treatments)

Personal services are an emerging area and there are no known instances of these types of robots in Australia yet. Companion robots are becoming more common, particularly for elderly or people with disabilities, as they can replace or augment companion animals, providing a level of comfort and care and increased mobility (see Chapter 6). These may be in the form of a humanoid or wheeled robot, and often resemble 'cute furry creatures' (e.g., cats, dogs, seals such as the Paro robot - see case study p. 67).

7.5.4 Main findings for robotics in personal services

The personal services sector is expected to grow due to increased outsourcing of household services by cash-rich and time-poor households. Households are increasingly applying their own robotic solutions to solve personal chores such as lawn mowing, pool and floor cleaning. The sector's workforce is the youngest and one of the lowest paid, with low skills meaning robotics could potentially have a large impact, taking away mundane work and leading to upskilling of the sector. There are two main ways that robotic technologies can benefit personal services: firstly in reducing labour costs by assisting or replacing human workers, and secondly, in increasing product or services sales by interacting and influencing customers by using social robots. Service robots in everyday environments or public settings are still a novelty in Australia but they have significant potential.

Image courtesy of XM2

Case Study: XM2 - cinematography

Since 2014, XM2 Aerial has been pioneering the use of unmanned aerial vehicles (UAV) or drones on movie sets around the world.

The demands of movie making means today's cinematography is technically complex, requiring precision image capture, balanced with flexibility to react to constantly changing storylines and shot requests. This is making traditional means of hoisting cameras or using helicopters to get above ground shots time consuming, rigid, costly, and in some cases, dangerous tools of trade.

UAV are the perfect solution for the modern cinematographer. With a never-ending design process, XM2 has continuously developed bespoke UAV systems and workflows that meet the needs of major movie productions in multiple ways. A recent example was on the production of the recently released movie Pacific Rim: Uprising. XM2 were deployed to South Korea as the entire 2nd Unit team. They were able to use UAV to replace traditional dolly, cranes and booms, completing what would have taken 2-3 weeks shooting, in just 6 days.

The rise of the drone is providing movie producers and creatives with a tool to capture never-before-possible shots, with high-quality imagery in a fraction of the time and at much less cost.

Case Study:
Smart concierge robots in hotels

For the last two years Hilton and IBM have teamed up to pilot a smart robot that acts as a hotel concierge, answering guests' questions and learning as it works.

The NAO humanoid robot from Softbank Robotics is designed to interact with hotel guests and answer questions about hotel amenities, local attractions and dining options. The robot uses IBM's Watson machine-learning APIs, like speech to text, text to speech and its natural language classifier. The more guests interact with the robot, the more it learns, adapts and improves its recommendations. Watson helps the robot understand and respond naturally to the needs and interests of hotel guests leading to deeper guest engagement, improving customer service and satisfaction.

Image courtesy of Ambrogio

Case Study:
Lawn mower robots – automation in landscaping

As more people outsource personal services to contractors, robotic lawn care equipment and software is being used to automate landscaping.

Lawn mowing can be physically demanding, there are labour shortages and business tends to be low margin but demand for such services is rising. Robotic lawnmowers can handle steep 45% slopes and cover up to 2 hectares. They are equipped with sensors to avoid knocking into fences, tree stumps and other obstacles. Robotic mowers can also be supported by smart cloud-based lawn care software that allows online booking of landscaping services, job scheduling, dispatching, invoicing and payment tracking. Landscaping robots are also plowing snow, blowing leaves and mulching.

7.6 Utilities

7.6.1 Australia's utilities

The utilities sector encompasses essential services that underpin modern society, including electricity, gas, water, sewerage, and waste services. While often near invisible, this sector is vital to the ongoing success of all other sectors of the Australian economy.

Much of the utilities sector is run by government, or quasi-government owned organisations (state, regional or local depending on utility and location). However, with recent deregulation, some utilities are offered by private sector companies, notably in electricity and waste management. Utilities are worth $AU41 billion to the Australian economy (2.4 per cent of GDP) and employ approximately 140,000 people.

The ratio of women to men in electricity, gas and water is 1:3.5, well below the average for the services sector (1:0.9) [WGEA16].

Electricity and gas supply are generally broken into a wholesale and a retail network, with downstream industries purchasing services at either, or both, levels. Domestic use is generally limited to purchasing utility services at a retail level, except in some rural locations.

Australia's water assets are vast. The urban water industry provides enough drinking water to fill Sydney Harbour four times each year. It also uses 300,000 kilometres of water and wastewater pipes, enough to circle the earth six times. In July 2015, the value of Australia's urban water assets was estimated to be $AU160 billion. Most of Australia's water assets are publicly owned, the exception being the Sydney Desalination Plant which was designed and constructed under government ownership and then transferred to the private sector through a long-term lease in 2012 (EY-INF16).

The energy part of this sector is being disrupted by the advent of efficient solar (photovoltaic and other) and high-power density batteries (e.g., Tesla Powerwall for homes, plus the South Australian government's big battery). This means end consumers can reduce reliance on energy networks provided by others for the generation of energy.

Snapshot | **Utilities**

Reliable, secure access to water and power services underpin Australia's economic prosperity.

$41b output

140k people employed

>$160b in assets

Key activities include

supply of water | supply of gas | supply of electricity | sewerage | maintenance of infrastructure

Sector Definition

water, electricity, and gas distribution, generation and infrastructure

Key Robotic Technologies for the sector

Safer designs | Perception and control in complex operations | Locomotion | Multi-robot co-operation

Challenges/ Opportunities

Safety | Scale | Remote operations

7.6.2 Robotics and utilities today

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, transporting gas under high pressure. 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 [SW18].

For a nation with a low population density, installing and maintaining services to remote (and even local) communities is an ongoing challenge. The work is often dangerous (at heights, energised), time critical, and occurs in remote and hard-to-access areas. This confluence of challenges is well-suited to solutions by robotic technologies. Opportunities include removing workers from high-risk activities, allowing remote unmanned operations, and increasing oversight of utility infrastructure and operations by having extra sets of "eyes" monitoring key resources and alerting or taking action when an issue is detected.

7.6.3 The future of robotics in utilities

The inspection and maintenance of Australia's extensive network of infrastructure assets, managed by utility organisations, is critical for the maintenance of essential services. Robotic technologies have an important role to play in both inspection and maintenance, with the potential for a broader range of applications currently being explored.

Some applications of these technologies include:

- autonomous pipe and cable inspection
- autonomous installation/connection of pipes and cables
- autonomous construction of new assets (particularly in remote areas)
- physical support of field workers and autodetection of risks
- remote repair and refurbishment of assets
- maintaining physical security of assets via unmanned security patrols
- robotic solar collectors (aligning to perfect position, and location, for maximum efficiency)
- robotic water purifiers deployable after major weather events.

7.6.4 Main findings for robotics in utilities

Reliable, secure access to water and power services underpin Australia's economic prosperity. Australia has a vast network of critical infrastructure assets required to deliver water and energy to our homes and workplaces and to remove waste. Our electricity grid spans more than 5,000km and is one of the largest interconnected power systems in the world. Australia has more than 37,000km of natural gas transmission pipelines, transporting gas under high pressure. Sydney alone maintains more the 21,000 km of water pipes. For a nation with a low population density, installing and maintaining services to remote (and even local) communities is an ongoing challenge. The work is often dangerous (at heights, energised), time critical and in remote and hard to access areas. This confluence of challenges is well-suited to solution by robotic technologies by removing workers from high risk activities, allowing remote unmanned operations and increasing oversight of utility infrastructure and operations by having extra sets of "eyes" monitoring key resources and alerting or taking action when an issue is detected.

Images courtesy of CRC-SI

Case Study: ROAMES

The Queensland University of Technology (QUT), Cooperative Research Centre Spatial Information (CRCSI), and Ergon Energy's Flight Assist System (FAS) technology reduces pilot workload, enhances pilot safety, and enables rapid data capture to help improve the task of state-wide power line network inspection.

The costs of managing a large power line network are significant, including high physical demands on, and personal risk to, workers. Queensland's Ergon Energy's network includes over 150,000 kilometres of power lines, 100 million trees, and 600 towns and cities.

Traditionally, the vital task of inspecting vegetation encroachment on powerlines was performed by time-consuming and expensive ground crew inspection. The alternative of using inspection aircraft requires flying for long periods of time at low altitude above power lines, which is potentially unsafe and tedious for pilots. To overcome these issues, QUT, CRCSI, and Ergon developed the FAS aircraft autonomy technology. This includes optimised flight planning, in-flight quality assurance, and resilient flight control technology that plans and then executes semi-autonomous flight over power line infrastructure at low altitudes to capture high-quality sensor data. The aerially-collected data is the key enabler for the Remote Observation Automated Modelling Economic Simulation (ROAMES) system. ROAMES has enabled a substantial reduction in the maintenance costs of Ergon Energy's power line network (by $AU40 million per year) and has changed the way large-scale power infrastructure is managed. For example, in February 2015, Category 5 cyclone Marcia destroyed 350 homes. ROAMES enabled rapid prioritisation of recovery activities and Ergon Energy restored power to more than 51,000 customers (80 per cent of those impacted) within a record 10 days, saving more than $AU10 million. In 2015, the ROAMES system was awarded an International Edison Award for Innovation and a Queensland Spatial Excellence Award.

Case Study: Sydney Water

Employing in-pipe robotic tools allowed Sydney Water to perform cost-effective advanced condition assessments. It enables Sydney Water to intelligently identify actual 'end-of-life' replacements.

The cost of asset renewal programs has been reduced from approximately $AU50 million per year to $AU30 million. Sydney Water invested as part of a consortium-run project worth $AU12 million. The project involved 10 major Australian water utilities.

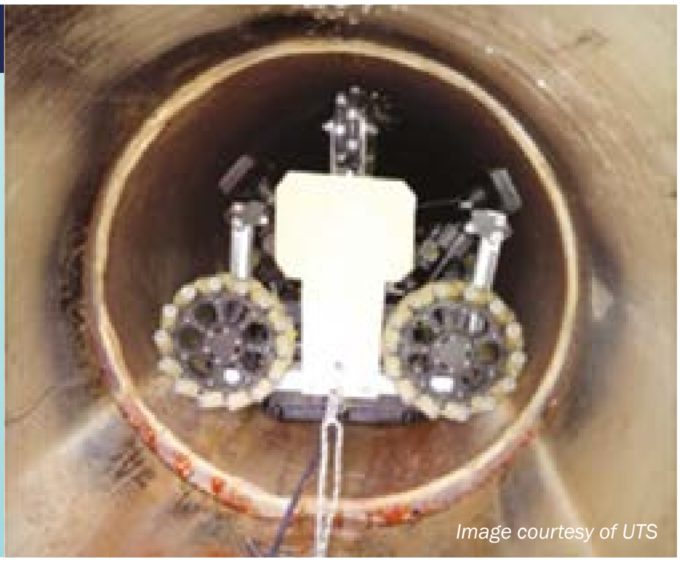


Image courtesy of UTS

Case Study: A robotic vision system for automatic inspection and evaluation of solar plants

An Australian university (ANU) has been the first to trial intelligent drones for automated inspection of solar power plants.

The project is an industry-researcher collaboration funded by the Australian government's Australian Renewable Energy Agency (ARENA) developing a cost-effective robotic inspection system for automated monitoring of concentrating solar power (CSP) and photovoltaic (PV) power plants using cameras mounted on ground and aerial drones.

The project, which commenced in 2016, is the first time that a flock of drones carrying optical sensors, such as optical, polarisation and thermal cameras, laser scanners, empowered by intelligent computer vision solutions has been deployed for automated inspection of solar power plant facilities. Advanced data driven and deep learning based visual data analysis techniques contribute to the accuracy of measurement and detection.

Improving energy production capacity and decreasing long-term operating expenses will make large-scale solar power plant facilities more attractive investments and therefore boost the Australian renewable and clean energy sector. The visual inspection technology has the potential to provide automated and affordable inspection solutions for smaller-scale household roof-top PV installations as well.

7.7 Construction

7.7.1 Australia's construction industry

Construction is worth $AU124 billion to the Australian economy (7 per cent of GDP) and employs 1.16 million people. Although the sector appears large, with over $AU356 billion revenue [IB17], it is heavily fragmented, with more than 328,000 businesses operating in the industry. 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 2.8 per cent share of overall revenue. The third largest entity contributes less than 1 per cent, and most remaining businesses are small-scale non-employer companies made up of sole proprietors and partners [IB17]. This diverse, shared market 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. 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 [IB17]. The ratio of women to men in construction (1:8) remains well below the average for the services sector (1:0.9).

Despite a strong safety culture, construction remains a dangerous industry with 401 workers dying on construction sites between 2003-2013, and 35 construction workers seriously injured every day in Australia. Construction sites are busy places. Many contractors work side-by-side and heavy vehicles come and go. In this environment, consultation, cooperation, and coordination are essential to ensure the health and safety of everyone on site. Safety is a high priority in the construction industry due to the high number and rate of work-related fatalities and serious injuries [SWA18].

Snapshot | **Construction industry**

Dominates the Australian Services sector and is a leader in the Asia-Pacific region.

- $124b output
- 1.16m people employed
- 328,500 businesses

Key activities include

- construction of buildings and infrastructure
- civil engineering
- irrigation projects
- repairs and renovations
- demolitions and excavations

Sector Definition

buildings (residential and non-residential), infrastructure and industrial

Key Robotic Technologies for the sector

- Reliable Mobile 3D perception (Lidar Vision)
- RegTech - Regulation Technology
- Robust cognition – including People tracking
- Vision for other safety related tasks

Challenges/ Opportunities

- Safety
- Labour costs
- Corruption - perverse incentives - lack of transparency
- Opaqueness of process leading to sub-optimal performance


Image courtesy of Blue Ocean Robotics


Image courtesy of Laing O'Rourke

7.7.2 Robotics and the construction industry today

Construction is in dire need of robotic vision. It is a harsh, geographically large and disparate, unstructured, and perpetually changing environment where high cost critical operations occur. Currently, work within the industry is not transparent and is sparsely monitored. It is not physically possible to have enough sets of 'always alert' intelligent eyes monitoring, and understanding, progress to generate metrics that feed into the type of control paradigm commonly found in manufacturing. Robotic vision presents an opportunity for the required real-time, real-world, robust and reliable information needed to underpin the development of improved monitoring in the industry.

Productivity in construction is significantly lagging comparable industries, and construction is very low (second to bottom) in terms of digital maturity [DIG16]. Robotic vision will enable the capture of benchmark of performance, and drive core measures upon which productivity enhancements can be proposed, made, and measured.

> Productivity in construction is significantly lagging comparable industries, and construction is very low (second to bottom) in terms of digital maturity

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. However, the main driver for the application of robotic technologies in the 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.

There is an ongoing skills shortage in the construction industry. Australia has an inherently shifting and ageing workforce, with younger generations seemingly reluctant to pursue traditional occupations. Robotics and automation can help fill jobs vacated by the ageing workforce that are unwanted by younger people entering the workforce. 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 that will allow performance towards outcomes to be measured across difficult environments.

7.7.3 The future of robotics in the construction industry

Forty years ago, robots were viewed as the solution to labour shortages in construction, but the diffusion of such technology has been much lower than anticipated [IFRSR17]. Unlike the manufacturing sector (see Chapter 5), construction sites are unstructured, cluttered, variable and congested, making them difficult environments 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 [IFRSR17]. Processes that can be automated in building construction include materials handling, materials shaping (cutting, breaking, compacting, brick laying, machining), structural joining (assembly), and concreting [IFRSR17]. Robotics is also increasingly seen as an enabler for architectural design, allowing custom, one of a kind, sometimes additive built-up, complex structures [IFRSR17].

The automation of heavy machinery has the potential to improve the safety and efficiency of construction operations, which involve complex tasks in a range of unstructured environments. Typical robot technologies, such as motion control, navigation and computer vison, are increasingly integrated in previously manned platforms (e.g., cranes). Advances in technology will see robotics tackling increasingly complex physical and cognitive tasks. There will also be a strong industry need for regulation technology (RegTech), robotic and vision systems that can be deployed to monitor and enforce worker safety, and identify and ameliorate potential hazards. Some examples of the types of robots that might be seen on future construction sites include:

- the GO-FOR robot – that you can direct to get tools/supplies
- autonomous spotter – helps monitor safety autonomously
- health monitoring – never work alone: a robotic buddy
- bricklaying and timber or steel truss building robots, painting robots.

Construction is predominantly an operational excellence business. It is a broad gambit of relatively smaller tasks, designed, planned and sequenced to culminate into a built outcome. This heavily intertwined set of tasks span technical, business, and workers. As such, any conception of the need must be sympathetic to this. A purely technological solution has considerable barriers to adoption if it does not fit into business flow and process. Uptake is also unlikely if workers are jarred, threatened, or perhaps simply don't comprehend the offering.

7.7.4 Main findings for robotics in the construction industry

Construction is a harsh, geographically large and disparate, unstructured and perpetually changing environment where high cost critical operations must occur. Robotic technologies can play a crucial role in reducing injury and fatality rates and also improving productivity. 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. The ongoing skills shortage in the construction industry is exacerbated by the younger generations' reluctance to pursue traditional occupations. Robotics and automation can help fill jobs vacated by an ageing workforce. Typical robot technologies such as motion control, navigation and computer vison are increasingly integrated in previously manned platforms, advances in technology will see robotics tackling increasingly complex physical and cognitive tasks. There will also be a strong industry need for regulation technology (RegTech), 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.

Image courtesy of Laing O'Rourke

Case Study: Toolbox Spotter robotic vision system for autonomous spotting in construction

Serious work place incidents are all too common - in 2017 Safe Work reported 195 Australians lost their lives and 107,355 suffered serious traumatic injuries in work place incidents. The national impact was estimated at $AU61.8 billion, the associated property aspect at $AU17 billion and as a nation we spend $AU100+ billion annually on prevention, insurance, and compensation.

Closer to home – an internal review suggested 15.4% of Laing O'Rourke Australia's recorded incidents 2008-2018 may have been Toolbox Spotter preventable. Furthermore, analysis of Safe Work's data reveals that 'heavy' construction operations significantly and disproportionally contribute to incidents and that over 84% of all incidents name a failure in spotting, distraction, lapses of attention, and/or communications as a key factor in the incident occurring.

Laing O'Rourke has been developing and extensively trailing Toolbox Spotter to address this very need. Toolbox Spotter 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 ability to enable operations. This advanced ecosystem of extra sets of never tiring, always alert, always diligent, intelligent eyes has its mind on the team and its focus on the job. It sees and understands without special tags, markers or processes – Toolbox Spotter jumps straight onto the team to reduce fatalities, traumatic injuries, and property incidents, enable otherwise non-possible works, and decrease resource, workers' compensation and insurance costs; All while driving inherent safety in operations principles.

R&D thus far has seen 10,000s of hours of extensive R&D testing and exploration over a range of conditions; rain, sun, overcast, dusk and dawn, dusty, clear and crowded. These efforts resulted in a compelling and patented proof-of-concept with operations endorsement and with real impact – For instance, in the image above, the operator clearly saw the entire group of people behind him leave the area, but Toolbox Spotter saw a person in the blind spot and the operator was alerted. The operator was under pressure, believed the area was clear and was ready to return to work, but instead voiced concern at which point an unseen person in the blind spot responded. The operator asserted that Toolbox Spotter had just saved a life!

Case Study: Robots in architecture and custom construction

UAP is a Brisbane headquartered company that manufactures public art, custom architectural facades, and design furniture for leading artists, architects and designers around the world. The complexity of designs that artists, architects and designers now demand push the limits of what is feasible to manufacture with traditional fabrication techniques.

To meet this demand and ensure future competitiveness, UAP has invested in a 5-year Design Robotics project with the Innovative Manufacturing Cooperative Research Centre (IMCRC). This project is to investigate how robotic vision could be applied to its manufacturing processes, to make them more cost effective and allow for new kinds of art and design objects to be created.

The first problem that robotic vision is addressing for UAP is to allow for robotic polishing of metal sculptures after they are removed from a sand mould. This is a labour-intensive, dangerous and boring job that is currently difficult to automate because of the unpredictable shapes involved. Unlike in mass-manufacturing, where the actions of the robot can be programmed ahead of time, in UAP's manufacturing processes the items are often completely unique with no pre-existing computer file that describes their shape. Robotic vision is required to build an accurate model of the cast metal object that can be used to drive the polishing process.

Already UAP are reshoring work back to Australia from China due to the cost benefits associated with scanning and robotic technology. 50 hours of robotic operation allowed 800 labour hours to be re-shored back to Australia.

Images courtesy of UAP

Case Study: Fastbrick bricklaying robot company listed on Australian stock exchange

Fastbrick Robotics is a start-up company that is revolutionising the brick laying industry by using mobile robotic technology. The system uses a pre-existing plan of the building and environment, and with laser guidance (a mature technology), it is able to accurately and quickly lay out the bricks [AAS18].

Fastbrick Robotics have developed a truck mounted robot that works in conjunction with their proprietary building design software and has the capability to lay the bricks for a render ready, standard home in approximately 15 hours (around 1,000 bricks per hour).

The truck is fitted with a brick handling system which will cut and rout the bricks as required then send them along a 25-metre boom to a specially designed lay head. The lay head will apply a dedicated adhesive and lay the bricks to within 0.5mm of design specification under a laser guidance system, which manages any dynamic interferences (vibration, wind etc).

The safety of this system has been carefully designed and analysed to comply with the requirements of Australian Workplace Health and Safety legislation (minimising risk by design) and relevant standards (e.g., AS 4024.1-2014 Safety of Machinery and AS 62061 Functional safety of safety-related electrical, electronic and programmable electronic control systems).

Although fully automated while in operation, the machine is designed to be managed by trained operators. Safety of humans is fully assured by the system design.

Fastbrick Robotics has received worldwide attention for this highly innovative robotic system and have recently signed Memorandum of Understanding (MOUs) with Caterpillar and the Kingdom of Saudi Arabia, highlighting the global interest in this unique Australian robot. The KSA MOU is for the construction of 50,000 homes by 2022 and is estimated to require at least 100 bricklaying robots.

Contributors

This chapter was based on submissions for a Services sector workshop held on 17th November, 2017 in Sydney, NSW and with additional contributions on Construction based on a workshop held on 16th October 2017 in Canberra, ACT, with contributions from the individuals listed below:

Workshop – Services

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Alistair Usher, Academy of Science

Richard Hartley, Australian Centre for Robotic Vision, Australian National University

8 Defence

Australian defence needs cannot be satisfied by existing technologies alone. Solutions to defence challenges have the potential to significantly advance the autonomy of robots, human-robot teaming, and trust.

Image courtesy of DST

8.1 Australia's Defence Sector

The Australian defence sector is an essential part of the Australian economy, engaging thousands of Australian businesses and generating both direct and indirect employment. The defence industry in Australia constitutes about 10 per cent of total investment made by the public sector (i.e. all three levels of government – local, state and federal). In real terms, national defence expenditure was $AU8.4 billion (as at June 2017), an increase of 21.4 per cent from the previous year. Almost half (46%) of general government investment ($AU29.4 billion) goes to defence, compared to 43 per cent in the previous financial year.

The defence sector employs around 70,000 people and exports over $AU750 million of defence products and services. More than 3,000 SMEs are associated with the defence industry, accounting for approximately 50 per cent of all employment in the defence sector [AU17].

In response to international demand, the Australian defence industry has grown to be a world-class and technologically sophisticated industrial sector, offering enormous opportunity and innovative solutions. The Australian government has undertaken an integrated investment plan to create jobs and drive economic growth in the sector. It is expected that the defence budget will grow to two per cent of GDP by 2020-21, with the government to commit $AU34.6 billion in 2017–18 and $AU150.6 billion over the Forward Estimates (MD17).

Australian defence needs cannot be satisfied by existing technologies alone. Solutions to defence challenges have the potential to significantly advance the autonomy of robots, human-robot teaming, and trust. 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.

Robotics can 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 of 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.

Snapshot Defence Industry

A world-class, technologically sophisticated industry with strong support from the Australian government to increase exports.

$29.4b
investment

$700m
exports

>3,000
SMEs

70,000
people employed

Sector Definition

Businesses with capacity to supply defence-specific or dual-use goods or services in a supply chain that leads to the Australian Department of Defence.

Key activities include

- Administration
- Supervision
- Foreign military aid
- Defence research
- Operation and support of military and civil defence affairs

Challenges/Opportunities

- Limited human workforce
- Dirty, dynamic and dangerous environment
- Ethics
- Safety
- Labour costs

Key Robotic Technologies for the sector

- Cognitive machines
- Trust
- Human-autonomy integration/teaming

8.2 Strategic importance of robotics to national security

Protecting Australia requires coordination between the military, civil federal, state, and local security agencies, and private contractors. These entities are responsible for protecting and deterring incidents, mitigating injuries and loss of life to themselves and civilians, and minimising property damage. Robotics can help military, intelligence, police and emergency service personnel achieve these goals.

The Australian Defence Force (ADF) and the defence industry generally, refer to robotic systems as unmanned systems. This term applies to all forms of military, border patrol, national security and emergency response robots that keep humans out of harm's way. Unmanned systems offer tremendous versatility, persistent functionality, the capacity to reduce the risk to human life, and an ability to provide contributing functionality across all key defence areas. These systems provide an increasingly valuable means of conducting a wide range of operations in uncertain, unstructured, and degraded environments. The ADF are now moving towards deployment of trusted autonomous systems (see Case Studies on p. 124 & 125).

Military operations are conducive to using unmanned systems, as are missions and applications shared with national security services. Examples include chemical, biological, radiological, and nuclear (CBRN) detection, counter-improvised explosive device (C-IED) actions, precision strike, and humanitarian assistance. While the largest number of deployed unmanned systems are in the defence forces, these systems are increasingly appearing in other emergency services environments, particularly disaster response (see Chapter 10 – Environment).

It is difficult to quantify the potential lives that may be saved by deploying unmanned systems in place of having defence personnel placed in high-risk situations. Every ADF deployment consideration made by government considers the human cost as well as the financial cost. Unmanned and autonomous systems allow the ADF to continue to operate in environments that have become increasingly lethal to defence personnel and widen future response options. For example, scouting robots (aerial and ground) mean that Army soldiers do not have to venture, uninformed, into unknown territory. This reduces the chance of their being engaged or injured.

Over the next decade from 2017–18, the $AU200 billion Integrated Investment Program demonstrates the government's commitment to creating a more potent and capable ADF by growing a local defence industry that will create jobs and drive economic growth. In the 2016 Defence White Paper, the government announced it would invest $AU1.6 billion in the defence industry and innovation programs over ten years. All three elements of this investment, the Centre for Defence Industry Capability, the Defence Innovation Hub, and the Next Generation Technologies Fund, are now operational.

8.3 The future landscape

The Defence White Paper 2016 provides guidance on the ADF's strategic direction and capabilities for the future. It aims for a more capable, agile and potent future force, to conduct independent combat operations to defend Australia, protect interests in our immediate region, and contribute to global coalition operations. More emphasis will be placed on the joint force and bringing together different capabilities. This will enable the ADF to apply greater force, more rapidly and effectively, when required. Significant opportunities exist for extended use of robotics.

> Over the next two decades, Australia's defence forces will operate in a geostrategic environment of considerable uncertainty with traditional categories of conflict becoming increasingly blurred.

To provide forces with comprehensive situational awareness, Defence's intelligence, surveillance and reconnaissance (ISR) capabilities will be strengthened. Defence's imagery and targeting capacity will have greater access to strengthened analytical capability, enhanced support and space-based capabilities. Armed, medium-altitude unmanned aircraft will improve surveillance and protection. Defence's ability to contribute to border protection will be enhanced with the introduction of more capable offshore patrol vessels, new manned and unmanned aircraft, and a new large-hulled multi-purpose patrol vessel. The land force will be equipped with a new generation of armoured combat reconnaissance and infantry fighting vehicles. These platforms have the potential to become robotic and autonomous, and to be augmented by off-platform robotic systems.

Over the next two decades, Australia's defence forces will operate in a geostrategic environment of considerable uncertainty with traditional categories of conflict becoming increasingly blurred. This era will be characterised by protracted confrontation among state, non-state, and individual actors using violent and nonviolent means to achieve their political and ideological goals. National security agencies also face considerable uncertainty as climate change and natural fluctuations in weather patterns, couple with an increasing Australian population to put an unprecedented number of civilians at risk of experiencing increasingly violent environments. Changes in workforce demographics also challenge the technical competence of federal agencies, demanding innovative responses and careful compromises.

Defence has responded to these challenges by increasing future investment in industry innovation and next generation technologies.

8.4 History of defence robotics

Defence systems are heavily reliant on computer 'vision' technologies. These technologies span the electromagnetic spectrum from radio frequency to microwave, infrared, visible, ultraviolet and ionising radiation, as well as multi-spectral and hyper-spectral imaging. Acoustic imaging is used for underwater active sonar systems. Also important for defence are event-based sensors for computer-based scene analysis (as opposed to traditional frame-based sensors to assist human analysis). Such sensors process information based on efficient smart pixels that create events instead of images.

Like the highly successful leveraging of robotics in the mining industry (see Chapter 4), the defence sector also has experience with field robotics for military operations. For example, the Royal Australian Airforce (RAAF) Heron (a remotely piloted unmanned aircraft system) flew from 2010 to 2012 in Afghanistan. Since then, it has been used for training prior to the introduction of the MQ-4C Triton. Similarly, Scan Eagles in Afghanistan were used for intelligence, surveillance and reconnaissance (ISR) missions between 2007 and 2012, flying 6,200 missions and 32,000 hours. These systems were eventually replaced with a high-end, military grade tactical unmanned aerial system (UAS) for tactical reconnaissance and surveillance missions. Army Shadow 200 operated over 10,000 hours of flying intelligence, surveillance, targeting and reconnaissance (ISTAR) operations in 2012 to 2013.

> To ensure investment is directed in the right areas, Army is embarking on experimentation and research to better understand the optimal application and balance of smart machines for future use.

Over the past ten years, in Afghanistan and Iraq, the Australian Army has also employed ground robots for a variety of security roles including reconnaissance, vehicle inspection, and the detection and identification of enemy improvised explosive devices (IEDs). Electronic counter measures were rapidly fielded to provide force protection from remote-controlled IEDs. These systems responded autonomously to create jamming effects. Following the success of the US predator drones, Australia initially deployed relatively cheap and light, rapidly acquired systems.

In terms of training, Australia will introduce autonomous small arms target systems into service. These provide moving and reactive 'human' targets that add realism and challenge to combat shooting training. The Army will also add to its existing Brigade level unmanned aircraft systems (UAS) by introducing into service military grade UAS to every combat platoon and combat team. Black Hornet UAS will be available down to platoon level, and Wasp UAS to combat team level. The Army is also providing a commercial off-the-shelf multi-rotor UAS to every unit in the Army – Regular, Reserve and Cadets – for training and experimentation.


Army ScanEagles


RAAF Heron

Shadow 200 launch

Warrant Officer (WOFF) Rodney Amos with Talon counter IED robot

Sailors from HMAS Yarra take control of the steading line as they deploy the ships Double Eagle mine disposal vehicle during mine operations at Exercise DUGONG 2015

In the future, the Army anticipates further investment in autonomous ground vehicles for reconnaissance, logistics and casualty evacuation, and manned and unmanned teaming between helicopters and future UASs. The Army will integrate autonomous active protection systems that can detect and neutralise incoming munitions on the new armoured vehicles.

To ensure investment is directed in the right areas, Army is embarking on experimentation and research to better understand the optimal application and balance of smart machines for future use.

The Royal Australian Navy (RAN) operates mine detection robots that are tethered to, and controlled from, Mine Hunter Coastal vessels. Electrically powered Bofors Underwater Systems Double Eagle mine disposal vehicles are equipped with a searchlight, closed-circuit low light television camera and on-board close-range identification sonar. Commands are relayed via a fibre optic link inside the vehicle's tether, which also relays sensor images for display on the ship's multifunction console in the operations room. Each Double Eagle vehicle is fitted with either a disposal charge slung beneath or an explosive or mechanical cutter designed to sever the wire rope or chain holding moored mines.

8.5 Future operating environment

Network Centric Warfare development from the 1990's accelerated the ADF's networks that connect ISR assets, decision-makers, and strike assets. The US has recognised in their 3rd Offset Strategy that this approach has since been widely emulated in unique ways by state and non-state actors. This creates vulnerabilities in existing protective networks. For example, ADF protection by establishment of close-in ports and airbases become vulnerable to attack, surface ships become easier to detect at range, non-stealthy aircraft become vulnerable to integrated area defence systems, and Australia's reliance on space for ISR, navigation and communications services is open to denial and is termed Anti-Access and Area Denial (A2/AD).

Future operating environments are unlikely to be the same as they are currently. The explosion in population growth towards 'mega cities' will see an increasing chance of our Army operating in urban environments. Many of these cities will be in littoral environments, where the air, land surface, under-ground, riverine, sea-surface, sea sub-surface, electromagnetic and cyberspace meet. Such environments will be lethal, where urban guerrillas mix with non-combatants in a complex social and technical infrastructure.

The Royal Australian Air Force's (RAAF) Plan Jericho considers a new capability development imperative where "transient advantage is the new normal". In the past, slow and steady updates yielded a sustainable capability advantage in a relatively predictable environment. Today, the ADF needs to move fast to achieve transient advantages to stay ahead of adversaries in a relatively unpredictable environment. Australia's significant long-term investments in manned platforms, in the form of future submarines, joint strike fighters, and combat vehicles, remain critical. These stalwart platforms may be 'capability augmented' to achieve transient advantages by rapid development of deployable Trusted Autonomous Systems.

8.6 The need for trusted autonomous systems

In Defence, most applications of field robotics have been in carefully-managed, or uncontested, situations with remote human pilots or operators, but that is now changing. These situations and systems are increasingly being challenged with electronic warfare and adapted commercial technologies. The situations in which these robotic systems are most needed for the future are contested, actively hostile and unpredictable, where the pilot may not be human, and the consequences of mission failure may be high. This approach is termed 'trusted autonomous systems'. The inventory for robotic capabilities that fit this description is bare.

The anti-access/area denial (A2/AD) environments described earlier, whether land, sea or aerospace domains, each with their unique challenges, have capability implications for trusted autonomous systems. The requirements include: operating where manned platforms cannot survive, without the guarantee of direct communications, extending manned platform sensors, performing trusted decision-making and achieve effects, using alternate navigation to GPS, and using own (organic) ISR and communications.

In Defence, trusted autonomous systems are about the whole system: humans and machines working together to achieve operational missions and goals. The premise for this is that teams of humans and machines can perform better than humans alone, or machines alone. The strengths of one, be that human or machine, can offset the weaknesses of the other.

The Australian Defence Science and Technology (DST) program "Tyche" conducts strategic research in Trusted Autonomous Systems. The program seeks to develop and understand new technologies that enable machines to maintain fitness and act trustfully in an uncertain and open world. A biennial review of the program was published in 2017. Tyche continues to lead advances in these technologies for the ADF and maintains strong relationships with science and technology partners from the Five Eyes (FVEY) community and throughout the region.

8.7 Trusted autonomous systems, public safety and ethical development

On moral grounds, some may contend that military operations should not be subject to the progress of automation and artificial intelligence evident in other areas of society. There have been calls in the media to ban 'lethal autonomous weapons', 'killer robots' and 'the weaponisation of AI'. Conversely, there is also a case for understanding Defence and National Security applications of this technology, now and into the future.

The inclusion of the term 'trust' in Defence's autonomy science and technology programs reflects the primacy that Defence attaches to human control over autonomous systems. The emphasis of Defence research is on how to build trust into a system that will be reliable, operate with integrity, and dependably execute a mission or tasks in dynamic environments.

In Defence, humans and machines working together to achieve operational missions and goals means augmenting the workforce, not replacing it. In the future, AI decision-making and human decision-making will need to be highly integrated, with each assessed equally on its merits. This includes the option of allowing the machine to, at times, override the human. The introduction of 'rules of engagement' components (essentially legal expert systems) within weapons and weapon systems illustrate this point. The resulting 'ethical weapons' would have the ability to assess and decline targeting requests when the rules of engagement violations are deduced. Decisions to override these 'ethical weapons' could be logged for subsequent review. Research towards 'ethical weapons' is planned for the Defence science and technology program.

> The inclusion of the term 'trust' in Defence's autonomy science and technology programs reflects the primacy that Defence attaches to human control over autonomous systems.

Defence programs seek to advance technologies and policies for trusted autonomous systems that are safe, secure, compliant with international laws of armed conflict, rules of engagement and in concert with the ethical standards of Australian society.

TRUSTED AUTONOMOUS SYSTEMS

DEFENCE CRC

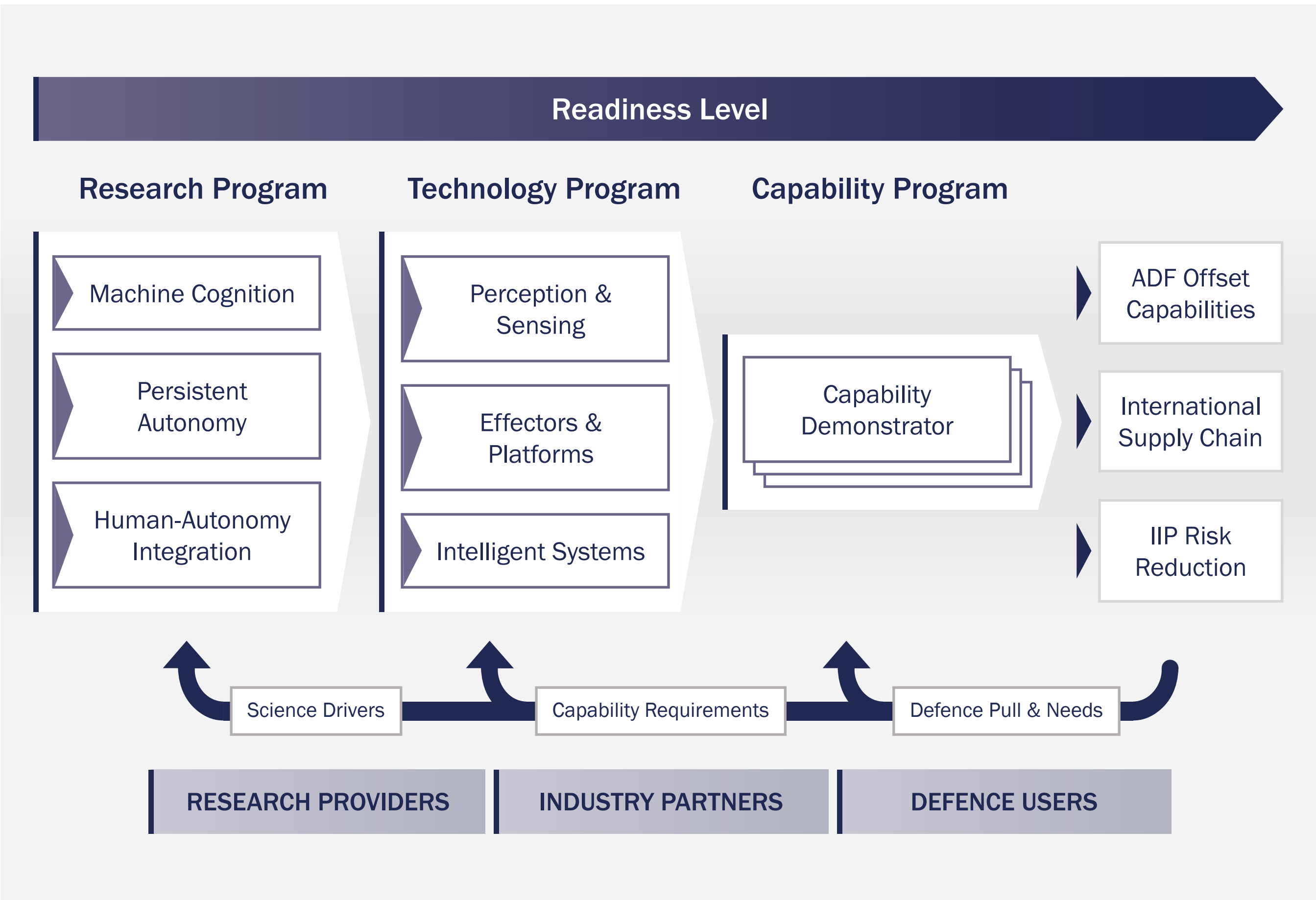
8.8 Defence Cooperative Research Centre

The Minister for Defence Industry, the Honorable Christopher Pyne MP, announced the launch of the Defence Cooperative Research Centre (CRC) in Trusted Autonomous Systems on 6 July 2017. This represents a $AU50 million investment from the Next Generation Technologies Fund (NGTF), a new government initiative that formed part of the 2016 Defence Industry Policy Statement. This is the first Defence CRC (DCRC) to be established under the NGTF. The Trusted Autonomous Systems DCRC is chaired by Mr Jim McDowell, who has had an extensive career in the Defence industry, most recently at the University of South Australia. The DCRC will receive annual funding of up to $AU8 million with a maximum of $AU50 million over a seven-year period. It will be a collaborative program that brings together industry (particularly SMEs), academia, and publicly funded research agencies to create an interlocking research and innovation capability. It will focus on developing capability in the form of unmanned platforms that ensure reliable and effective cooperation between people and machines during dynamic military operations.

The DCRC success rests on:

1. Creating and fostering game-changing research of world standing, that pushes the theoretical and practical boundaries of future trusted autonomous systems.
2. Delivery of autonomous systems and robotics technology with clear translation into deployable defence programs and capabilities for Australian Defence.
3. Building an environment in which Australian industry has the capacity and skills to deliver complex autonomous systems both to Australian Defence and as integral members of the global defence supply chain.

This is illustrated by the three pillars and flow in the following strategy diagram.



The goal of this DCRC is to deliver world-leading autonomous and robotic technologies to the ADF that enables trusted and effective cooperation between humans and machines.
The objectives include:

1. Develop highly self-sufficient and survivable systems; (SAE level 4+)[1]
2. Develop highly self-determining and self-aware systems; (SAE level 4+)
3. Develop human-autonomy systems that are human and context aware
4. Increase the speed to reach a deployable state for trusted autonomous systems
5. Increase the scalability and reduce the cost of autonomous systems technology solutions
6. Educate in the ethics and legal aspects of autonomous systems and shape national policy
7. Advocate and shape national regulations.

The research program has three themes which reflect responses to a common question about the lack of physical robots in our daily lives: "Autonomous systems have been promised for decades, why haven't they arrived yet?". Is it because:

- They aren't smart enough?, potentially implying that robots need machine cognition
- They aren't resilient enough?, potentially implying that robots need persistent autonomy
- People don't trust them?, potentially implying that robots need human-autonomy integration.

The technology program aims to deliver key components into the capability demonstrator program as well as pull through and integrate outcomes from the research program. Three areas for component technologies include:

- Perception and Sensing – including resilient perception, scene situation and self-understanding, modular low-cost intelligent sensors, bio-inspired sensing.
- Effectors and Platforms – self-healing platforms, adaptable platforms and effectors, bio-inspired platforms, micro-systems, novel actuation, low observability.
- Intelligent Systems – multi-modal multi-platform data fusion, multi-platform decision making, human-system integration.

> The DCRC will receive annual funding of up to $AU8 million with a maximum of $AU50 million over a seven-year period.

The capability program aims to showcase through demonstration, integrated autonomous system technology, and research at a level that is realistic against actual and potential defence requirements. The first Capability Demonstration activity is Autonomous Warrior 2018, led in conjunction with RAN Exercise Ocean Raider in Jervis Bay in November 2018. It will feature contributions by Australian Industry and FVYE partners from The Technical Cooperation Program (TTCP) with their Autonomy Strategic Challenge.

> The goal of this DCRC is to deliver world-leading autonomous and robotic technologies to the ADF that enables trusted and effective cooperation between humans and machines.

The DCRC further aims to conduct activities of 'common good' for Industry and the nation, in advancing the ethical and legal design of trusted autonomous systems, and systemic assurance to underpin the certification of products and technologies.

The approach of the DCRC is agile, with only a part of the total budget committed at start up in 2018. As a result, ongoing opportunities will exist over the life of the program to embrace new industry ideas and research breakthroughs.

[1] In the spirit of the SAE International standard J3016 Level 4 "High Automation" for automotive vehicles, or above. Level 4 means the machine(s) may be human piloted but never need to be. If in trouble machine(s) seek human assistance. If assistance is not forthcoming machine(s) go into a safe mode of operation.

8.9 Defence capability future needs

A new concept to embrace autonomous systems

Military operations cannot be immune to the progress of automation and artificial intelligence evident in other areas of society. AI has often been framed in the news as human-adversarial. People continually hear of "progress" in terms of machines defeating humans, such as playing Go and the spectre of taking our jobs. Despite this adversarial framing of AI and autonomy, true strategic advantage lies in shifting the paradigm to one of collaboration. Kasparov, once defeated by Deep Blue, now advocates Centaur Chess, a form where human-machine teams compete. The world champion in chess today is not a machine alone, but a human-machine team. For the ADF, this signals the need to evolve the concept of network-centric warfare, to include AI decision-makers embedded in unmanned platforms, and, as decision aids in manned platforms that are highly integrated with human decision-making. Such a concept was first developed in 1999, extended in 2005, and forms a significant part of DST programs today.

Agile Capability Development

To deliver on the transient capability edge requires rapid pull through of ground-breaking research into an integrated system for rapid deployment. This requires agile development of software and hardware systems. The following table provides some contrasts of expected changes.

The Agile approach, in sympathy with the need for testing trusted autonomous systems in emulating real-world conditions, requires significant and well-instrumented test ranges to be developed that can work with ADF elements as needed. Australia offers a strategic advantage to the world in this respect, due to having 'big' air, maritime, and land spaces to conduct such tests. In partnership with Australia's innovative regulatory authorities, the potential to build a strong body of evidence of the reliability of these systems will be important to future product certification. Of course, this must be underpinned by new technologies for assurance. Improved intentional systems including multi-agent technologies means that mission goals and plans may be adapted in software. The verification of the trustworthiness of machines that think and reason more like humans will require new certification methods.

Trusted autonomous systems in the Defence Integrated Investment Program (IIP)

The following tables map the planned Defence capabilities to opportunities for trusted autonomous systems drawn from the public 2016 Integrated Investment Plan. This opportunity totals over $AU200 billion and, despite trusted autonomous systems being a small component of this in terms of cost, the numbers are staggering, as is the potential breadth of impact of these technologies.

Today	Future
Robots piloted by people under controlled conditions	Autonomous systems operate in teams with humans in complex and contested environments
Acquisition an Achilles heel of Western strategy	Acquisition an enabler of transient strategic advantage
Platform-based capabilities	Low observable platforms augmented by autonomous system teams
More spent on systems engineering documentation to provide 30+ years through-life support	More product delivered due to reduced lifecycle support, self-documenting code and test automation
Platform used many times for a 50-year life	Use once or a few times then adapt, upgrade or throw away
Small number of expensive platforms	Multiple cheap platforms, adapt vision sensors, and effectors to suit
Value proposition for Defence industry is in system integration and through-life support	Value proposition for Defence industry is in evolving ever-smarter machines that integrate with people

8.10 Technology needs and goals

The trusted autonomous systems necessary for achieving Defence missions require research, development and fielding of systems under realistic conditions. Considering that the scope of trusted autonomous systems is machines (potentially embodied as robots), humans and their integration, seven principles for future Defence systems are advocated. All seven principles are based on a foundation of adaptation. Each of the seven principles may be applied to some extent, ranging from homogeneity and centralisation at one extreme, to heterogeneity and decentralisation at the other, determined according to operational dynamics, complexity and perceived risks. The seven Trusted Autonomous Systems principles are:

1. **Ability to devolve decision making**: a single human decision-maker or a centralised decision cannot always be afforded. Autonomy is founded on this principle.
2. **Capacity for ubiquitous decision-making capability:** a similar and significant capability for decision-making on (potentially) every military platform that can run software, which may span in scope from missiles through to headquarters, allows scalable mass and graceful gradation of decision-making capability.
3. **Automated decision aids and automated decision makers**: is the primary means by which the potential for ubiquitous autonomous systems is achieved as a force multiplier.
4. **Human-machine integrated decision-making:** offsets machine weaknesses with human strengths, and human weaknesses with machine strengths to achieve systemic robustness. It aims to enable the human to be the hero and ameliorate the hazards.
5. **Capacity to be distributed** (physical) and **decentralised** (intent): allows for graceful degradation to precision strike, and a diversity of alternate mission goals in the face of compromise to systemic integrity. This extends the principle of Mission Command in the ADF to include trusted autonomous systems.
6. **Socially coordinated:** allows unity of human and machine decision and action, with dynamic command and control structures rather than fixed ones, through social contracts and agreement protocols.
7. **Managed levels of operation:** constrains the binding of social agreements around self-control, common location, common intent, and cooperation/competition given available resources.

From this follows three core research areas:

- **Machine Cognition:** autonomous decision aids and autonomous decision makers to achieve self-determining and self-aware systems.
- **Human-Autonomy Integration:** human-machine integrated systems, human-machine and machine-machine social coordination, and managed levels that include human-autonomy teaming to provide unity.
- **Persistent Autonomy:** adaptation of automation subject to fundamental uncertainty to achieve self-sufficient and survivable systems.

In turn, the technology needs related to these research areas include:

Machine cognition

- **Sensor fusion** (machine sensation) – machine learning and data-driven techniques, to integrate multiple Defence and commercial sensor technologies including vision sensors, improving target acquisition.
- **Object fusion** (machine perception) – machine learning and AI techniques to detect and track objects in volumes of time and space, and attribute the information that characterises them, improving automatic target recognition.
- **Situation fusion** (machine comprehension) – AI techniques to detect and track situations based on multiple objects and their relationships as meaningful symbolic representations described in language. This allows machines to identify their operating context, to improve perception and apply the appropriate control routines.
- **Scenario fusion** (machine projection) – AI techniques to detect and track projected ‘future worlds’ described in language. This allows machines to autonomously identify threats, warnings and opportunities and prepare to take action.
- **Integrated resource management and replanning** – tightly couples allocation of resources including own effectors, adapt active sensor state, according to risk and conduct online, dynamic planning to form appropriate automated behavioural control responses.
- **Agent theory of mind** (others minds and own) – enables machines to represent and reason about their own ‘mental’ state and those of others, including humans, to allow them to treat them appropriately, rather than as non-intentional environmental objects.
- **Intentional systems** – representation of cognitive elements in machines, including beliefs, desires and

intentions to improve human explainability and traceability of machine state.

- **Semantic learning systems** – machines that learn context and meaning without the need for exhaustive semantic engineering.
- **Autonomous knowledge acquisition** – machines that acquire knowledge autonomously that is directly applicable for use with its semantic language constructs.

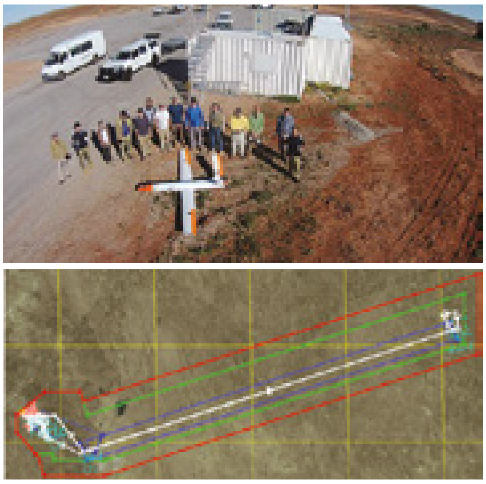
Human-Autonomy Integration

- **Agreement protocols** – support binding agreements between humans and agents, to unify intent and capability (e.g., plans) that are lawful and accountable.
- **Interaction models, systems, and technologies** – develop models to understand and improve human engagement and performance with autonomous systems, including mixed initiative.
- **Reciprocal trust and reputation** – technologies to provide appropriate transparency, confidence, feedback and reputation to improve human trust in machines where appropriate and convey when not to trust.
- **Narrative and story-telling** – explain machine state, actions and reasoning to humans at all levels of fusion and planning to improve human awareness and control.
- **Emotion recognition** – technologies to identify, characterise and track human emotional state to adapt interfaces and interaction modes and improve total performance, including through mixed initiative strategies.

Persistent Autonomy

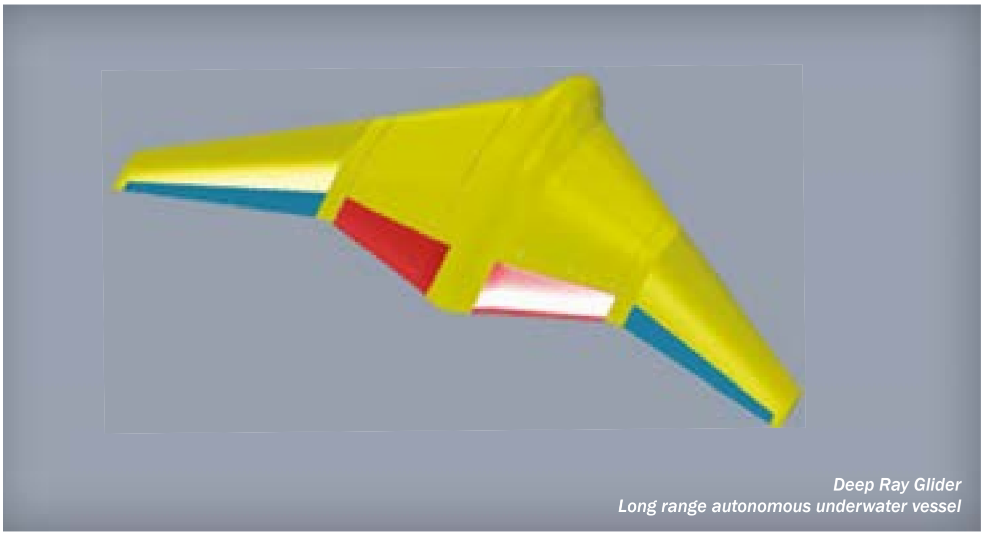
- **Assurance** – new approaches to verification and analysis for adaptive and learning systems to advance integrity and trust certification in autonomous systems.
- **Viability maintenance** – strategies to improve robot survival in dynamic environments over large volumes of time and space.
- **Evolutionary control** – determines new control laws under conditions of unpredicted degradation.
- **Self-organisation and self-healing** – technologies to assist individuals and groups adapt and survive.
- **Novel and low cost sensors and actuators** – capabilities that permit new forms of processing that significantly reduce size, weight and power and may be used ubiquitously.
- **Low observable techniques** – to reduce signatures of autonomous systems in all environmental domains.
- **Multi-domain systems** – robotic and vision systems capable of operating across land, sea surface, sea sub-surface, air and space domains.
- **Alternate navigation and timing** – means to provide accurate and low-cost navigation in complex environments where satellite-based global position systems may be denied or unavailable.
- **Alternate communications** – means to provide survivable and low-observable communications for multiple autonomous systems operating in complex and denied conditions.
- **Moral machines** – technologies to enhance system compliance with international humanitarian law and encode those laws and rules of engagement in autonomous systems to identify and protect non-combatants and symbolically-marked objects.

Autonomous Warrior 2018
Demonstration and evaluation of military utility of autonomous technologies
Jervis Bay November 2018



Alternate Navigation
Accurate and low-cost navigation where GPS may be unavailable

Survivable networks
Swarming autonomous platforms support survivable networks



Deep Ray Glider
Long range autonomous underwater vessel

8.11 Development Plan

The key attributes from the Defence White Paper are mapped to capability streams as follows:

Key Attributes	Defence Capability Streams
Decision-making capability	• Intelligence, surveillance, reconnaissance, electronic warfare, space and cyber
Enabled, mobile and sustainable forces	• Key enablers • Air and sea lift
Potent and agile offensive response	• Maritime and anti-submarine warfare • Strike and air combat • Land combat and amphibious warfare

Appendix 14.2 provides a detailed table that breaks down capability streams by function, program, active development years and investment range. It provides a narrative specific to robotics, computer vision and trusted autonomous systems, and with reference to the relevant Integrated Investment Plan section.

Image courtesy of DST

Case Study: Aerospace robotics

Our neighbours have straits, Australia has oceans.

Northrop Grumman's MQ-4C Triton unmanned aircraft system (UAS) provides real-time intelligence, surveillance and reconnaissance (ISR) over vast ocean and coastal regions. The aircraft can fly for more than 24 hours at a time, at a maximum altitude just above 55,000 feet and an operational range of 8,200 nautical miles.

Triton will be equipped with a unique and robust mission sensor suite that provides 360-degree coverage on all sensors, providing unprecedented maritime domain awareness, target acquisition, fisheries protection, oil field monitoring and humanitarian relief. Triton will be invaluable in the protection of Australia's territorial waters.

Case Study: Land robotics

Army seeks a significant combat advantage from the sensors, smarts, protective and lethal systems that land robotics can carry.

Praesdium Global are striving to become an international leader in military unmanned ground vehicles (UGVs). One of a range of robotic systems they are developing is a UGV "SCOUT", a small 70 kilogram unit capable of carriage in armoured vehicles. Featuring ease of operation, rapid deployment and recovery, and equipped with an array of advanced sensors, it includes autonomous launch and recovery from its external mount 'cocoon'. SCOUT offers an ability to project soldier presence forward, update situational awareness, and gain the initiative on the enemy.

The Mission Adaptable Platform System (MAPS) developed by Praesidium Global is a multi-role system trialled with Army.

NUASU and Thales staff conducting integration at Jervis Bay

Case Study: Combat management system and unmanned aerial systems integration

Robots produce data, humans need to use it.

Autonomous systems produce significant amounts of data, and we need to optimise the data presentation to inform human decision-making. In 2016, Thales Maritime Mission Systems leveraged previous self-funded research to integrate the Insitu ScanEagle system with both the frigate guided missile (FFG) platform and the Australian Distributed Architecture Combat System (ADACS). In 2017, the RAN's first operational deployment with an embarked UAS took place with the ScanEagle system on HMAS NEWCASTLE. The integration enhances operational value with seamlessly merged UAS data within the existing ADACS track management paradigm, enabling UAS mission tasking form ADACS whilst maintaining software safety.

Mission Systems is a small team within Thales, based in Sydney and Perth, who provide systems integration, software and support services for Naval mission systems. Missions Systems products include ADACS, the Orion integrated Maritime, Coordination and Surveillance System (IMARCS), and the award winning Stingrae Enhanced Boarding Party Capability.

Case Study: Maritime robotics

Long-range undersea surveillance is critical to Australia's security.

Wide area surveillance of the oceans requires a diversity of solutions. In July 2017, Ron Allum Deep Sea Services (RADS) was awarded an AU$3.17 million Defence contract to explore the feasibility of a novel, high-performance glider for long-endurance, undersea surveillance. As one of Australia's highly innovative SMEs, RADS offers a range of products and services specialising in systems capable of operating at extreme ocean depths. RADS technologies include: a complete, scalable energy system for vehicles, thruster motors, pressure tolerant brushless direct current (DC) motors, and structural syntactic foam built from hollow glass microspheres and fibres suspended in an epoxy resin for multiple maritime applications allowing complex shapes that do not crack or distort under extreme hydrostatic pressure.

Contributors

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This chapter also drew on submissions and a workshop held in Brisbane, QLD, on 17th January 2018 and draws heavily on a defence roadmap document prepared by DST.

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9 Infrastructure

Infrastructure robotics is a key transformative technology that can revolutionise Australia's economy in the construction and resource sectors.

Image courtesy of UTS

9.1 Australia's infrastructure sector

To efficiently function, countries rely on infrastructure, which, at its most basic, consists of transport, communications, power supplies, and buildings.

Social infrastructure is also important and includes schools, hospitals, universities, prisons and related services such as national security, defence, healthcare, and education and training. Infrastructure is a source of much economic activity, however it is costly to build and maintain. Last year the Australian government is estimated to have spent $AU251.8 billion on infrastructure, with $AU237.3 billion on social and $AU14.5 billion on economic infrastructure [IA17]. This is further represented by:

- General infrastructure (including Regional Development) $AU5.1 billion
- Transport and communication $AU9.4 billion
- National security (Public order and safety) $AU5.2 billion
- Health care expenditure $AU170.4 billion (see Chapter 6)
- Education and training $AU33.2 billion (see Chapter 7)
- Defence $AU28.5 billion (see Chapter 8).

Cities are one important form of infrastructure, with 80 per cent of Australia's economic activity concentrated in cities [EY-INF16]. Australia's existing infrastructure 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. Australia's population of approximately 24 million people is expected to increase by a further 11.8 million people over the next 30 years. Infrastructure will need to grow to cater for this population growth [IA17].

Infrastructure can be publicly (government) or privately owned. For example, Australia's urban water sector remains publicly owned and operated however, Australia's ports, airports and energy sectors are primarily privately owned or leased (see Chapter 7).

A growing challenge for Australia's infrastructure is the increasing regularity of extreme weather events. With climate change, the atmosphere is becoming warmer and wetter. Heatwaves are becoming hotter, lasting longer, and occurring more often. Australia's fire season is lengthening, leading to increased bushfire risk, and the intensity of extreme rainfall events and coastal flooding is projected to increase [CC17]. Public expectations that infrastructure will function at peak levels for maximum time has also risen. There is little tolerance for slow recovery from 'outages', even those created by extreme weather events or natural disasters.

9.2 Robotics and infrastructure today

Infrastructure robotics is a key transformative technology that can revolutionise Australia's economy in the construction and resource sectors. It will lead to a new era of smart resource and infrastructure management, positioning Australia's global competitiveness in this area. Currently the construction and resources sectors (see Chapters 4 & 7) contribute more than 15 per cent of Australia's GDP each year. The Australian government has committed significant physical infrastructure investment (more than $AU70 billion from 2013-2021), as part of the national economic plan for jobs and growth [PC17]. This is primarily to meet significant population growth, as by 2031 more than 30 million people will call Australia home [CR1] and 75 per cent of this growth will occur in cities where infrastructure is already close to capacity [EY-INF16].

While this investment growth provides further opportunities to grow jobs and domestic businesses in conventional markets, it creates extra demands on government and local councils to maintain additional infrastructure over large land masses. Australia is also renowned for building and maintaining world-class infrastructure services. This investment, combined with a surge in the Asian middle-class (one of Australia's important trading partners), provides an unprecedented opportunity for Australian businesses to capitalise on global infrastructure spending on buildings, roads, bridges, water, ports, energy and telecommunications infrastructure. Hence any opportunities

> By 2031 more than 30 million people will call Australia home.

The need for robotic vision for rail and ground vehicles

A study published by CRC Rail in 2014 [ACR14] stated that from 2000 to 2009, there were 695 collisions between road and rail vehicles. Approximately 36 per cent occurred at public level crossings with passive controls, approximately 51 per cent occurred at public level crossings with active controls, and 97 people were fatally injured. The incidence was compounded by the presence of pedestrians crossing intersections, especially the elderly with sensory deficiency.

Recommendation was made for the introduction of low-cost, intelligent transport systems, (integrated in-vehicle, passenger and light transport systems) with the potential to significantly reduce accidents at railway level crossings. In dense urban environments where rail-based systems, like trams, are more prevalent, better sensor augmentation of automotive vehicles that interact with the transportation network has becomes an imperative.

In addition to preventing accidents, autonomous systems like embedded sensor networks, which generate big data, can inform predictive health analysis in near real time for road, rail tracks and bridge-like infrastructure. Autonomous robots can aid the embedded systems by increasing the spatial and temporal reach of locations between fixed sensors or in infrastructural elements devoid of embedded sensors.

Monitoring of Australian roads beyond the urban environments is a critical challenge with limited resources available. Aside from RoadCrack [ACR14] which can perform road crack detection at high speeds, few systems can perform repairs in the field. Advances in additive manufacturing and fast prototyping techniques allow for potentially rapid in-situ detection and repair by autonomous vehicles.

to build on Australia's existing industry and research strengths to capitalise on these opportunities would be highly valuable.

Advanced robotics in infrastructure could achieve these outcomes. Increasing automation in this area will enable Australia to be more competitive globally by fundamentally changing how infrastructure is built, managed, maintained and decommissioned. With governments and industry required to do more with less, intelligent robotics and physical automation is a cost-effective way of addressing global maintenance and construction issues. This is especially the case when building and maintaining (especially ageing) infrastructure, or difficult-to-access infrastructure over large geographic areas, while removing humans from dangerous working environments. In addition, governments globally will be facing greater challenges in maintaining and constructing assets due to impacts of climate change, extreme weather conditions and terrorism related incidents. Hence intelligent infrastructure solutions will be required to gather and provide crucial information more rapidly and cost-effectively to respond to natural disasters or terrorism related incidents.

> The Australian government has committed significant physical infrastructure investment (more than $AU70 billion from 2013-2021), as part of the national economic plan for jobs and growth.

Overall, Australian businesses and the community rely heavily on a wide range of supporting infrastructure to ensure a high standard of living and the success and prosperity of the economies dependent on this essential infrastructure. To ensure Australia can maintain our high living standard, with rapid population growth, we need to transition the construction, inspection, maintenance, and decommissioning industries towards advanced robotic technologies.

Snapshot › Infrastructure Sector

Australia's population is set to increase by 11.8 million people over the next 30 years and infrastructure will need to expand to cater for this increase.

$251.8b
investment (2016-17)

For physical infrastructure the cost is
$14.5b

Estimated value add is
$187b (2011)

Sector Definition

The fundamental facilities and systems serving a country such as roads, bridges, tunnels, water supply, sewers, electrical grids, telecommunications

Key activities include

- Transport and communication
- National security
- Education and training
- Healthcare and defence
- Building and maintenance of general infrastructure

Challenges/Opportunities

- Distance
- Safety
- Labour costs

Key Robotic Technologies for the sector

- Safer designs
- Multi-robot co-operation
- Locomotion
- Perception and control in complex operations

9.3 The future of robotics in infrastructure

Despite the decline in resource-related construction, many major infrastructure projects have still been committed to, or, are under construction in areas where the resources sector dominates, such as northern Australia. According to Deloitte Access Economics data, northern Australia has 66 major projects worth around $AU201 billion being constructed or committed to, as at September 2016. These form around 46 per cent of all such projects across Australia and, due to their remote location, present unique challenges in transport of materials, supply of labour and communications [AIR16]. All are areas where robotic technologies can play a role.

There is also tremendous potential for application of these technologies in the inspection and maintenance of Australia's extensive network of existing infrastructure [ACR14, IA15]. This infrastructure includes on/above ground structures, below ground structures, and underwater structures.

On/above ground structures

On and above ground structures such as buildings, roads, bridges, power/communication towers, wind turbine blades, solar power assets, and ports can be inspected cost-effectively using unmanned aerial vehicles (UAVs) and remotely operated aircraft systems [QDS17] with a suite of sensors, including cameras. These platforms are increasingly becoming robust, stable, and efficient, showing extended longevity with inherent larger payload handling capacities. Basic inspections using close-circuit television (CCTV) technology has been in the market for many years. Biologically inspired robots able to climb complex tower structures are being developed to carry out hectic and unsafe inspections. Robots operating in undesirable constrained environments, such as inspection of bridge arches and girders, are being developed and deployed. For example, complex inspection of Sydney Harbour Bridge (SHB) arches are now a reality using biologically inspired inchworm robots [SMH15, ABC16]. Autonomous grit-blasting robots, Sandy and Rosy, have been removing the paint of Sydney Harbour Bridge since 2013 [BBC13, UTS14]. Roads and railroads are expected to be inspected through highly efficient and accurate automated technologies for detecting defects, such as quality of lane markings, cracks and potholes, through multimodal data fusion methods [CSI16].

Building inspection systems with UAVs and climbing robots can reach the difficult to access areas with ease, avoiding occupational health and safety (OH&S) issues associated with human operators.

They are expected to be repaired by highly automated processes. Smart road conceptualises the built-in intelligence to the infrastructure by embedding cameras, automatic toll readers and other sensors to effectively manage traffic gridlocks, parking, on-demand and multimodal transport, response to incidents and other related issues while improving safety, efficiency and cost. The information made available to autonomous vehicles can improve the situation awareness, efficient journey planning, and advanced navigation capabilities in crowded urban roads. The Australian government is already trialling 'vehicle-vehicle' and 'vehicle-infrastructure' communication systems as part of the cooperative intelligent transport initiative [TIC16]. Sensing and vision systems are already heavily used in building information and inspection systems. Smart buildings with embedded sensors can efficiently control the building management systems to reduce waste while improving the quality of life. Building inspection systems with UAVs and climbing robots can reach the difficult to access areas with ease, avoiding occupational health and safety (OH&S) issues associated with human operators.

Belowground structures

This includes many below ground infrastructures, such as oil/water/waste water pipes, large diameter tunnels, long-haul stretches, inverts, crowns, culverts, and manholes. Such infrastructures are difficult to access and may have other challenges such as the presence of debris, highly corrosive chemicals, and pressurised water/oil. The robotic platforms are increasingly capable of navigating such harsh environments over extended period of times, producing CCTV, 3D reconstructions, and defect profiling with ground penetrating radars, laser sensors and sonars. They can, to some extent, adapt to pipes with different sizes, shapes, and materials to accurately estimate the remaining 'intact' material for end-of-life estimations. Further, they are capable of preventative maintenance in terms of laying different types of liners and coatings. The sensing and robotic aspects of liners and coatings will be further investigated in the recently announced multinational 31-member partnership with Cooperative Research Centre project (CRC-P) on smart linings for pipes and infrastructure.

Image courtesy of UTS

Underwater structures

A variety of robotic platforms are used for monitoring underwater structures, which include unmanned underwater vehicles (UUV), unmanned surface vehicles (USV), remotely operated vehicles (ROV) and submarines. They have cameras, acoustic, and other sensors for inspection of oil and gas pipes, ship hulls, underwater pylons, dams, and ocean beds. The robotics and vision systems are not only expected to carry out inspections, but they are frequently being used to undertake cleaning, paint/corrosion removal, repairing (welding) and deep-sea operations.

Non-technical challenges in infrastructure

Over the next decade, intelligent robotic technologies will have a significant impact on transforming smart infrastructure, inspection and maintenance. These transformations are likely to present abundant challenges; technical as well as non-technical. The key robotic technological advances required by Australian industry are outlined in Chapter 11, along with the key technical challenges facing Australia's infrastructure over the next 15+ years. Non-technical challenges include:

- high cost of development, market penetration and certification
- acceptance of the technology by the workforce due to fear of losing jobs
- public acceptance of the technology
- acceptance of broad legislative and insurance frameworks
- data security and privacy issues
- requirement of early high-quality demonstration and completeness before adaptation.

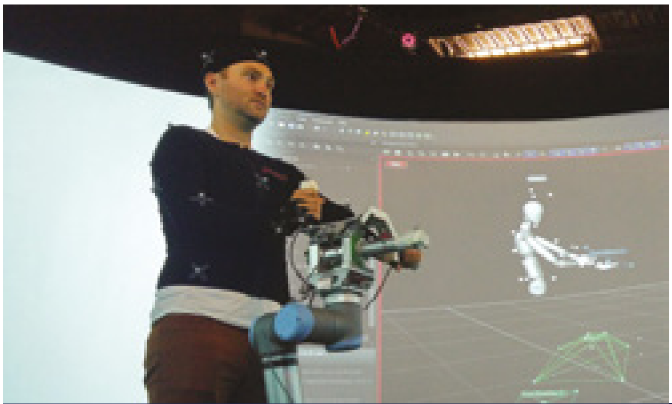
Technical challenges in infrastructure

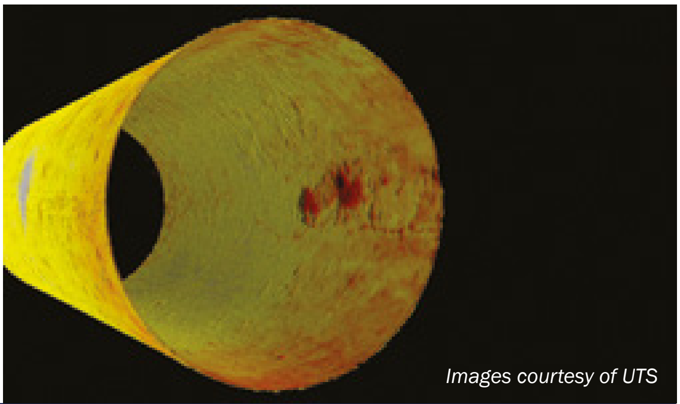
As identified in the Australian infrastructure plan [IA17], Australia has a large infrastructure maintenance backlog specifically in public owned/operated assets. There is a gap in the technology dealing with effective and efficient inspection and maintenance. Inspection needs robust sensing modalities, including vision and deployment strategies such as robotics. Maintenance requires sensing and robots as well as manipulation and actuation capability. The technologies need to be safe, efficient, robust, easy to use and of low cost to operate.

- **Safer designs:** Establishment of acceptable levels of safety, and safety certification, is needed for systems driven by advances in systems design methods that integrate safety into the design cycle, guaranteeing safety performance.
- **Perception and control in complex operations:** Significant improvements in perception, localisation and motion control systems (both in dynamic and unstructured 3D terrains, underwater and on the ground), and in terms of handling the effects of extreme conditions on perception and localisation.
- **Locomotion:** In complex structures such as towers, multi-shaped tunnels and pipes, bridges, chimney stacks, underwater structures and tall walls.
- **Multi-robot co-operation:** Command and control of teams of both heterogeneous and homogeneous robots including mixing robot teams with human teams working in close collaboration; scene interpretation and cognitive interpretation of both object and environment.

9.4 Main findings for robotics in infrastructure

Australia's existing infrastructure 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 can help to overcome these challenges by providing a cost-effective and safe means to build, manage, maintain and decommission infrastructure, especially in remote areas. Australia's population (currently 24 million) is set to increase by 11.8 million people over the next 30 years and our infrastructure will need to expand to cater for this increase. There is also growing public expectation that infrastructure (such as access to water and the internet) will always function at peak levels, regardless of challenges created by extreme weather events or natural disasters. Advanced robotic technologies are necessary to ensure continuation of Australia's high standard of living, and the success and prosperity of all sectors of the economy reliant on essential infrastructure.





Images courtesy of UTS

Case Study: Robotic technologies to look after critical water mains in large cities

Failure, and leakage, of pipes in water supply and distribution networks contributes to loss of potable water and has potentially serious economic, political and consequential costs. Water utilities worldwide face this issue, as pipe networks become older and more prone to failure.

The value of Australian buried assets is around $AU80 billion, with significant maintenance and repair costs. In 2011, Australian water utilities embarked on a major initiative focusing on the large cement-lined cast iron critical water mains (CWM) that comprise extended parts of older drinking water networks and are the most vulnerable. Together with US and UK water industry partners and leading-edge research capabilities at various Australian universities, a significant initiative was established, aimed at better targeting pipe renewals as the essential component of a CWM management framework.

After gaining a comprehensive understanding of non-destructive testing/evaluation (NDT/NDE) condition assessment (CA) techniques and industry practices, the Centre for Autonomous Systems at University of Technology Sydney (UTS) embarked on the development of advanced sensing interpretation techniques with increasing levels of confidence. This work included the design and deployment of bespoke robotic systems for the inspection of CWM. Sydney Water was the major stakeholder in the Advanced Condition Assessment and Pipe Failure Prediction Project (ACAPFP) research scheme with a cash investment of about $AU6 million. In 2016, Sydney Water estimated that learnings from the project had allowed them to advance their current maintenance practices by suitably amending condition assessment contracts and data collection protocols. Sydney Water also recognised a reduction in the cost of the annual CWM renewal program from $AU40 million in 2008-12 to $AU30 million in 2012-16.

Case Study: Autonomous grit-blasting robots for steel bridge maintenance

Abrasive grit-blasting is regularly used across many industry sectors for the removal of rust, scale, paint and other preparation surfaces. The high-pressure blasting process is an important and necessary maintenance and manufacturing step for infrastructure. Currently this process presents significant health risk to human workers, as it often leads to fine dust, lead-based paint, injury, and fatigue.

With much of Australia's existing infrastructure (e.g., Sydney Harbor Bridge), it was deemed safe for humans to do the maintenance. However, changes in current workplace, health and safety (WH&S) requirements have now deemed these jobs too dangerous or hazardous for human workers. Hence there is an urgent need for advanced robotic solutions to enable this existing infrastructure to still be serviced and maintained.

New South Wales Roads and Maritime Services (RMS) and the University of Technology Sydney (UTS) invested in the development of autonomous robots for removing rust and old paint on the Sydney Harbour Bridge. Once placed within a steel structure, a user can simply activate the robot which then automatically senses and explores an unknown 3D environment, builds a 3D map, plans collision-free motion, and performs blasting operations [BBC13, UTS14].

The major benefit of the robots is the drastic reduction of worker exposure to hazardous grit-blasting environments, compared to the existing manual blasting process. It significantly improves workers' OH&S by reducing their exposure to large forces, fine dust/paint particles and the dangerous blast stream, while providing operational efficiencies. The technology has been spun-off through an Australian start-up called Sabre Autonomous Systems for companies in the world to address this growing issue. This demonstrates examples of how Australia can create high quality jobs in science, technology, engineering and mathematics (STEM).

Images courtesy of UTS

Case Study: Maersk Oil - using drone technology to conduct offshore maintenance inspections of cargo tanks

Maersk Oil has 12 cargo tanks that require regular inspections to minimise operational downtime through preventative maintenance.

Through drone technology, inspection times have been reduced from five days (using a four-person rope and scaffolding access team) to one day (using one UAV expert pilot and one inspector), with analysis of inspections conducted in minutes onshore. This reduced human safety risks and saved GBP£5,000 per cargo tank inspection, without reducing the quality of the inspection.

Case Study: XM2 Industrial - remote sensing from UAV

XM2 Industrial is helping large organisations tackle complex problems by acquiring, processing and analysing new data collected from unmanned aerial vehicles (UAV).

Commonly referred to as remote sensing, this activity includes the collection of data about objects or areas from a distance, typically from satellite or aircraft. This has led to many advances in scientific research, along with the sensors capable of acquiring sophisticated data.

Remote sensing is gaining traction in broader commercial application using UAV with payload carrying a range of sensors including LiDAR, hyperspectral and imaging to collect data. The data being analysed is having significant positive impact on industries such as agriculture, asset and infrastructure management, and construction. Automation and computer vision are also being applied to the flight of the UAV, as well as in data processing and analytics.

As an example of the intersection of these emerging technologies, XM2 Industrial is developing autonomous flight systems and data processing algorithms for inspection of blade condition on wind turbines globally. Partnering with the largest wind turbine manufacturer in the world, this form of remote sensing will create highly efficient renewable energy by optimising performance, ensuring turbines remain in service uninterrupted, with longer life cycles.

The ability to use advanced analytics in the acquisition and analysis of data from UAVs is providing experts with information vital to solving problems such as food and energy security, and enabling smarter management of the natural environment and scarce resources.

Nuclear decommissioning and handling radioactive material

Australia has 34 per cent of the world's recoverable uranium and is the world's third-ranking producer, exporting 7,081 tonnes in 2016/17, valued at $AU596 million.

All of Australia's processed uranium is exported and Australia has no nuclear power plants and only one nuclear medicine reactor (OPAL) run by the Australian Nuclear Science and Technology Organisation (ANSTO). OPAL is used for research and to produce radioisotopes for cancer detection and treatment. ANSTO follows the ALARA principle (as low as reasonably achievable) to ensure workers receive minimum doses of radiation. When the OPAL reactor is operating, plant rooms and pumps have pipes that carry the reactor coolant, and these emit elevated levels of ionising radiation. Robots hardened against radiation could serve a useful purpose in limiting radiation exposure to maintenance and operational crews, by monitoring and servicing the plant room during reactor use.

Another use for robotics would be in nuclear decommissioning. The precursor to OPAL, Australia's HIFAR reactor, was decommissioned over 10 years from 2007 at an estimated cost of $AU50 million. At the time, robotic technology was not available to help with decommissioning but could be deployed when OPAL is ready to be decommissioned. In the bigger picture of the nuclear fuel cycle, there are also opportunities to use robots for radiation waste processing and waste sequestration. In May 2016, the Royal Commission into the Nuclear Fuel Cycle recommended that South Australia set up an international high-level waste storage facility and repository, but this option is not being pursued.

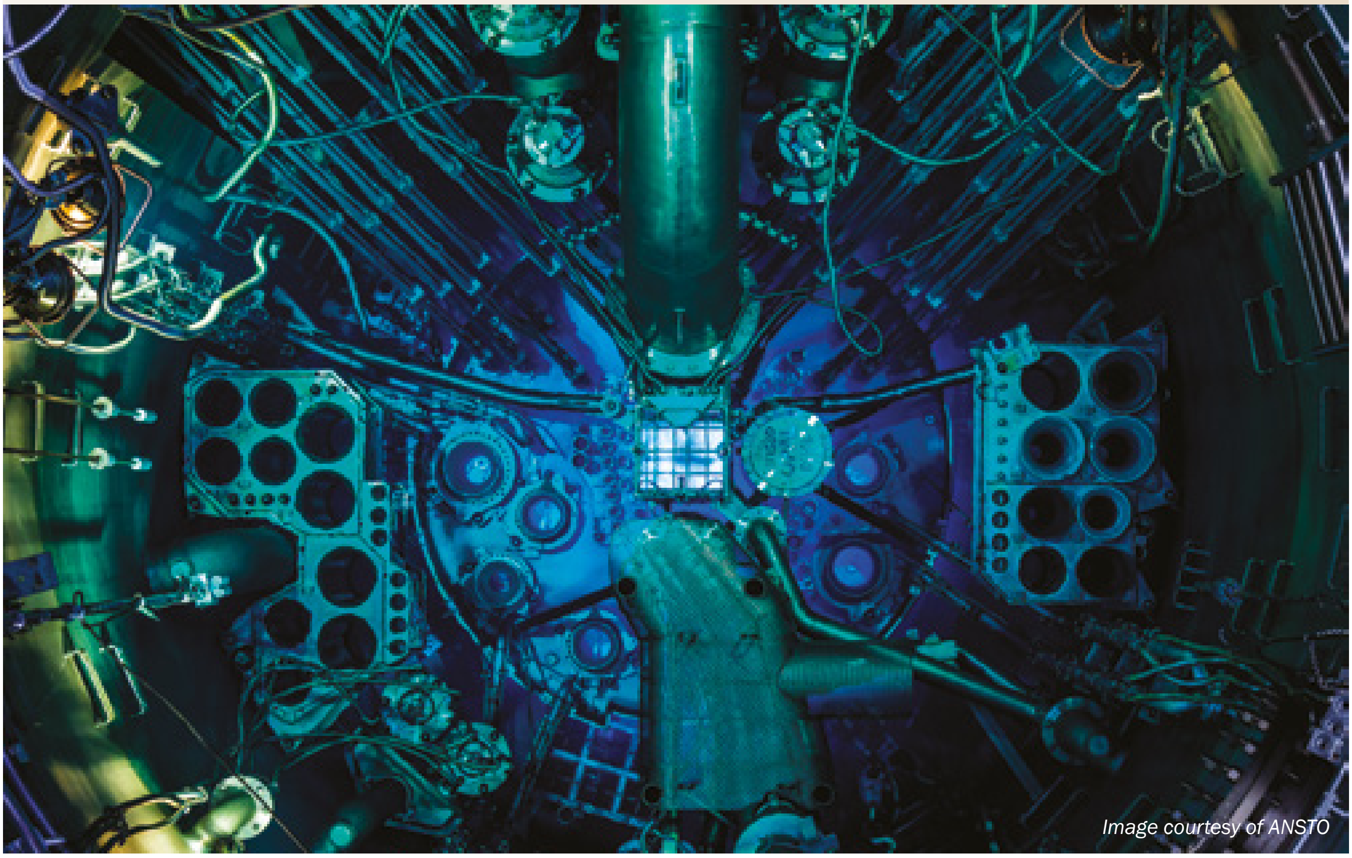


Image courtesy of ANSTO

National security

Australia spends $AU5.2 billion on national security every year. Surveillance robots can be used to assist human security guards covering a large territory or in situations where surveillance is tedious, costly or hazardous.

Typically, they are based on a mobile robot platform, equipped with a variety of sensors (microphones, radar, tele-operated pan-tilt camera, infrared, motion detector) that can be adapted to varying tasks in a variety of applications. For example, a robot might be fitted with a chemical sensor if there is a risk of a gas leak. The most frequent use of robots is to neutralise explosive devices and to clear landmines and firing ranges. National security robots are often technical derivatives of those used in defence applications (see Chapter 8).

National security robots must be able to control access to areas (e.g., critical infrastructure), detect anomalies and raise an alarm, and detect and inspect objects looking for change. To do this, the capabilities required by these robots include: biomimetic sensors for detecting or even identifying people, computer vision to analyse person behaviour, environmental conditions (presence and state of objects, infrastructure, and atmosphere) through adequate sensor channels (sound, vision, radiation, etc.), and computer vision applied to detecting the presence, location, status, and possible changes to the function of objects that might represent a threat [IFRSR17].

A whole class of search and rescue robots (SARs) and disaster response robots is also being trialled in different parts of the world (see Chapter 10). These robots have the potential to support our emergency services personnel. These include law enforcement, fire-fighting, disaster management and response (e.g., mine rescue), and infrastructure inspection robots.

Disaster response

Challenges facing Australia's natural environment, which ranges from temperate to sub-tropical climatic conditions, include: extreme heat, cyclones, increased water temperatures impacting marine ecosystems, low population density but high urban sprawl, and prevention of bushfires (CSIRO estimates 4,500 fires a week start in Australia).

The use of drones to help identify and then manage these types of disasters could have significant impact on limiting the cost, projected to increase from $AU9 billion a year to $AU33 billion by 2050. The role of technology to help identify and manage these types of natural disasters could have a large positive impact on both the environment and the economy.

Images courtesy of Firetail

Case Study: The Firetail - responding to natural disasters

An idea hatched by two guys in a shed in Albury is capturing attention in the world of disaster response. Back in 2014, helicopter pilot Jack Hurley joined with a small team of engineers to create an unmanned aerial vehicle – also known as a UAV or drone – that could be used to quickly capture photos and data after a disaster like a flood or cyclone.

Recognising that it is very expensive to get an aircraft to take photos from the air, Jack and his team set out to create something that was affordable, easy to operate and mobile, but still rugged enough to withstand the challenging environments of the Pacific. Their invention, Firetail, is a low-cost UAV system used to respond to natural disasters and identify areas that most urgently need assistance. The Firetail is an unmanned aerial system (UAS) consisting of a low-cost foam wing and Australian-made and designed Firetail autopilot and application that enables both the collection and presentation of real-time geo-referenced images and maps for damage assessment. The Firetail folds into a standard backpack and can be deployed in a matter of minutes. The geo-referenced images collected by Firetail can be delivered in real time to the Firetail cloud anywhere in the world, with users able to review stitched together geo-referenced images upon landing.

Firetail won the Australian government's 2016 Pacific Humanitarian Challenge as an innovative solution to emergency response. As reported by tech publisher Gizmodo, 'the impact of Firetail in countries hit by natural disasters could save numerous lives'.

Image courtesy of The Canberra Times

Case Study: Telstra's UAVs to help restore essential services

Telstra recently demonstrated the UAV technology it will use across Australia to help restore vital mobile services in disaster-hit communities during severe weather events.

Fitted with sophisticated cameras and flown up to heights of 120 metres by specialist pilots, these UAVs are used to monitor and inspect telecommunications towers, allowing affected services to be restored potentially days earlier.

The UAVs would be valuable for emergency services during disaster response as phone services, other than the emergency services radio network, are vital to give emergency warnings to the community through SMS text messages.

Using UAV technology, Telstra can get into a disaster site quicker and make the working environment safer. Previously, Telstra needed cherry pickers and time for rigging staff to traverse from base station to base station to conduct inspections. Now, ground based staff using easily portable drones can inspect mobile infrastructure much more quickly and thoroughly, even when access tracks to mobile sites are cut.

With more than 8,500 mobile network sites around Australia, delivering coverage spanning 2.4 million square kilometres, Telstra's mobile network is the largest in the country. The UAV technology allows Telstra to quickly and efficiently monitor telecommunications towers and replace any damage as soon as possible.

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Alistair Usher, Australian Academy of Science

Peter Lunn, Manager of Science Agencies branch, Australian Government

Richard Hartley, Australian Centre for Robotic Vision, ANU

10 Agriculture, environment, space

Australia has a set of unique drivers to adopt and exploit robotic and remote sensing (including computer vision) technologies to monitor, manage, and protect the natural environment.

Image courtesy of QUT

10.1 Agriculture, forestry and fisheries

10.1.1 Australian agriculture, forestry and fisheries

The Australian agriculture, forestry and fisheries industry was estimated to have grossed more than $AU60 billion in 2016-17, with exports reaching a record $AU52.6 billion [ABA17-1, 17-2, 17-3]. Most exports were from agriculture, with 5.9 per cent from forestry, and 2.9 per cent attributed to fisheries. Demand is expected to increase rapidly due to the surge in the middle-class population in Asia and the rise of the bioeconomy (e.g, biofuels and plastics). The demand from Asia may result in a doubling of agricultural exports by 2050, while the bioeconomy is expected to be worth $US90 billion worldwide by 2020. On a broader scale, the United Nations Food and Agriculture Organisation have estimated that the world must increase agricultural output by 70 per cent to guarantee food security by 2050 [FAO17].

Agriculture, forestry and fisheries face many challenges in Australia. While Australia exports more than 50 per cent of the food it produces, there is tremendous waste along the food value chain, with estimates that as much of half of all production is wasted before it reaches the consumer. In Australia, approximately 50 per cent of the land mass is devoted to agriculture but $AU2.5 billion is lost due to weeds, and a further $AU1.5 billion is spent trying to control these. The ancient fragile nature of Australian soils means many areas are infertile, requiring high use of chemical fertilisers and making them highly susceptible to erosion and nutrient runoff. Approximately 46 per cent of Australian famers report issues with soil and land while 38 per cent of farmers experience issues relating to water (e.g., access, salinity, floods, and droughts) [KPMG16, NFF17].

Remote and regional areas of Australia, where agriculture and forestry activities are concentrated, cover 85 per cent of the Australian land mass and produce 40 per cent of gross domestic product (GDP) (see Chapter 4). However, the vast distances present numerous challenges in service delivery, freight distribution, and telecommunications. Like most developed countries, over the course of the 20th century, the proportion of the Australian population residing in rural areas and/or working in agriculture has declined dramatically. Now, less than 10 per cent of Australians live in regional or rural areas. At the same time, the 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. Approximately 37 per cent 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 48 years, while the average farmer is 52 years old. Over the past 30 years, the median age of farmers has increased nine years, while the number of farming households has almost halved, from 168,000 to 85,700, over the same time [ABA17-1]. 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.

> The global opportunity in AgTech is estimated to be worth almost $AU250 billion.

Agricultural technologies (AgTech) is defined as the collection of digital technologies that provide the industry with the tools, data and knowledge to make more informed real-time decisions to improve productivity and sustainability [KPMG16]. Typically, AgTech concerns autonomous vehicles, computer hardware and software, cloud computing, cloud robotics, UAVs, the internet of things (IoT), precision agriculture, and big data and analytics. The global opportunity in AgTech is estimated to be worth almost $AU250 billion, with growing interest and focus from industry, government, investors, corporates and farmers driving significant innovation, focus and funding. The market for UAV solutions alone in agriculture is valued at $AU42.2 billion [IB16]. Real momentum has been generated in the sector and it is predicted that AgTech is set to become Australia's next $AU100 billion industry by 2030 [KPMG16].

Snapshot

Agriculture

Agriculture is Australia's most productive sector, AgTech is set to become Australia's next $100b industry.

$60b revenue

310,000 people directly employed (2.5% workforce)

$48.7b exports

Key activities include

- Growing (turf, flowers, vegetables, fruit, nuts, grain and other crops)
- Farming (sheep, cattle, poultry and other livestock)
- Nurseries
- Fisheries and aquaculture
- Forestry and forestry products

Sector Definition

Growing crops, raising animals, harvesting timber, fish and other animals from a farm, ranch or their natural habitats.

Key Robotic Technologies for the sector

- Autonomous vehicles
- Connected devices
- Sensor networks
- Drones
- Robotics

Challenges/ Opportunities

- Safety
- Labour costs
- Access to talent
- Ageing population
- Distance
- Scale

10.1.2 Robotics and agriculture, forestry and fisheries today

As with many industries, farming has undergone several technological revolutions. The first involved the replacement of animals with machinery to do farming tasks, allowing the size of farms to increase, but also requiring that operations were low in complexity. The current revolution is digital. Digital technology applied to agriculture, forestry and fisheries brings together biology, technology, and human factors. It enables the use of information extracted from purposefully collected data to manage agricultural, forestry, and fisheries production systems to optimise yield, increase efficiency, and ensure sustainability [CSI17].

The drivers for adoption of robotics to agriculture include [TP17] the intensification of food production, nature's resilience, high inefficiency in value chains, limited land use (and competition with other land use cases), population growth, and personal habits and beliefs regarding food including food safety, environmental conservatism and food provenance.

The application of AgTech requires the use of machinery and robotics, connectivity and integration (e.g, block chain and interoperability), sensor systems that are supported by adequate telecommunications and infrastructure. This context needs to be linked with informatics and cybernetics to manage the agricultural and environmental value chain [TP17]. Productivity growth in the agricultural sector outstrips the rest of the economy by a factor of two, suggesting that Australian farmers are quick to adopt and adapt to technological change [KPMG16].

Economic demands, over-ageing, and shortages of skilled farm labour in agricultural regions, food and fibre requirements of a growing world population, and stringent standards will continue to drive the commercial need for agricultural robots [IFRSR17]. The main types of agricultural robots deployed today are autonomous vehicles and automation of crop farming (e.g, fruit-growing, market gardening, and ornamental horticulture). Robot deployment occurs in greenhouses and on the land. The use of UAVs for inspection, metrology and aerial-based precision farming seems set to expand in areas such as soil and field analysis, surveying, seeding/planting, crop spraying, irrigation, and plant health assessment. Future UAVs may come in fleets of autonomous drones that tackle agricultural monitoring tasks collectively, or as hybrid aerial-ground drone actors that could collect data and perform a variety of other tasks [KPMG16].

The advantages of applying robotic technologies enables enhanced agriculture, forestry, and fisheries production through:

- novel technologies, such as sensors, robotics, real-time data systems, and traceability, all integrated into the full production chain
- better management and use of waste and water
- protection of food sources through enhanced biosecurity
- managing, harvesting, maintaining, and establishing forests as well as nursery production of trees
- management of diseases, invasive weeds, and pest animals (including feral animals), which currently cost farmers more than $AU4.7 billion a year [TP17].

Environmental sustainability is high on the agenda for many consumers, so food production practices need to increase productivity while having minimal or even positive impacts on the environment [KPMG16].

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 [NZJF16].

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 [NZJF16]. A recent workshop by Forest & Wood Products Australia identified that robotics has the potential to deliver social, safety and environmental benefits to forestry. Additionally, it provides the opportunity to attract a new generation of workers to the industry and helps the sector to be viewed as innovative and technologically sophisticated [FWPA18]. Automation in wood harvesting could also lead to environmental advances including reduced soil compaction, and the ability to spot koalas and other wildlife using remote image sensing [FWPA18]. Other drivers to adopt robotics in forestry include the need to accurately and precisely assess forest inventories, reduce costs, increase the speed of data acquisition, correlate ecological knowledge with remote-sensing technology to predict and quantify the fibre characteristics of trees, and new forest-renewal methods that maintain and support natural biodiversity while maximising potential forest-site productivity. 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 [FWPA18].

In the fisheries industry, fish farms must be monitored and maintained on a regular basis including fish welfare monitoring, facility inspections, control of feed rationing, and lice counting [EAA17]. Such daily tasks are carried out by service vessels with several crew on board in sometimes dangerous conditions, such as the open ocean.

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, the 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) [EAA17].

10.1.3 The future of robotics in agriculture, forestry and fisheries

Automated, but manually driven harvesters are already available for different types of agricultural goods. However, except for robots for animal care, livestock and greenhouse automation, service robots have not reached a wider use on a commercial basis. This is due to most applications being dependent on advanced sensor data processing, which is still a challenge in terms of the required dependability in difficult outdoor environmental conditions [TP17].

The opportunities for the Australian agriculture, forestry, and fisheries industries in adopting robotic technologies include safety, attracting young people into a more technologically-advanced workplace, the ability to export into the global AgTech market, more employment opportunities, and improved productivity and sustainability. The application of digital technologies in general results in:

- improved situational awareness – getting intelligence from sensing
- informed decision making for value-chain management
- better and easier compliance with regulation
- access to new markets and business models
- efficiency through automation and autonomy
- an agile innovation pipeline
- requirements for a new (more highly skilled) workforce.

Some current and potential use cases of these technologies include:

- Sensor networks applied within agriculture to tag and track livestock, in aquaculture to measure oyster heartbeats, and to place collars on native pests such as flying foxes.
- Field and crop management - monitoring large outdoor areas to collect real-time high resolution and precise information for efficient use of resources including variable rate application of fertiliser and water, variable seeding etc.
- Weed and pest management - detection and targeting application of specific treatment towards yield increases and further improving Australia's 'clean and green' reputation. Reduction in the cost of management while increasing effectiveness.
- Smaller autonomous ground robots - to replace large machinery achieving reduced soil compaction towards increasing yields, and increasing efficiency through multi-task/field deployment.
- Coordinated heterogeneous multi-robot systems - interfacing between ground and aerial robots including robots for different tasks and from different manufacturers. Additionally, integration with manually operated systems/machinery and other external data sources (e.g; remote sensing).
- Novel decision-support systems and strategies - for site-specific crop management, automation of repetitive tasks, provision of information, and capabilities that benefit the wider supply chain and agricultural researchers.

It has become clear that current activities in robotics address the following major agricultural trends where there is strong growth potential [TP17]:

Precision agriculture: water, nutrients and care will be dispensed on an as-needed basis of individual plants.

Aspects of phenotyping, and crop and weed detection/discrimination and management are treated by advanced sensing.

Farm-based bio-factories for mass-producing medicines/ vaccines, flavourings, and fuels based on plants.

Support in animal farming: a combination of the needs in food traceability, securing animal health, hygiene and well-being, and support of the farmer (e.g, milking robots).

Quality control through terrestrial and airborne crop and animal herd monitoring.

- Remotely-piloted aircraft - for precision agriculture, biosecurity, environmental monitoring, infrastructure monitoring, and post-disaster surveying.

Robots are an efficient and effective way of deploying sensors to help with resource management. They can provide cost effective pesticide application in agriculture, invasive species management, aerial mapping and infrastructure assessment.

Drones are used by a range of governmental agencies for fishing surveillance, aerial distribution of agricultural chemicals, biosecurity against pest weeds, timber salvage assessments, collection of pest impact imagery, crop biomass sensing, and toward improving farming practices.

Robotics will impact on the sector in two main areas: robot-enabled sensing and robot-enabled acting. Robot-enabled sensing involves using the robots as platforms to carry sensors to collect data and then to use the data for land and water management.

A review of several agriculture industry roadmaps identifies numerous issues now, and in future years, that will directly affect Australia's ability to meet the growing demand of expanding markets locally and abroad. A number of these issues may be alleviated by introducing robotic and vision technologies. The issues identified include, but are not limited to [TP17]:

- an ageing workforce
- productivity growth and international competitiveness
- soil and water management
- climate change and variability
- conservation of biodiversity
- stagnant R&D investment
- complex IP arrangements
- community perceptions of a 'sunset' industry
- farm ownership models
- concerns about foreign investment and labour
- regulatory environments e.g, CASA regulations for UAVs
- biosecurity.

While efficiency is considered an on-going priority for the agricultural industry, the recent *CSIRO Future's Report in Food and Agribusiness* [FA17] identified three specific areas that Australian agriculture should target as a means for increasing demand and profit, including:

- products for health and wellbeing
- sustainable solutions
- premium/high end products.

Through selective harvesting and disease/pest treatment, targeted use of water, improvements in efficiency and fast response to consumer demand, robotics can play a role in helping meet these opportunities.

Australia's Agricultural Future [ACO15] makes an excellent case for introducing robotics and specifically identifies a range of opportunities for robotics and automation, citing technologies implemented in other industries or currently being trialled in agriculture itself. However, concerns exist over the pathways for developing and introducing these technologies including stagnant research funding, complex IP agreements, and enticing the required skilled workforce (see Chapter 2). Growth opportunities for Australia's food industry include supplying safe, premium meat, fish, dairy, wine, vegetable and processed, branded product to China's growing middle class.

10.1.4 Main findings for robotics in agriculture, forestry and fisheries

Australia's agriculture, 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 of 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.


Image courtesy of QUT

Case Study: Harvey - the capsicum-picking robot

The horticulture industry in Australia has a gross value of more than $AU8 billion dollars per annum. Australia produces more than 36,000 tonnes of capsicum per year, worth approximately $AU92 million, mostly grown in North Queensland [DAF14].

The Queensland Government supported QUT to develop a new agricultural robot prototype designed to harvest capsicums – nicknamed 'Harvey'. Harvey was developed as part of the Queensland Department of Agriculture and Fisheries (DAF) three-year strategic investment in farm robotics [SIF17]. The SIFR team, led by Professor Tristan Perez, determined the major challenges associated with robotic harvesting were around image processing (green fruit on green background, and heavy ambient occlusion), and manipulation due to the unstructured environment of the crop. The team developed an algorithm to detect approximately 70 per cent of in-field capsicum that improves on state-of-the-art vision systems and is comparable with detection by humans.

Harvey's robotic arm has a camera and a unique cutting tool attached to it. Using data from the camera, the robot detects the fruit and cutting location and plans and controls the robotic arm and harvesting tool to detach the fruit from the plant. Field trials within a real protected cropping system demonstrated a success rate of 60% for harvesting capsicum with an average picking rate of 20 seconds [LE17]. The combination of state-of-the-art robotic-vision software and novel crop-manipulation tools enable successful harvesting of the crop. This advancement promises significant benefits for horticulture growers, who export more than $AU2 billion in products every year.

Image courtesy of SwarmFarm

Case Study: SwarmFarm - robots applied to solving world food challenges and why this is relevant to Australia

SwarmFarm Robotics is a technology company based near Emerald in rural Queensland. SwarmFarm never set out to automate agriculture or save labour – rather, their philosophy is to create new farming systems that are not possible on the back of a tractor.

The company was founded by farmers who have spent 20 years farming with modern technology that has seen such equipment as tractors, sprayers and planting machinery become increasingly larger and more complex. The farmers came up with the idea that multiples of small, lightweight robots working together in a 'swarm' would be the driver of new AgTech into farming.

The SwarmBot platform is an entirely new development that has evolved from the ground up. It utilises robotic technology and an ecosystem of independent developers that create modular technology for application to the platform.

The SwarmBot is a platform for carrying smart tools and implements around paddocks in a much more precise and repeatable manner than is achievable on board a tractor.

Ultimately, this technology will make it easy for farmers to put new AgTech in their paddocks, undertake new field practices, and deploy technology into their farming systems by using 'swarms' of smart, mobile, and automated robots.

SwarmBots are already being successfully used in commercial broadacre cropping operations, with scope to expand the technology to other agricultural industries. The innovative Queensland start-up is working with a leading global supplier of technology and services, Bosch, to redesign its unique SwarmBot robotic platform for commercial production. In this partnership, SwarmFarm Robotics will develop the final production model of the SwarmBot ahead of commercial sales to farmers in mid-2018.

10.2 The Environment

10.2.1 Australia's environment

Australia has some of the cleanest air and cleanest water in the world. It is the largest island continent and one of only 17 countries to be described as "mega-diverse", supporting between 600,000 and 700,000 native species of plants and animals. Many of these species are found nowhere else in the world [ASN17]. Offshore, Australia's economic exclusion zone (EEZ) covers a greater area than the landmass of the continent itself, and apart from abundant sea life, it is home to the world's largest coral reef. 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 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 $AU2 billion in the environment each year.

In this roadmap, the environment refers to climate, water and natural resources that affect conservation, human survival and economic activity. It also includes threats to this environment such as habitat loss, pollution (e.g., litter, air and water contamination), pests and biosecurity threats.

10.2.2 Robotics and the environment today

Despite the Australian continent representing one eighth of the planet's land surface, Australia has only 0.32 per cent of the Earth's population. Furthermore, most of Australia's population (90%) lives in urban coastal areas, largely separate from the bulk of the country's biodiversity and natural assets. Hence, Australia has a set of unique drivers to adopt and exploit robotic and remote sensing (including 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 and accidental releases.

> Robotics have a critical place in measuring and assessing the health of coral reefs across tropical marine Australia.

The threats and opportunities relating to the broader Australian environment are vast and significant. The risks from local as well as global influences (e.g., goods movement, resource extraction, pests, fires, and climate change) require constant vigilance at massive scales. This is made more difficult due to the vastness, land and sea-scape diversity, and low-population densities of much of the continent. 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.

Environment-based tourism is of significant economic importance to Australia, contributing $AU56 billion each year to the economy. For example, the Great Barrier Reef hosts two million visitors every year, contributing $AU6.4 billion to the Australian economy, and is directly responsible for 64,000 jobs in related sectors such as tourism [DEL171] (see Chapter 7). Robotics have a critical place in measuring and assessing the health of coral reefs across tropical marine Australia. First trials of reef protection technology, such as COTSbot and Rangerbot (see Case Studies p. 155-156), required the establishment of guidelines on the application of robotic and vision technologies for use in helping to protect the Great Barrier Reef. Similar guidelines are required if these technologies are to help solve other environmental challenges.

Snapshot Environment

Australia hosts almost 700,000 native species, many of which are found nowhere else in the world. Sixteen of Australia's unique habitats have been given world heritage listing.

$1.98b investment

7.8 million international visitors

64,000 people employed

Sector Definition

The natural environment encompasses all living and non-living things that occur naturally including climate and weather.

Key activities include

- Monitoring
- Identifying environmental risks
- Ameliorating or removing the risk
- Remediation

Challenges/Opportunities

- Biosecurity (disease)
- Weeds
- Pest animals
- Pollution
- Climate change

Key Robotic Technologies for the sector

- Vision-based repeat survey and change detection and quantification
- Persistent land, sea and air robotic platforms
- Automated vision-based threat assessment (biosecurity)
- Vision-based habitat classification
- Rehabilitation and maintenance robots

10.2.3 The future of robotics in the environment

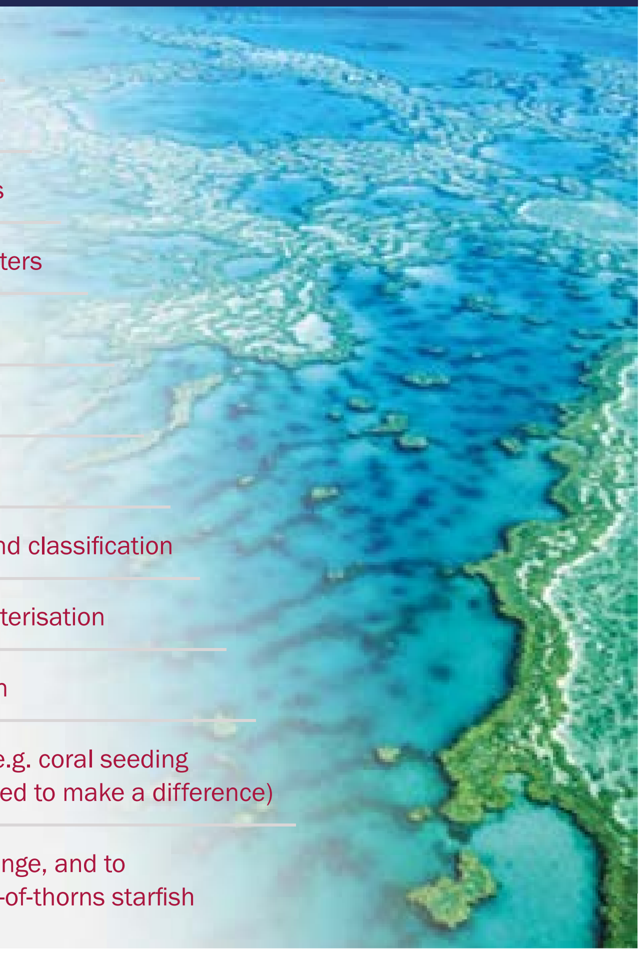
Australia has a long and world-leading history of successful deployment of robotics for environmental monitoring and management. There are considerable research and operational examples of environmental robotics in air and sea domains, such as the use of:

- UAVs beyond line of site (BLOS) for the automated detection of Marconia (introduced plant) in the rainforests off Cairns
- UAVs for the detection and automatic classification of koalas for conservation activities
- UAVs for the detection and threat assessment of locus through the Australian outback
- underwater robots and automated classification algorithms for the long-term and repeat monitoring of marine habitats around Australia (see Case Study p. 156)
- underwater robots for the automated detection and injection of Crown-of-Thorns Starfish on the Great Barrier Reef (see Case Study p. 155).

Vision-enabled robots can be deployed in long-duration fleets on land, in the air and in the water, to collect data to be used for exploration, mapping, understanding, stewardship and remediation. 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.

The following list is specific to the robotic technologies that can be deployed to protect the Great Barrier reef, these include:

- collision avoidance of coral reef obstacles
- intuitive mission planning tools
- tropical water vehicle biofouling management techniques
- maintaining performance in highly dynamic coral reef waters
- underwater shallow water, short range communications
- accurate geospatial positioning
- ability to accurately capture complex reef structure
- automated fish and benthic species image recognition and classification
- SeaSim or lab-based test bed and unit under test characterisation
- robotics applied to building reefs via physical intervention
- industrialisation of the remediation of the environment (e.g. coral seeding where, due to the sheer volume, robotics must be deployed to make a difference)
- collecting baseline data to identify and then quantify change, and to detect specific threats, for example, pests such as crown-of-thorns starfish



Similar lists could be developed and applied to all of Australia's environmental challenges. Robots performing operations including physical sample and sensor reading collection will greatly benefit from cloud robotics offloading computation to remote resources.

> A more robotic/coding literate community can also contribute to environmental protection and the advancement of science.

Many of the challenges for use of robots and computers in the environment relate to the sheer distances and persistence required for unsupervised operationalisation across the varied landscapes of the Australian continent. There are a range of technologies that are necessary to help detect, mitigate and solve environmental challenges, many of which may be developed for use in different domains. Such technologies include:

- Autonomous vehicles to access remote tropical marine areas under all weather and traffic conditions. This includes travelling vast distances and operating for months at a time.
- Addition of multifaceted 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.

Workforce Implications

There are many gaps that need to be filled in Australia's workforce for the full potential of robotic technologies to be realised. These include:

- robotics piloting, maintenance and operations planning training
- programmers to develop bathymetry and oceanographic modelling tools for mission planning
- 24/7 operations teams to support nationwide missions for marine science
- machine learning specialists to tune and generate repeatable information from collected datasets
- image recognition specialists to use static and dynamic traits to classify individual or species level appearance and behaviours
- automated workflow specialists to manage increased data requirements in a scalable fashion
- process and environmental engineering specialists with understanding on how to exploit robotic technology for large-scale land and sea-scape remediation/restoration.

A more robotic/coding-literate community can also contribute to environmental protection and the advancement of science. For this to be successful, the technology must be intuitive and sufficiently advanced to allow auto-classifications and guidance on appropriate remediation activities and then recording and analysis of results. A key opportunity will be in the creation of intuitive user-interfaces for robotic tools to enable citizen science. It is important to engage people with the technology.

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, 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.

10.2.4 Main findings for robotics in the environment

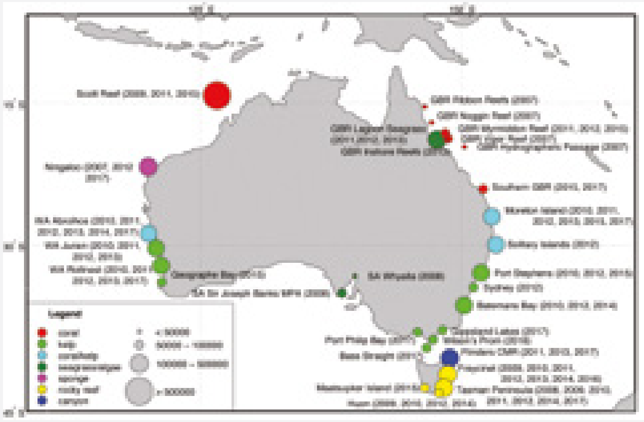
Australia has a unique biodiversity, a long, and world-leading, history of protecting and conserving native flora and fauna, and successful deployment of robotics for environmental monitoring and management. Vision-enabled robots can be deployed in long-duration fleets on land, in the air and in the water, to collect data to be used for exploration, mapping, understanding, stewardship and remediation. Many of the challenges for use of robots and computers in the environment relate to the sheer distances and persistence required for unsupervised operationalisation across the varied landscapes of the Australian continent. 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. A more robotic/coding-literate community will contribute to environmental protection by enabling citizen science.

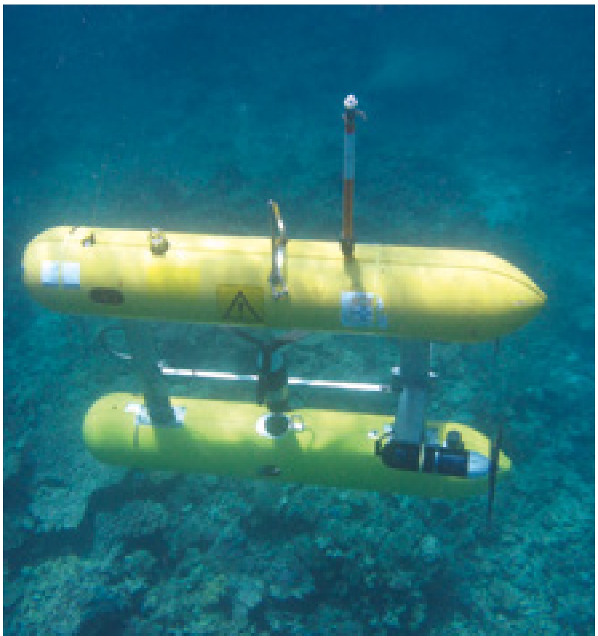
Case Study: The crown-of-thorns starfish (COTS) robot (COTSbot)

Crown-of-thorns starfish (COTS) are one of the biggest threats to the Great Barrier Reef (GBR). These starfish literally eat coral, and while native to the GBR, have bred to unsustainable plague numbers across the reef. Current population control of COTS outbreaks requires the manual injection of bile salts into each starfish. However, the sheer number of COTS and the size of the GBR means that new and complementary approaches are required.

A revolutionary new advancement in robotic environmental monitoring and management, called the crown-of-thorns starfish robot (COTSbot) is the world's first robotic submersible, created to automatically seek out and inject COTS with the toxin. The goal is to provide a tool for upscaling the control of COTS numbers, which are responsible for an estimated 40 per cent of the reef's total decline in coral cover.

The unique aspect of the COTSbot is that it can see and think for itself. It uses a specialised visual recognition system to identify COTS in the visually challenging environment of the GBR using algorithms from the Australian Centre for Robotic Vision. The robot is designed to cruise about a metre above the coral surface, looking for COTS. When it sees one, a robotic arm extends to inject the starfish with bile salts, proven by James Cook University to be effective in controlling COTS numbers within 24 hours of application. The COTSbot prototype was proven during trials on the GBR and has now been redesigned for increased production, usability and deployment by a range of user groups including researchers, marine park authorities, and citizen scientists.





Images courtesy of The University of Sydney

Case Study: IMOS - robots used for environmental monitoring and protection

Australia's integrated marine observing system (IMOS) was established in 2007 with support from the Commonwealth through the National Collaborative Research Infrastructure Scheme (NCRIS). The objective of this program was to provide access to critical infrastructure to support marine science research on a national scale. A pilot study was funded to examine the use of autonomous underwater vehicles (AUVs) to support the observation of benthic habitats.

In 2009, the IMOS AUV facility and stakeholders at university and government research labs within New South Wales, Tasmania, Western Australia and Queensland nodes of the IMOS program proposed to establish an integrated benthic ecology program at key sites around Australia. The program was designed to collect observations using AUVs to document and monitor changes in benthic habitats.

Benthic reference sites were established as part of this program in 2009. These sites have been revisited on an annual or semi-annual basis for the duration of the funding period to provide a sustained set of observations at these locations. This includes AUV-based georeferenced imagery and bathymetry, together with measurements of conductivity, temperature, depth, chlorophyll-a, CDOM and backscatter in red.

AUV dive sites were selected to capture habitats at a variety of depths and latitudes along the east and west coasts of Australia. The general sampling methodology using the AUV was designed to monitor the benthic habitat components of reefs that contribute to overall reef biodiversity, productivity and resilience. The sampling design was to be optimised using information from existing survey data to define initial transect locations, which included multibeam bathymetry at many sites. The processes of interest occur at multiple spatial scales, so a nested hierarchical sampling method was adopted to detect changes at these differing scales. The program has been very successful over the past decade, collecting millions of images of the seafloor around Australia and making these available to the scientific community through online data portals developed by the facility and IMOS affiliated groups. These observations are providing important insights into the dynamics of key ecological sites and their responses to changes in oceanographic conditions through time.

Case Study: Mapping coral type and coral bleaching with aerial robots (drones)

Advanced, miniature cameras on drones are capturing details of landscapes that have previously been invisible. QUT researchers are using them to fly low over reefs, capturing almost 100 times the colours captured by standard cameras.

“High-altitude surveys of reefs may lack the resolution necessary to identify individual corals or bleaching effects”, says Associate Professor Felipe Gonzalez, who is leading a team of researchers and unmanned aerial systems (UAS) engineers from QUT in a partnership project between QUT and the Australian Institute for Marine Science (AIMS).

“Normal cameras record images in three bands of the visible spectrum –– red, green and blue –– and mix those bands together to create colours as humans see them. A hyperspectral camera captures 270 bands in the visible and near-infrared portions of the spectrum, which provides far more detail than the human eye can see. Since we’re flying it on small UASs –– commonly known as drones –– at 30-100m over the water, we can get an incredibly high resolution,” Felipe says.

The team has used the drones over Western Australia’s Ningaloo Reef and collected vision from the Great Barrier Reef while AIMS conducted complementary underwater surveys.

QUT is now working on building underwater housing for a hyperspectral camera so the technology can be used in marine robots.

“The huge amount of information we can get will allow us to classify coral species, sand and algae, or coral bleaching based on unique spectral signatures, which act much like fingerprints,” Felipe says.

Researchers are building artificial intelligence algorithms to automatically recognise and classify the signatures, so these can be added to a database for future research. This kind of analytic software could also be used in detecting invasive plants and crop diseases.

Case Study: Aerial robots (drones) – revolutionising wildlife monitoring and conservation

Advanced drone-based systems are enabling the surveillance and location of threatened fauna with the highest-accuracy achievable up to now. QUT researchers have employed these devices to detect and locate koalas by conducting flight campaigns in New South Wales, and areas of neighbouring Queensland, including Logan, the Gold Coast, and the Australia Zoo Wildlife Hospital on the Sunshine Coast.

The research team has developed a unique combination of unmanned aerial vehicles (UAV) with thermal imaging, statistical modelling, and artificial intelligence (AI).

“We’ve found thermal imaging allows the detection of even well-camouflaged koalas effectively and our counting and tracking algorithms discriminate the shape of a koala from a possum, birds or other animals,” says Associate Professor Felipe Gonzalez, who is leading a UAV research team in collaboration with statisticians from the ARC Centre of Excellence for Mathematical & Statistical Frontiers (ACEMS) and biosecurity officers from the Australia Zoo Wildlife Hospital.

The project has already proved the technology can save councils valuable time. In a single test, it takes biosecurity experts over two hours to conduct roughly the same survey a UAV took just 30 minutes to complete.

The technology not only counts koalas and displays their location in georeferenced maps, but it can also monitor their movements and population fluctuations over time.

“This project is primarily focused on assessing koala populations, but this technology can easily be adjusted to monitor other species however, in conservation or pest-cataloguing such as feral cats, wild pigs and dingoes,” Felipe says.

Researchers and council delegates expect that having access to this information would contribute to supporting councils and ecologists into more efficient planning programmes for koala conservation.

Case Study: Drone use in the Raine Island recovery project

Raine Island is located on the northern tip of the Great Barrier Reef (GBR), approximately 620 kilometres north-west of Cairns. It supports the world's largest remaining green turtle nesting population and is the most important seabird rookery in the Great Barrier Reef World Heritage Area. The vegetated coral cay is just 21 hectares in size but holds significant environmental and cultural values. The entire island is a protected national park (for scientific purposes) and is not accessible to the public.

However, changes in the island's landscape have caused tidal inundation—killing newly laid eggs which cannot survive underwater—and causing as many as 2,000 adult turtles to die (in a season) from overturning and entrapment in rocky cliffs and from heat exhaustion on the nesting beach. The Raine Island recovery project aims to protect and restore the island's critical habitat to ensure the future of key marine species, including green turtles and seabirds. As such, a range of approaches have been employed, from manual intervention to the use of robotic drones and computer vision, to protect and assess the management actions taking place.

Drones are a key technology being used to measure and assess landscape topography and changes over time, as well as to collect imagery of seabirds, turtles and sharks for population analysis. A range of collaborators have been using the technology and have created a world-first operating procedure for the use of drones for scientific use on conservation areas such as Raine Island. Computer vision is now being used to facilitate the automated counting of animals under all weather conditions, and day and night, to allow timely assessment of remediation actions between field campaigns.

10.3 Space

10.3.1 Australia's space industry

The space industry in Australia currently generates total revenues of $AU3 to $AU4 billion and employs approximately 10,000 people. It comprises around 388 companies (more than 75 start-ups), 56 education and research institutions, and directly involves around 24 government agencies [ACIL17]. In September 2017, the Australian Government approved the establishment of a national space agency. It is widely believed this will support the sustainable growth of Australia's space industry by advancing technology innovations and furthering scientific discovery.

> A study of socio-economic impacts indicated that regional activity by NASA generates $US2.60 of economic output for every dollar spent.

In 2016, the global space economy was valued at $AU335 billion. Capturing a share of this market is desirable as it is a reliable growth industry that has proven resilient in the face of economic downturns [GSS17]. Approximately 80% of National Aeronautics and Space Administration's (NASA) annual budget is spent in industry and at universities.

A study of socio-economic impacts indicated that regional activity by NASA generates $AU2.60 of economic output for every dollar spent. The value of augmented global navigation satellite systems (GNSS) in Australia will add up to $AU13.7 billion to the Australian economy by 2020 [ACIL13], while the value to Australia of earth observations from space (EOFS) is expected to be worth another $AU1.3 billion by 2025 [ACIL15].

The space industry has been embedded in the Australian economy since the introduction of domestic satellite telecommunication and broadcasting services in the 1980s, and more recently, the advent of the internet. Space-enabled services provide benefits and boost productivity of other sectors, which in turn can have capabilities that overlap with the space industry [GSS17]. Examples discussed in this roadmap include: services (mainly financial, construction, and transport) (see Chapter 7), resources (see Chapter 4), manufacturing (see Chapter 5), and agriculture (see this Chapter). Many of these industries require highly skilled technical expertise such as data analytics or engineering, and are at the forefront of applying spatial data received from satellite and space-based infrastructure. These industries are likely to continue to benefit from and add to space industry capability in Australia [ACIL17].

Australia's location in the southern hemisphere, and in line with the longitude of Asia, creates advantages for participation in the international space industry supply chain [ACIL17].

> The space industry in Australia currently generates total revenues of $AU3 to $AU4 billion and employs approximately 10,000 people. It comprises around 388 companies (more than 75 start-ups), 56 education and research institutions, and directly involves around 24 government agencies.

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 calibration and validation. Australia is also well-positioned for satellite communications and control operations including access to many satellites for EOFS and GNSS.

10.3.2 Robotics and the space industry today

Countries invest in space capabilities to fulfil national objectives including military success and defence strategies, leadership and prestige, development and resource management, and economic growth and diversification [GSS17]. Canada provides an example of a country that has benefitted from investment in the space industry. The Canadian government directly funded Canadarm, the robotic arm that was used to manoeuvre hardware in and out of the cargo bay of NASA's space shuttle. Canadarm was developed in the late 1970s by a Canadian industrial consortium and its success led to Canada's role in the International Space Station (ISS) as supplier of the robotic mobile servicing system. This system played a key role in ISS assembly and is now used to move equipment and supplies around the facility. Canada is now recognised as a world leader in space robotics and the nation even features a picture of the Canadarm on the Canadian $5 dollar bill.

Australia is the largest consumer of data from earth observation satellites (EOS) so developing additional capacity

Canada today is recognised as a **world leader in space robotics** and the nation even features a picture of the Canadarm on their $5 dollar bill.

Snapshot — **Space Industry**

Australia is creating a space agency to capitalise on the growing global space industry.

$ $3-4b revenue

10,000 people employed

Key activities include
- Space manufacturing
- Space operations
- Space applications and ancillary services

Sector Definition
Economic activity related to manufacturing components that go into Earth's orbit or beyond.

Key Robotic Technologies for the sector
- Satellite-enabled robotics
- Remote sensing
- Multiscale modelling
- Satellite-triggered observation and response

Challenges/Opportunities
- Talent retention
- Clear national space strategy
- Support for launch sites and launch capabilities in Australia

for EOS can provide Australia with a competitive advantage. The creation of Australia's space agency will encourage further development and use of CubeSats (tiny satellites for space research that weigh less than 2 kilograms) for collecting data. The market for small satellites like CubeSats is expected to be $AU23 billion over the next decade. CubeSats can use vision-based navigation for autonomous cooperative docking [AA18], for example on the International Space Station (ISS), although this has not been tested in practice [PI18].

Several global space companies, including US aerospace and defence giants Boeing, Lockheed Martin, and Northrop Grumman, maintain a significant presence in Australia.

Australia currently collects data from more than 20 satellites and relies on a strategic partnership with NASA to launch satellites and gain access to NASA's deep space network. Australia hosts one of NASA's network satellite bases, ground facilities for the US wideband global SATCOM (WGS) system, and mobile user objective system (MUOS) programs. Australia's close strategic alliance with the United States (US) means it is also a key partner in several US-led military space activities, including satellite programs and space situational awareness (SSA), with radar and optical space surveillance systems located here.

The competitive attributes that Australia has which make it successful in the space industry include high levels of education, proximity to other nations with space budgets and business-friendly policies, an advantageous geographic location in the southern hemisphere for satellite ground stations, world-class capabilities in ground systems, software, and applications, and close strategic alliances with space powers including the US [ACIL17]. Several global space companies, including US aerospace and defence giants Boeing, Lockheed Martin, and Northrop Grumman, maintain a significant presence in Australia. High-tech jobs associated with these companies, and servicing Australia's own space infrastructure, ensure Australia has the capabilities necessary to take advantage of future commercial opportunities in the space industry. The Australian Government plans to increase defence spending to 2 per cent of GDP by 2020-21, representing a further growth opportunity with access to high-resolution commercial satellite imagery – a key driver for the ADF (see Chapter 8).

A series of articles about Canada's golden age of robotics by Tom Green describes Canada's emergence as a robotics powerhouse [ARR17]. In much the same way as Canada has built on its initial 1975 Canadarms, by developing a series of robot arms (Canadarms 1, 2, and 3) for NASA Space Shuttle orbiters and the ISS, the Australian space industry could be a catalyst for the development of an Australian robotics industry. While Australia has many similarities to Canada, including low population density, a culture of ingenuity, and an economy with strong contributions from primary industries, it has been lacking an overarching challenge for discrete robotics groups to tackle as a national initiative. Australia's new space agency could spark a similar golden age for Australian robotics, focussed on building upon proven remote sensing capabilities. Consequently, we are keen to see robotics recognised as an essential technology platform by Australia's new space agency.

Australia has strong capabilities in integrating data received from satellite and space-based infrastructure into

Australia currently collects data from more than 20 satellites and relies on a strategic partnership with NASA to launch satellites and gain access to NASA's deep space network.

ground-based applications to enable automation driven by demand from the Department of Defence, disaster management agencies, agriculture, built environment, and finance and insurance [ACIL15]. Other areas where Australia could apply robotics technologies within the space industry include the manufacture of nano- and micro-satellites, giving both satellites autonomous and vision capabilities, the autonomous handling associated with launch missions, and space applications linking EOFS with robot operations in sectors such as agriculture (this Chapter), resources (see Chapter 4), logistics (see Chapter 7), aviation and defence (see Chapter 8). Such applications could also build on Australia's strength in position, navigation and timing (PNT), and in sensor fusion (the integration of multiple signals), essential attributes for controlling autonomous systems. There is also an emerging capability in manoeuvring and managing space debris through the work of the Space Environment Research Centre at Mount Stromlo where robotics could be applied.

10.3.3 The future of robotics in the space industry

The space industry increasingly relies on technologies from other industries, not developed specifically for space. Key areas of technology for use in space exploration are artificial intelligence/machine learning and intelligent systems, autonomy, nano-sensors, cyber physical systems (digital twins), batteries, robotics, and IoT [GSID17]. Approaches to space exploration are evolving to make the most of these new technologies. In the future, there will be complex manned 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 an orbital framework under which to carry out missions within a cooperative network. There will be potential for systems ranging from semi-autonomous all the way to fully autonomous to handle operations, encompassing satellites to space logistics. Imaging and sensing satellites will be a cornerstone of thorough exploration and scientific progress, informing, and sometimes controlling, surface activities. There will be a need for rovers to explore, with landers acting as base stations, and automated laboratories to slowly build up capability and become more complicated networks of robot/robot cooperative systems.

Robots will increase the capability and capacity of missions. They can be used to prepare habitats for humans to live in when they arrive on the surface of the exploration site. Sensing satellites and scouting rovers will help human survival, while optimising activities, and increasing safety. Smart vehicles and assistive robotic systems such as exoskeletons will be deployed to help collect samples, and transport personnel and material. Automated laboratories, working at the direction of human operators, will allow for much faster analysis of greater volumes of material. Cooperative robotic systems and networks will form a hub that will allow long-term sustainable exploration of space and build-up of capabilities. Greater robotic independence and

Opportunities for Australian robotics in the space sector might include:

- satellite enabled robots
- multiscale modelling, remote sensory and airborne
- satellite triggered observation and response (e.g., bushfire monitoring)
- autonomous aerial and ship development
- in-space repairs and maintenance
- earth observing satellites (EOS)
- use of the novaSAR satellite to calibrate and validate on-earth robotics systems that rely on EO data.

automation will be an important development, allowing for smart rovers and automated laboratories to perform valuable science without direct human intervention. These advances will also have benefits for people on Earth in the future.

Australia has significant strengths in GNSS and GNSS-based PNT, a growing sector of the global space industry [GSID17]. Most of the growth in GNSS devices (more than 9 billion units), will occur in the Asia Pacific region. This creates a market opportunity of more than $AU100 billion for value-added services.

> Space mining is an area where Australia can leverage its existing reputation as a global leader in mining combined with strong field robotics capability, and expertise in resource extraction technologies.

A more speculative market opportunity exists in asteroid mining. It is becoming increasingly attractive to use space resources 'in-situ', that is, to extract resources from space for use in space (e.g, from asteroids, the moon, Mars). In the future, it may also become technically feasible to transport resources back to Earth to supplement local supplies and possibly even replace on-Earth mining operations to preserve the environment. Space mining is an area where Australia can leverage its existing reputation as a global leader in mining combined with strong field robotics capability, and expertise in resource extraction technologies. This should be a crucial part of the Australian space agenda. Asteroid mining would raise the profile of Australia's space industry and demonstrate technology capabilities, positioning Australia as a participant in the low Earth orbit (LEO) economy [ED17].

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 sparsely populated areas form ideal testing grounds. Abandoned mine sites could be used to test asteroid mining capabilities. Operating mining systems remotely can naturally be extended into space, if the required base capabilities, such as space communications, space hardware, and space technical environments are available.

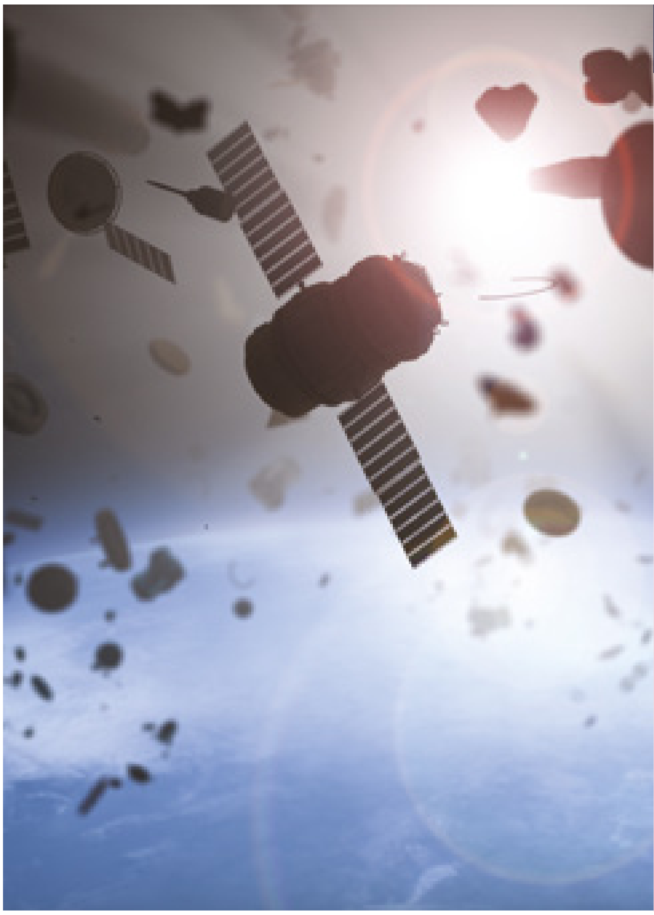
The ability to deploy teams of humans and robots in space exploration relies on effective collaboration. Multi-robot systems for exploration make a lot of sense in terms of cost, robustness and reusability. Whereas early research focused on how multiple robotic assets can collaborate in teams including humans and non-embodied agents, there is growing interest in the human dimension of interaction within such collaborative human-robot teams. Unlike autonomous systems designed primarily to take humans out of the loop, the future lies in supporting people, agents, and robots working together in teams in close and continuous human-robot interaction. Research into how software agents and robots can seamlessly participate in teamwork alongside people in carrying out complex real-world tasks will be an important focus area. Just as important, developers of such systems need tools and methodologies to ensure that such systems will work together reliably and safely, even when they have been designed independently.

> Greater robotic independence and automation will be an important development, allowing for smart rovers and automated laboratories to perform valuable science without direct human intervention.

Australia has a strong education system with a good research and development base in space technologies. The key challenge for the Australian space industry is to build a path from research to industrialising and commercialising the resulting products and services. Many Australian graduates and researchers with space capabilities leave to work overseas, and while some are attracted back, the lack of employment opportunities in the sector is a key challenge [ACIL17].

10.3.4 Main findings for robotics in the space industry

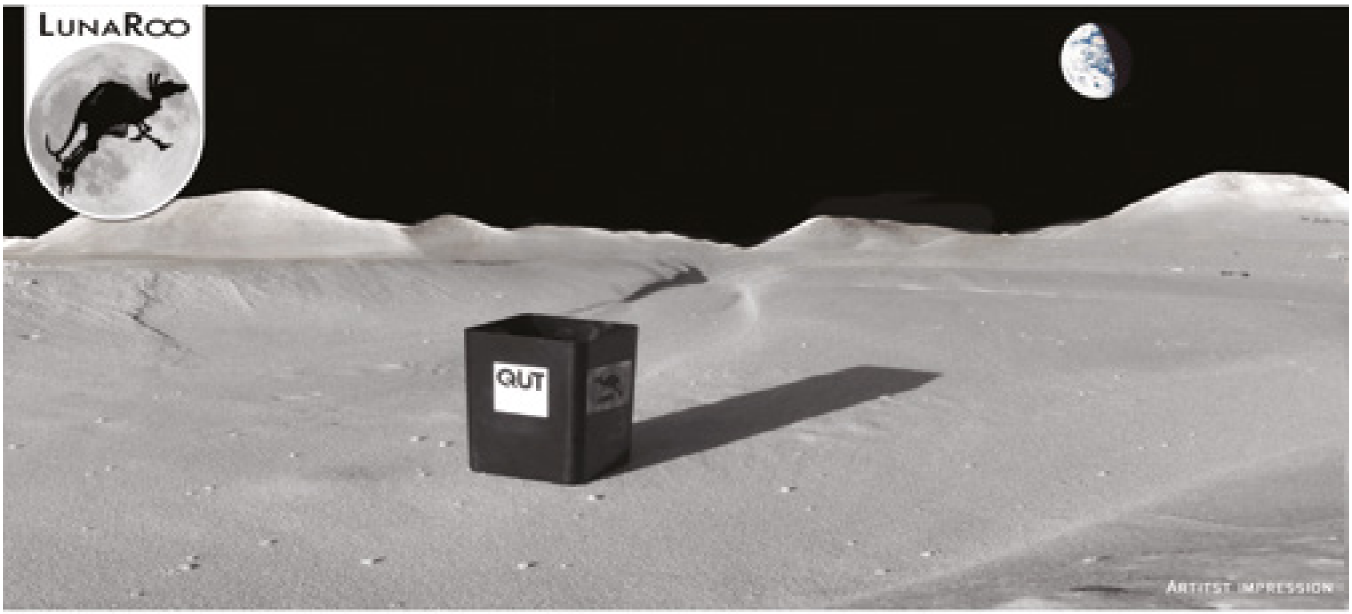
Australia is creating a space agency to ensure it can take advantage of the growing global space industry. This is a great opportunity to showcase Australia's robotics capabilities by developing technologies for space applications. Australia currently collects data from more than 20 satellites, relying on strategic partnerships with NASA to launch satellites and to gain access to NASA's deep space network. Australia is the largest consumer of data from EOS, and space-enabled services boost the productivity of all sectors of the economy. Australian attributes that will support a successful space industry include high levels of education, proximity to other nations with space budgets and business-friendly policies, an advantageous 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. Australia's plan to increase defence spending represents a further growth opportunity.

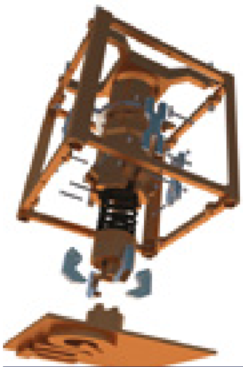


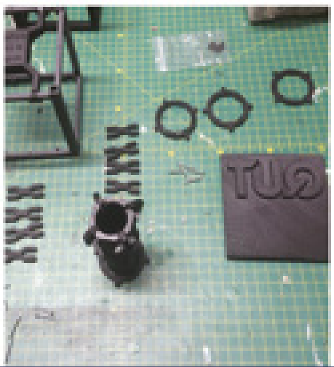
Space Debris

Space debris, also known as space junk, space waste, space garbage and so on, is a term for the mass of defunct, artificially created objects in space. This includes old satellites and spent rocket stages. As of December 2016, five satellites have collided, generating further debris/trash above Earth.

As of 5 July 2016, 17,852 artificial objects had been tracked by United States Strategic Command, however these represent only the objects big enough to be detected. Collision with debris has become a hazard to spacecraft. With the coming boom in cube satellites, more organisations will need a policy on collecting their own debris from launches, a type of clean-up policy. New technologies will need to be introduced and developed for the collection of space debris. Australia can play a role in collecting space debris while generating capital in the collection of such debris.







Case Study: LunaRoo

The Australian Centre for Robotic Vision's LunaRoo project developed a small hopping robot concept for future lunar use. LunaRoo uses jumping as a mechanism by which to overcome obstacles and gain height for imaging the local area. Based on the CubeSat concept, it is compact enough to fit in a 100 millimetre cube, weighs less than 1.3 kilograms and aims to jump to heights of 20 metres on the Moon.

In low gravity environments, LunaRoo can acquire images from a unique perspective (think drone for bodies without atmosphere) for traversability analysis, obstacle detection, and beyond-horizon planning to act as a scout for rovers or humans. It can also use this height to briefly bridge line-of-sight communication gaps or to roam further afield as a rover itself as a long-range explorer. LunaRoo’s primary strengths are its simplicity, small size and weight, and its great terrain traversal properties. It’s a very flexible unit and has been designed with payload space to allow it to carry out a broad range of scientific missions. It is to be solar powered to keep mass down, and to allow for long distance activities. Interaction with the regolith is also an important aspect for any jumping robot and this is accounted for with the design of the mechanism and the inclusion of foot options.

Collaborations with NASA’s Jet Propulsion Laboratory (USA), the European Space Agency’s Advanced Concepts Team and DLR (Germany) are in the exploratory stages.

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This chapter also drew on submissions and a workshop held in Canberra, Australia, on 16th October. Submissions and attendees at the workshop are listed below:

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11 Technology mapping

Robots that perceive their environment; sense, understand, and learn to improve performance over time; and respond robustly and safely, even in difficult sensing conditions and changing environments, are key for many emerging robot applications.

Image courtesy of Woodside Energy

The preceding chapters have detailed some of the current uses of robots, the potential impact that robots can have across all sectors of the Australian economy, and opportunities for future applications. Despite all the promise, where are all the robots?

While Australia has had robots in manufacturing since the 1950s, there are still many heavily manual occupations, such as construction, where robots do not seem to have made inroads. Activities like manufacturing and logistics can be highly ordered and planned environments where robots operate separately from people. To date however, only large manufacturers have been able to impose sufficient structure on their operations to make best use of robot capabilities while SMEs have failed to take advantage of the benefits robots can provide. To have impact in SMEs in manufacturing and other sectors of the economy, robots need to be able to operate in disordered and even chaotic unstructured environments, and, near people. This requires robots to be skilled at making intelligent decisions in a constantly changing world and to do so in a way that is safe to humans.

Robotic vision, the application of computer vision to robotics, is the standout example of the breakthrough science and technology required to enable robots to operate safely in unstructured environments. Robots that perceive their environment; sense, understand, and learn to improve performance over time; and respond robustly and safely even in difficult sensing conditions and changing environments, are key for many emerging robot applications. However, vision, or seeing, is a complex process.

In some robots, vision may involve more than the processing of visual information from cameras, including sensory information from LIDAR, radar or ultrasonics. Natural vision is tightly coupled to both memory and action. Robots must be able to understand the scene around them to robustly perform tasks that involve objects and places. They must also be able to use their vision to control actions and take account of rapid and continuous feedback. Robots with visual perception – that can see and respond as humans do – are necessary to sense, understand and operate in complex and unstructured real-world environments.

Robots of the future are likely to look very different to those seen in the world today. People no longer expect robots to appear like humans, and the boundaries between smart materials, artificial intelligence, automation and robotics are blurring [BBV17]. Robots will also be able to do an ever-increasing range of activities. It is anticipated that robots of the future will:

- protect, care for, and keep people company throughout their lives
- cultivate and tend to food supplies
- transport people and materials without being given instructions
- explore space and colonise extra-terrestrial environments
- monitor and repair both the built and natural environment
- be nano-sized and deployed in the human body to detect and fight disease, and
- build and repair themselves.

Robots of the future may be more like artificial organisms, applying many of the characteristics of biological organisms and, in some cases, integrating with them. Smart skins are an application of this that can be applied to both robots and humans. Smart synthetic skins can give robots (and prosthetics) better tactile sensitivity [ACS16]. When applied to humans, they may develop into smart bandages or power-assisted clothing [BBV17]. Eventually, soft robotics could be used to restore the functionality of diseased and damaged organs and structures. Smart prosthetics may enhance human capabilities and overcome disabilities caused by accident or disease, with the next step being integration of biomechatronic body parts to both humans and animals, creating blended, cybernetic organisms (cyborgs).

This chapter details the technological advances that will see robotics applied across all sectors of the Australian economy. These will build on grand challenges identified by the global robotics community [SM18] and the Australian Academy of Sciences (AAS) report on the Future of Autonomous Robots, which details research gaps [AAS18] but also recognises that truly transformative advances often come from unexpected directions. Finally, Amara's Law recognises that while humans overestimate what might be achieved by technology in the short term (5 years), they tend to underestimate what can be achieved in the long term (15 years) [AL17]. Twenty years ago, unmanned aerial vehicles (drones) were only accessible to nation states and now a child can afford, and fly, an autonomous drone. It was only 11 years ago that the DARPA Urban Grand Challenge saw the world's first demonstration of self-driving cars and now there are self-driving cars being tested on the world's roads. The pace of technological change is rapid and many ideas that once seemed far-fetched are now within reach.

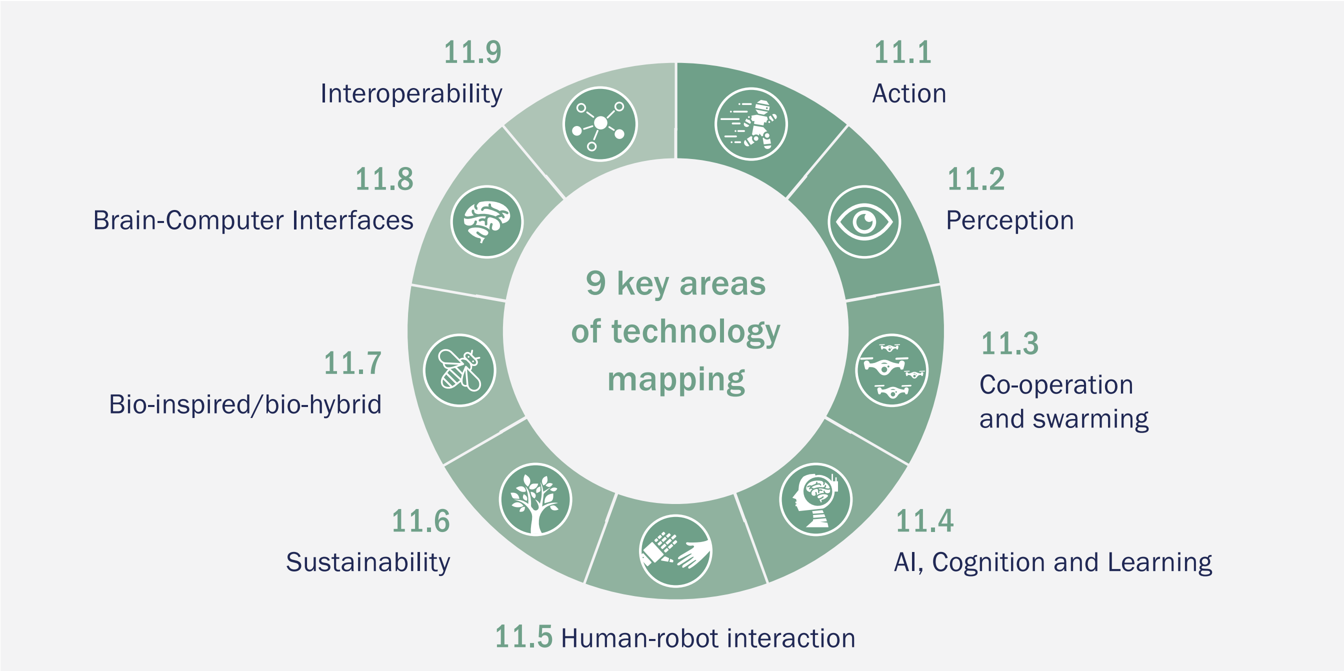
Falling prices and increasing performance of sensors, processors, storage devices, and communications hardware has created four technology drivers that will have an impact on the development of robotic technologies in the next five to 10 years [SM18]. These are:

1. The integration of components for computation and storage is resulting in a software centric architecture that tightly couples computation, storage, networking, and virtualisation resources - a framework that is being called "hyper-convergence". Soon, sensors and wireless communication devices will be part of this hyper-convergence.

2. The convergence of the hardware for consumer electronics (e.g, smart phones, tablets, and virtual reality devices) and intelligent autonomous systems (e.g, UAVs, robots, and self-driving vehicles) with concurrent advances in 5G wireless technologies.

3. The development of new smart materials and bio-inspired soft robotics, along with new battery technologies to supply the energy requirements to drive robotic systems will be key.

4. Cognitive systems relying on statistical machine learning and AI are becoming mainstream. Tools from data science, machine learning, and predictive analytics are now being routinely used to extract information from text and speech, and to recognise objects from imagery such as pictures and videos.



11.1 Action

The characteristic feature that turns a machine into a robot is the ability to take autonomous action. This may be through the manipulation of objects of locomotion through the world. Action encompasses both the knowledge required for a robot to interact with its environment, and the actuators and control systems required to enable a robot to move and take action.

When robots take action, it is usually to perform a specific task or set of tasks. There is still a long way to having the technology required for multi-purpose robots, for example a vacuum-cleaning robot that could also pick up clothes. The drivers to have complicated multi-purpose robotic systems are not yet apparent but may emerge in the future. The breakthroughs required to improve the ‘action’ capability of robots include clever use of physical principles, improved actuators and advanced materials to improve robot movement strength, endurance and range (section 11.6), and deeper integration of action, perception and cognition [AAS18]. This section deals with the former, while section 11.6 deals with advances in actuators and control.

For robots to navigate and explore involves path planning, obstacle avoidance, localisation and mapping, which involves: advanced simultaneous localisation and mapping (SLAM) techniques, semantic understanding (section 11.2), cooperation (section 11.3), learning (section 11.4), and robustness (section 11.6). Robots need to be able to learn, forget, and associate memories of scene content, to gain an in-depth (semantic) understanding of their environment, to reason and discover and distinguish new objects through learning, and to evolve via continuous learning [SM18]. They also need to be able to adapt, learn, and recover after mistakes, to make and recognise new discoveries, and have the physical robustness to withstand harsh, changeable environments, rough handling, and complex manipulation, and to self-repair when required [SM18].

Action is an integral function of a robot with its surroundings, human users, and other robots, and is integrated with perception and cognition (section 11.2). Robots must act in increasingly complex environments, often under unknown and/or extreme conditions with limited, or no, communication. For example:

- Robots in tunnels or mines must cope with rough terrain, narrow passageways, and degraded perception.
- Robots undertaking nuclear decommissioning must withstand radiation and restricted access.
- Robots used to construct and assemble infrastructure must be resistant to dirt, dust, chemicals and large impact forces [SM18].

The long latency and low bandwidths of communication in these environments slows down robot action and can also pose a risk to the robot’s survival. Australia is particularly impacted by low bandwidth – high latency challenges due to our immense geography and poor network coverage. For this reason, the technologies for robots to be able to act autonomously, despite these challenges, is imperative.

For robots to manipulate objects requires dexterity. Improvements in manipulation are required for robots involved in almost all service robotics applications [US16].

Grasping, in-hand object manipulation, and the execution of complex and intricate tasks, requires mechanism design, materials, planning and perception and involves the collection of a range of information, such as tactile feedback, object shape, contact locations and centre of mass. Manipulation also requires a clear control algorithm to effectively execute a manipulation task [SM18]. Soft compliant skin with inbuilt tactile sensing, where a robot senses the degree of force required to complete a manipulation task and to reliably grasp objects, remains at immature levels and does not come close to human capabilities. There is still five to 10 years of research and development required to progress the state-of-the-art to enable robots to do simple household tasks, such as stacking a dishwasher.

11.2 Perception

Perception describes how robots sense and process data to obtain an understanding of their environment. For robots to operate safely and effectively in unstructured environments, where they currently are not applied, the ability to perceive is a fundamental requirement. Perception represents a complex interaction between sensors and software, algorithms and data representations. Robots also need to have human-like scene understanding and situational awareness. True scene understanding can require an element of imagination, for example, being able to imagine consequences, and this represents a completely new frontier challenge for robots. The slow pace of progress in perception limits the usefulness and uptake of robotics in most sectors of the Australian economy, making it an obvious area to target [AAS18].

A robot's perception must process and fuse sensor data at a sufficient rate for the task. For example, a robot moving around people must be able to detect and avoid collisions in a fraction of a second. Perception systems must also parse useful and relevant sensor data about a robot's environment from irrelevant data. For a self-driving car to navigate it must perceive where it is in relation to the road, surroundings and other actors such as cars, pedestrians and cyclists. It may need to ignore or subtract distracting elements like snow or rain to enhance its understanding of its immediate environment. Creating a representation of a robot's environment is a key part of perception. It is required so that the robot can reason about which action to take, and must interface with the robot's action systems [AAS18].

True scene understanding can require an element of imagination, for example, being able to imagine consequences, and this represents a completely new frontier challenge for robots.

Today, most large-scale applications of robots rely on very limited perception capabilities or no perception capability at all. Industrial robots are most effective when the operating environment is carefully designed. Tasks must be carefully limited so that the robot only needs to capture information directly from specific simple sensors and uncertainty and surprise is engineered out. The challenge is to go beyond these limitations and for the robot to operate in unstructured environments, fusing data from many sensors and adapting dynamically to changing circumstances. Key to a robot's success is whether it can perceive its own place in the environment (where am I?), the likely effects on the environment from any actions the robot plans to take (what is here and how can I interact?) and the ability to measure the effect of its own actions (what have I done?) [AAS18].

Future research should tackle how sensor data is processed, how a robot's environment is represented, deeper integration of perception with action and cognition including machine learning, especially deep learning (section 11.4), and biological mimicking (section 11.7). Over the next twenty years, it is reasonable to expect to see many work-arounds applied to address some of the limitations currently imposed by robot perception. For example, controlling the robot's environment or making it well-understood through widespread continuous mapping, deployment of multiple sensors and improved robot-robot communications [AAS18].

11.3 Co-operation and swarming

As robots increase in number, their activities will need to be co-ordinated. There will be opportunities for robots to co-operate on tasks, and to have similar robots act as a collective (robot swarming) to complete tasks. Nature has been used as an inspiration for multi-robot co-ordination. Robot swarms allow simple, inexpensive modular robotic units to work as a team. Swarms can act as force multipliers, able to do the same task(s) as larger more expensive single robots and, by co-ordination, solve complex problems. The advantages of multi-robot systems include:

- redundancy – if one robot breaks down, the mission can continue
- scale – multiple robots can cover large spatial distances or domains
- flexibility – by distributing capabilities across multiple platforms, more flexible and adaptive robot systems are produced
- adaptability – robots can come together in the best configuration to solve one task, then reconfigure for a different task [USR16].

Swarms rely on evolutionary algorithms and decentralised intelligence to produce complex behaviours, but these have generally only been applied to swarms of the same type of robot [USR16]. Depending on the task, it makes sense for some swarms to contain a range of robots with complementary skills to give them more flexibility [USR16]. Imagine combining UAVs to give an aerial view of the environment, with ground robots that can be tasked to take action depending on the information they receive from the sky. The resulting system is a heterogeneous team, that may consist of different dynamic configurations, sensing capabilities, spatial footprints, or behavioural strategies [USR16].

Centralised intelligence that works in real-time is required to provide a means of communication between multiple agents, while allowing local control of single robots to adapt to unexpected events. The coordination of multiple robots requires robust and systematic communication protocols, which have not yet been widely agreed [AAS18]. The multi-disciplinary nature of multirobot systems is challenging, making it hard to design robust decision-making strategies in a dynamic environment where communication links may be broken. An emerging research area is communication-aware robotics – robots that actively move to maintain a communications network. Advances in the science of robot swarms requires swarms to be responsive to human commands, adaptable to changing conditions, robust to disturbances, and resilient to failure and change [SM18].

11.4 Artificial intelligence, cognition and learning

AI and learning are critical to robot cognition; that is, the way robots acquire knowledge and understanding of the world around them, then reason and make decisions. Cognition is the main challenge preventing robots from operating autonomously in unstructured environments. Robots are not yet as flexible or adaptable as humans and currently lack human-like intuition and reasoning abilities [AAS18]. Meta-learning, or learning how to learn new things, is a critical new AI capability that must be applied to robots [SM18]. To be able to learn on the fly, adapting to dynamic and uncertain environments and to understand their own limitations is critical for robots to find wider applications than those currently observed.

Robotic systems that know how to interact (with people, other robots and their environment), how to seek help, how to recover from failure, and how to become smarter are needed. Eventually, AI and learning needs to give robots the ability to model their own components and operations so that robots can adapt and evolve [SM18]. To achieve this, AI needs to be able to 'self-learn' complex tasks with a minimum of initial training data. Current machine-learning systems are data-intensive, requiring massive amounts of data to learn tasks, yet are unable to readily apply that knowledge to other domains. The complex and changing nature of the real world makes it difficult to build robust systems that readily learn, but the application of neuroscience to the development of AI systems is a start [SM18]. Once robots have successfully mastered a task they then rely on common task libraries to be able to share their learnings with other robots, building a giant store of robotic knowledge that is only starting to be appreciated. Sharing data is easy but a key challenge is how this learning is represented.

> Eventually, AI and learning needs to give robots the ability to model their own components and operations so that robots can adapt and evolve.

One of the greatest challenges in robot cognition is to develop cognitive capabilities that can push back the level of structure required in the operating environment, until robots can operate safely and effectively in unstructured environments. Breakthrough research directions include finding universally applicable approaches to transfer learning, being able to operate in both symbolic and non-symbolic logics, developing compact representations of the world that admit various forms of reasoning, and developing cognitive architectures that can reliably make sense of the surrounding environment and then take appropriate action [AAS18].

11.5 Human-robot interaction

Future robots will be expected to work safely side-by-side with people in a variety of different situations. To facilitate these interactions, robots must be intuitive, easy to use or understand, and built to be responsive to the needs of people while understanding their differences [USR18]. As robots gain more utility, and thereby more influence in society, it will become increasingly important to develop Australian systems that interact with Australians in a way that suits Australians [AAS18]. Research in human-robot interaction is becoming increasingly important, particularly regarding social robotics, which includes relevant aspects of robot action, perception and cognition, as well as understanding and modelling humans to give robots sufficient understanding to interact with humans in preferred ways [AAS18].

Human-robot interaction (HRI) requires a better understanding of human intent than currently available. Good design for HRI increases utility, and the likelihood that the system will be successful when used in any application as ultimately all systems are used/deployed/maintained by people. Strong capacity in HRI provides a competitive advantage to those deploying robotics. HRI may be either physical or social and is challenging due to the unpredictability of humans. Robots in the future will make decisions that determine the tenor of these interactions. They will need to interact with humans in a predictable,

Natural Language Processing (NLP) gives robots a way to accept instructions from humans without formal programming

reliable, ethical and fundamentally safe manner. Social interaction requires building and maintaining complex models of people, including their knowledge, beliefs, goals, desires, emotions and cultural/social norms. Just like humans, robots need to simplify their language depending on context, coordinate their actions to match human preferences, and be able to interpret the actions of others as representative of their inner goals [SM18].

Natural language is the main interface convention for social robotics as people have an expectation that humanoid robots (like people) will understand what they say and follow simple verbal commands. Natural language processing (NLP) gives robots a way to accept instructions from humans without formal programming. Once robots can apply NLP then they are also able to understand more about the human world and be able to learn from information that humans develop for other humans (e.g, from books). The next frontier will be in enabling robots to understand non-verbal communication – facial expressions, gestures, and body language – thought to be responsible for 80-90 per cent of the meaning found in human interactions. Biometrics, particularly applied to recognition of micro-expressions, will be increasingly important in human-robot interactions.

The three most significant challenges that stem from building robots that interact socially with people are modelling social dynamics, learning social and moral norms, and building a robotic theory of mind [SM18]. Our understanding of human social behaviour is not nearly as advanced as our knowledge of Newtonian mechanics or even human visual perception [SM18]. Understanding social interaction requires an understanding of social cues, social signals (which may be context-dependent and culturally determined), appropriate social and moral norms, and an understanding of empathy, ownership, and the need to keep a promise [SM18]. Displaying this understanding will be essential to build the long-term trust and relationships necessary for robots to operate side-by-side with people.

Robots currently lack comprehensive or integrated, rich, usable models of human mental states and are also not designed for long-term interactions. Robots need to integrate models of episodic memory, hierarchical models of tasks and goals, and robust models of emotion to create the detailed cognitive models that capture the psychology that humans effortlessly apply to understanding other humans [SM18]. Current social robots are designed for brief interactions rather than ones lasting months, years, or even decades. This expansion will require adaptable models of robot behaviour that personalise responses based on the length of time the robot has 'known' the people it interacts with.

Robots need to be able to predict and understand what the humans around them are intending to do. A robot will need the sensory and processing capacity to feed into a cognitive system that can develop a robust awareness of its environment, both of its own position, and all the other aspects within that environment, be they people, animals, other robots, or other inanimate objects. This requires a range of basic skills such as recognising human poses and activities, awareness of human attention, understanding speech and non-verbal behaviours such as gestures and body language, together with high level competencies that use such information to predict human intent and select appropriate actions. In the future, significant innovation is expected to occur when control is shared between robot and human, with 'human-in-the-loop' stimulus and motion mapping enabling robots to learn how to predict and adapt to real-world conditions and safely operate [AAS18]. More research, done in an integrated manner between roboticists, psychologists, cognitive scientists, and social scientists, into developing effective mental models is critical to extend this work to be generally applicable. Social cues differ between countries and cultures, and culturally appropriate models for Australia must be considered.

Research into the realm of social robotics, including human-robot interactions, is currently in its infancy and needs to keep pace with the rapid evolution of robotics technology. There are huge opportunities for the application of social sciences and interdisciplinary research will become imperative. Current research activity is not proportional to the potential impact of the human-robot interaction problem: Australia has an existing lead in some parts of the social robotics field that would be desirable to maintain [AAS18].

11.6 Sustainability: new materials and fabrication schemes, physical systems development, power and energy

Robots currently consist of gears, motors, and electromechanical actuators, but advances in new materials and manufacturing and construction techniques are changing the way that robots are built. Prototypes of new generation robots are increasingly power-efficient, multifunctional, compliant (to standards), and display biological features [SM18]. Widespread application of new materials and manufacturing techniques requires improved portable energy storage and harvesting, new materials with tuneable properties, and new fabrication strategies for these functional materials with the aim of eventually building robots that can build and repair themselves [SM18].

As the properties of new materials become better understood, it is possible to design entirely new robots. Some new materials combine both sensing and actuation, while robot designs are increasingly mimicking biological systems. Drawing inspiration from invertebrates, robots can be reimagined using a wide range of material properties (from soft tissue to bone) allowing seamless integration of dissimilar material properties, allowing distributed function, and reducing the need for complex assembly [SM18].

Multifunctional materials can increase the efficiency of robot design and simultaneously offer distributed networks of hierarchically structured sensors and actuators. The use of folding-based metamaterials (with tuneable electromagnetic or mechanical properties), multiphase composites (with simultaneous fluidic actuation or sensing), and textiles (embedded with electrical functionality) is yet to be fully explored, as is the biodegradability and recycling potential of robot-building materials [SM18].

> The ability of robots to self-maintain and self-repair in harsh environments over long time periods will be a critical factor in the successful automation of many tasks.

In the future, it is envisaged that artificial muscles may replace electric motors and gears as they are lighter, quieter, and have fast reaction times. Robots would also benefit from more energy-efficient perception inspired by biological processes. Digital computers are massive and energy intensive compared to the human brain, which is compact, powerful, energy-efficient, weighs just 1.5 kilograms and consumes around 20 watts. Computer chips and the boards on which they are mounted are 2-dimensional whereas our brains comprise highly interconnected 3-dimensional circuits [AAS18].

Fabrication and assembly is typically a serial process that is slow and difficult to scale to very large or very small scales, until the discovery of synthetic molecular machines [SM18]. These molecular machines have the potential to develop hierarchical materials. These can be used to enhance the function of robots by converging additive and subtractive methods of manufacture, with emerging technologies to generate new architectures. The current robotic frontier is the use of alternative methods of fabrication that combine techniques from micro-/nanoscale (e.g., surface and bulk micromachining, physical and chemical deposition, and microscale moulding, stamping, and functionalisation used in soft lithography), mesoscale (e.g., layering and lamination common in multilayer printed circuit boards), to macroscale (e.g., multi-axis subtractive methods).

Biological systems have an amazing ability to heal or accommodate damage which is desperately required in engineered systems that otherwise rely on redundancy to cope with catastrophic failures induced by damage [AAS18]. The ability of robots to self-maintain and self-repair in harsh environments over long time periods will be a critical factor in the successful automation of many tasks. The development of multiscalar materials able to adapt and heal over time, may help robots achieve the complexity found in natural systems [SM18].

> In the next decade, energy harvesting and storage techniques may be solved for robotics due to the strong drive for these technologies from other industries, such as the solar power and hybrid car industries.

Many of the desired applications for future robots will be in inhospitable environments without access to recharging stations, so reducing energy demand, improving efficiency, and increasing energy density of storage will be extremely important [AAS18]. The operational longevity of mobile robots is typically constrained by battery power, size, and weight. These may be in the form of compact, stable, high-energy density batteries for robots working in challenging conditions and/or extreme environments [SM18]. New battery technologies for robots are being developed that are safe and affordable, with longer cycle lives, robust temperature tolerance, higher energy densities, and relatively low weight. New areas of research include the use of: fuel cells, supercapacitors, silicon anodes with smart electrodes, new electrode designs for achieving enhanced capacities, and metal-oxygen, lithium-sulfur, aluminum-ion, and sodium-ion batteries. Advanced battery systems based on solid electrolytes, and flow-based, lithium-ion, lithium-sulfur, and lithium-organic batteries are also promising areas of study [SM18]. No battery can yet match the metabolic energy generation in organisms. Biohybrid robots with on-board generation or ‘foraging’ behaviours remain a research frontier [AAS18].

Energy-harvesting and storage techniques are potential solutions to the power and energy challenges facing robots. Such techniques include electromagnetic and electrostatic generators, as well as piezoelectric nanogenerators and triboelectric nanogenerators, and the use of bidirectional transducers (that allow sensors and actuators to behave as materials for energy harvesting or storage). Improving battery energy density and cost will require radical breakthroughs. While robots can ‘forage’ for energy by docking with stations where power is available or generated, and automatically recharge or upload data, no real-world systems have yet demonstrated these capabilities [AAS18]. As important as energy harvesting is, reducing robot demand for energy is achievable by implementing energy-efficient motion and perception algorithms. In the next decade, energy harvesting and storage techniques may be solved for robotics due to the strong drive for these technologies from other industries, such as the solar power and hybrid car industries. However, reducing the power and energy requirements of robots by clever adaptation of motion and perception algorithms is of equal importance.

New battery technologies for robots are being developed

that are safe and affordable, with longer cycle lives, robust temperature tolerance, higher energy densities, and relatively low weight.

New areas of research include the use of: fuel cells, supercapacitors, silicon anodes with smart electrodes, new electrode designs for achieving enhanced capacities, and metal-oxygen, lithium-sulfur, aluminum- ion, and sodium-ion batteries.

11.7 Bio-inspired/bio-hybrid

Bio-inspired robotics rely on the use of fundamental biological principles translated into engineering design rules to create a robot that performs like a natural system [SM18]. Bio-hybrid robots are created when biological material is directly used to design synthetic machines. Science robotics [SM18] show that the list of grand challenges for bio-robotics has remained largely unchanged over the past 30 years, consisting of batteries that match metabolic conversion, muscle-like actuators, self-healing material that manufactures itself, autonomy in any environment, human-like perception, and, ultimately, computation and reasoning. To accelerate the design, implementation and operation of bio-inspired and bio-hybrid robots requires the development of:

- materials that couple sensing, actuation, computation, and communication
- novel designs of heterogeneous, anisotropic, hierarchical, multifunctional materials (increasing material strength, stiffness, and flexibility, fracture toughness, wear resistance, and energy absorption)
- models of real-world, unstructured environments that can cope with the staggering complexity of how bioinspired robots effectively interact with the ground [SM18].

These advances provide robots with features such as body support, weight reduction, impact protection, morphological computation, and mobility.

Actuation and energy limit the performance of bio-hybrid and bio-inspired robots compared with animals. New technologies such as electromagnetic motors and artificial muscles are inefficient (particularly at small scales or in soft systems) and lack robustness [SM18]. Bio-inspired pick and place manipulation, and grasping, has seen significant progress, but no system matches the flexibility and dexterity of human hands. Miniaturisation of aerial vehicles relies on replicating biology as 1-2 centimetre wingspans must use flapping wings (fixed wings do not generate the required lift at practical air speeds). Small microflyers are now being equipped with compact lightweight miniature, insect-style compound eyes and might also use insect-like legs and feet to land on uneven surfaces [SM18]. While there has been progress in engineering miniature, biologically inspired robots, power is still a challenge. An alternative is to autonomously control animals to carry scientific payloads (for example, control of insects has been demonstrated) turning them into high-performance long-range flying robots [SM18].

11.8 Brain-computer interfaces

Robots of the future will also benefit from brain-computer interfaces (BCI). A BCI forges a direct, online communication between brain and machine and can augment human capabilities [SM18]. It allows brain activity to control a robot without the mediation of the peripheral, somatomotor nervous system. BCI has major applications in enabling paralysed patients to communicate and control robotic prosthetics and in rehabilitation for restoring neural function [SM18]. BCIs use machine learning to translate user intentions into outputs or actions. Recent advances in BCIs have been accelerated by allied technologies, including neuroscience, sensor technologies and component miniaturisation, biocompatibility of materials, and embedded computing [SM18].

For BCI to gain broader traction requires low cost implantable sensing with new microfabrication, packaging, and flexible electronics, combined with ultra-low power local processing, and wireless data paths. BCI currently faces the challenges of size (cumbersome), expense (high), dealing with artefacts of noncerebral origin in data processing, the availability of simpler techniques such as eye tracking or muscle-based devices, and dealing with tasks with high degrees of freedom. Exciting new research opportunities will accompany the development of BCIs in robot control, functional rehabilitation and in knowledge exchange with neuroscience [SM18].

Robots of the future will also be able to learn from the behaviour of natural systems such as humans, primates, other vertebrates and even insects [AAS18]. Creatures with relatively small, energy efficient, and 'simple' nervous systems can demonstrate impressive levels of cognition that robots can aspire to. Such learning includes guessing the intention of other animals, problem solving and tool usage, observation and imitation, and learning motor actions using mirror neurons. These animal behaviours may be the key for the basis of learning by imitation in animals and could also provide useful clues for the design of algorithms that will enable robots to learn through observation and imitation and inspire new robot learning strategies [AAS18].

Brain-computer interfaces use machine learning to translate user intentions into outputs or actions.

11.9 Interoperability

The enormous growth in the field of robotics has created a large number and variant of robot products, including manipulator arms, mobile bases and grippers. To test algorithms on these robotic products can be difficult due to the lack of interoperable hardware and software. Interoperability is the biggest challenge facing the adoption of automation and robotics in industrial applications in Australia (see Chapter 3) presenting commercial and technical challenges. Most users employ a mix of robotic systems from a variety of vendors, making standards for interoperability an urgent requirement in most industries apart from manufacturing, where the rigour in supply chain management in automotive manufacturing has ensured that interoperability is considered a standard feature. The future progress of robotic research relies on continued development of robust unified standards.

The creation of open-source platforms represents a good starting point and will ideally lead to the development of standards vetted by the open-source community. A good example of an open-source robotics platform is the robot operating system (ROS). First created in 2007 at Stanford and developed by start-up Willow Garage, it has now become ubiquitous in academia and is starting to have impact in industry. The term OS is a misnomer; ROS is component-based middleware that allows for the rapid assembly of existing and new components, running on one or more networked computers, to create a robot. The ROS ecosystem includes data loggers, data replay and visualisation. ROS has a large developer group which is guided by the Open Source Robotics Foundation. ROS-Industrial is a consortium that extends ROS to industrial applications. Non-open-source proprietary modules are now being developed for the ROS ecosystem. The accessibility of such plug and play frameworks is critical for ongoing R&D on robotic systems [AAS18]. It is also an area where Australia could potentially take a leading role for very little investment.

11.10 Main findings from technology mapping

Robotics is evolving so rapidly that it is easier to identify short-comings in current robot operation rather than to accurately identify key technologies that will be required in the future, however this chapter shows the importance of interdisciplinarity in the future of robotics. Many of the technologies described benefit more fields than robotics alone and will be solved by people beyond the usual robotics realm of mechatronic engineers and computer scientists. It is only through collaboration with biologists, chemists, physicists, social scientists, and other engineers and scientists that the full potential of robots will be realised. The earlier chapters of this roadmap also highlighted the importance of legal professionals, ethicists, and policy makers to ensure that new technologies can be adopted. The driver for an interdisciplinary and collaborative approach to the future of robotics is closely linked to the future we envision for Australia. A future where robots do the dull, dirty and dangerous tasks that are not best-suited to human beings and solve many of the world's most pressing challenges such as war, famine, natural disasters, environmental damage, poverty, and inequality. A future where robots help humans unlock their potential and explore the furthest reaches of the universe. A future where robots ensure that Australia is a prosperous nation that embraces a robot economy and builds national health, well-being and sustainability despite the challenges of its vast and remote geography.

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11.11 Technology Roadmap

Resources Sector

Area	5 year	10 year	15 year
Oil and Gas	Use of service robots has been projected to increase by 20% over the next 5 years. The inspection information, captured in digital form, serves as a baseline for future inspections and, as a result, can automatically calculate defect feature changes over time, leading to reduced human intervention, increased operational efficiency, reduced cost and improved safety.		
			Fully autonomous drilling and resource extraction in remote sites
Exploration (Mining)	Autonomous or semi-autonomous exploration (leading to reduction of contact exploration)		
Oil and Gas Mining Exploration	Individual autonomous ground, air, surface, underwater vehicles exploring on their own	Autonomous cooperation of team of vehicles, including heterogeneous (first demo)	Autonomous cooperation of team of vehicles, including heterogeneous (first demo)
Maintenance/ Safety	Standard monitoring triggering a call for detailed inspection which will be executed by robot (e.g, UAV)+vision (or other robot)	Autonomous inspection conducted by robot/UAV - relatively simple	More complex inspection conducted, e.g, geo-tech risk mapping and auto alert
Safety	Robots/UAVs that can constantly monitor the structural integrity of mine tunnels, as well as open-pit mines		
	Robots/UAVs for monitoring/inspection of operation, defects, changes, geotech risk etc.		
	Auto emergency braking and stopping on all mining vehicles (with close to zero false alarms)		
Maintenance	Some maintenance tasks achieved robotically NB: first need to identify which tasks e.g. which ones would be critical (e.g, stop vehicle) and hard to predict? (when can predict, know before the truck is out of order, so can send it to repair shop)		
	Changing tyre of truck auto in specialised facility (shed), with little variability (known truck, no damage, clean truck)	Changing tyre of truck in simple facility with some variations	Changing tyre autonomously on the spot (Where the truck is, and "as is")
Safety/ Productivity	Fleet of Autonomous trucks without people around (capability demonstrated, but not viable in practice)		
Exploration/ Safety	Inspection with robot with human giving high-level input (e.g, waypoints), with AR	Autonomous man-made structure inspection (e.g, pipelines)	Autonomous natural environment. inspection
Operation/ Efficiency	Automated logistics		
Safety/ Monitoring/ Productivity	Computer vision (for localisation, scene understanding) that is reliable and accurate		
Exploration/ Mine Construction	Autonomous, adaptable boring robot	Robots construct the mine	
Safety/ Rescue (+ Exploration)	Robots/UAVs that can be deployed via a borehole		

Area	5 year	10 year	15 year
	Improved Digital monitoring of equipment, predictive maintenance (not autonomy but linked to it)		
Exploration/ Extraction	Expansion of the ores that hyperspectral imaging can find in the rock face (in "nominal" conditions, i.e.: dry surface, stable illumination etc.)	Composition of rock face from hyperspectral imaging in variety of conditions: incl. wet surface, with illumination etc.	Composition of rock face in any condition + some depth
	Key: mine what needs to be mined. First exploration, then production. Take only the ore outside of the mine, no waste		
	Virtual geologist: various functions		
	Full sensor fusion suite with vision but also smell, gas sensors etc.		
Sensing/ Exploration/ Extraction	Distributed and low-cost hyperspectral sensing to identify ore body vs waste. Ubiquitous hyperspectral sensing		
	Need better sensors e.g, determine the full composition of the rock face, or even deeper		
Blasting/ Exploration/ Extraction	Analysis of content of dust (after blasting) (e.g, contains gold), Sensing capable of detecting ore (e.g, gold) in dust going off in blasting		Real-time analysis of ore content in dust, and where it lands after blasting
Safety/ Environment	Autonomous Continuous Monitoring of pollution, incl. diesel particulates		
Exploration	Cheaper sensing and equipment for advanced exploration (compared with current expensive autonomous drills)		
Production	Lower-infrastructure communication system. More flexible, and can adapt to fix local failures. Mobile communication system based on the autonomous vehicles	(nearly) Infrastructure-independent Communication system exploiting autonomous vehicles fleet, with vehicles acting in ways to ensure reliable and sound communication whenever needed. This opens opportunities, such as the communication network	
	Adaptable robots that are learning constantly (lots of variability)		
Extraction	Automate other tasks than vehicle driving (identify which tasks to complete first?)		
	Auto-separation of most types of ore from waste, in appropriate infrastructure (e.g, conveyor belt)	Auto-separation of most types of ore on the spot (e.g, inside the bucket of excavator, before loading truck, or in intermediate machine on site)	Auto-separation of all types of ore from waste, on the spot (e.g, inside the bucket of excavator, before loading truck, or in intermediate machine on site)
	Only crush stuff that is worth crushing (off extraction site)	Only crush stuff that is worth crushing (on-site)	
	Testing of smaller concepts of autonomous trucks	Deployment of smaller autonomous trucks	
	Robots that collect the right information at the right time (not just whatever whenever)		

Area	5 year	10 year	15 year
Exploration/ Construction	Autonomous robot that places explosives into pre-made holes (composition, formula and quantity pre-decided by expert people)	Autonomous robot that drills on site, prepares explosive on site and places it	>15: Blasting robot, deciding on the spot best explosive to use, "blast as you go", getting feedback on the way and using it. Even more: team of collaborating robots exchanging information
Equipment	Interoperability becomes standard in Resources sector (as currently for Manufacturing)		
Operation	Mass customisation of operations autonomously: adaptable planning systems that can be deployed quickly and adjust to the new site, and can learn "on site" to improve		
Monitoring/ Operation	Semantic mapping: robots (ground and air, possibly also water) capable of recognising and localising assets, and their status		

Manufacturing Sector

Area	5 year	10 year	15 year
Safety/Logistic/ Quality	Sensor networks provide live data as a service to enable discrete quality, logistics, and robotic function whilst integrating into manufacturing systems	Sensor networks provide live data as a service to enable holistic quality, logistics, safety, and robotic function whilst integrating into manufacturing systems	Sensor networks provide live data as a service to enable holistic quality, logistics, safety, and robotic function whilst integrating into manufacturing systems and decision-making tools to self- and continuously-improve operations
	Explainable discrete decisions	Certifiable discrete decisions	Reuse of certified decision tools for multiple applications
	Robust people detection and tracking	Understand and predict human behaviour	
	Semantic understanding – what it is, where it is	Semantic understanding – what it is, where it is, where is it going, what is it doing	
	Localised multi-agent planning and optimisation	Integrated factory multi-agent planning and optimisation	Mass holistic multi-agent planning and optimization
Production	Discrete new process steps are added to a factory without manual programming	A new production line is added to a factory without discrete manual programming of process steps, with minimal experience	A new production line is added to a factory without manual programming of process steps, logistics, and layout, without explicit expertise
	Simple transfer learning within process	Transferable learnt experiences/skills between processes	Experience libraries allow transfer of skills from other robots and other processes, sharing across industries
	Discrete tool libraries allow re-use of hardware and software from other robots	Discrete tool libraries allow re-use of hardware and software from other robots, sharing across industries	Automatic optimisation of hardware and sensing configuration and geometry to specific process
	Simulation or human demonstration allows task learning	High fidelity simulation allowing process learning	Multi-physics accurate simulation allows high fidelity validation and certification without hardware

Area	5 year	10 year	15 year
	Simulated production scenarios actively interrogate and optimise component design	Simulated production scenarios actively interrogate and optimise assembly design	Simulated production scenarios automatically interrogate and optimise product design
	Automatic navigation and path planning for well-defined discrete semi-structured scenarios	Automatic navigation and path planning for well-defined complex semi-structured scenarios	Automatic navigation and path planning for uncertain complex semi-structured scenarios
	Robust localisation in semi-structured environments with large moving monuments and varying lighting conditions	Robust long-term localisation in uncontrolled environments	
Augmented Human Performance	Assistant robots work cooperatively amongst people in structured environments	Assistant robots work cooperatively amongst people in semi-structured environments	Assistant robots routinely work cooperatively amongst people in semi-structured environments
	Robots can understand process specific simple natural language commands	Robots can understand process specific complex instructions in natural language	Robots can interact using natural language across multiple processes
	Certified sensing (including vision) allows safe cooperation in structured scenarios	Certified sensing (including vision) allows safe cooperation in semi-structured scenarios	Robots can understand their surroundings and guarantee worker and process safety
	Robots can detect incorrect input or process/system failure	Robots can explain incorrect input or process/system failure	Robots can correct incorrect input or process/system failure
	Robots can communicate their own intent	Robots can interpret and predict human behaviour, and communicate their own intent	Robots can interpret and predict human and environment behaviour, and communicate their own intent

Healthcare Sector

Area	5 year	10 year	15 year
Minimally Invasive Surgery (MIS)	Real-time 3D reconstruction of inside of joint/body from arthroscope/endoscope (during surgery)	AR system showing this reconstruction to the surgeon	
	3D arthroscopes	3D reconstruction aligned with MRI/CAT scan and/or X-Ray	
	3D arthroscopes	Camera (arthroscope/endoscope) automatically following the tool during surgery (probably visual servoing, camera held by a robot), all safely (i.e. no collision with body)	Robot does the cutting autonomously given instructions from surgeon (e.g., what volume should be cut)
	Real-time, clear and understandable view of the in-vivo surgery area from ultrasound		
	Manipulation of the joint (e.g. knee) by robot (instructions given by surgeon, e.g. in the form of a required joint configuration	Instructions given in form of desired view, open-loop	Closed-loop version: reconfiguration of knee by manipulator based on visual feedback and high-level instruction from surgeon
	Continuum/snake-like/flexible robots used in surgery, with "natural" interface	Instructions given in form of desired view, open-loop	

Area	5 year	10 year	15 year
	From assisted surgery to fully robotic surgery		
Simulation	Real-time planning tools to aid surgeons	Real-time planning tools for use in the OR	Real-time replanning during telesurgeries
Telesurgery	National Biomedical Testbed	Real-time planning for teleoperation	National telesurgical network
Diagnosis	Remote, contactless vital signs from vision, in the field	Remote advanced diagnosis in the field	Forecast disease progression from script history
Assistance for disabled/elderly	Robots that deliver supply to OR	Need to anticipate intentions	Patients moved by robots with reconfiguration (e.g., from bed to wheelchair)
	Robots that clean up OR after surgery	Autonomous beds that safely transfer patients from place to place	

Services Sector

Area	5 year	10 year	15 year
	Ability to navigate/understand the home (or shop, park, other...)		
	Reduce installation requirements / flexibility (consider robot vacuum that needs to be set up)		
	Manipulation (integration of vision, haptics and mechanisms)		
	Integration with built environment technologies - doors, elevators, household appliances		
	Human interaction - particularly voice as the Australian accent can easily confuse voice recognition systems developed in other countries/cultures		
	Standards for recharging to avoid proliferation of charging devices for multiple robot types deployed (compliance with AS3000 and local voltage/frequency)		

Construction Sector

	5 year	10 year	15 year
	Sensing and perception in the general real-world case	Actuation/mobility in the general real-world case	Cognition/action planning/decision making/leadership/bringing it all together in the general real-world case
	Robots will be able to see and understand at a human level. Enabling analytics, QA, decision making, planning, monitoring/supervision	Robots will have the skills and dexterity in movement to enable them to move around unstructured environments/ unmodified human terrain and to actively apply the 5 years capabilities in true collaboration with close and extended human teams	Along with the 5 year and 10 year capabilities robots will have the curiosity and agency to self-direct their contributions and actions, and to take leadership roles in mixed human-machine teams
Safety/Monitoring and Logistics	Dynamic persistent, ubiquitous mapping	Situation awareness (quality/ perception/"mixed traffic").	10 year + global scale – understand the role of all actors (human and robotic), their intent, etc
Logistics	Automation of transport vehicles		
	Optimisation via machine learning (i.e. ability to plan via prediction consequences of ambiguous and uncertain and complex/chaotic data flows) – two or three modes (traffic and people?)		Optimisation via machine learning (i.e. ability to plan via prediction consequences of ambiguous and uncertain and complex/chaotic data flows) global optimisation
Quality Assurance (QA)	Robust QA over a range of environmental conditions		
Certification	Certification by simulation		
Specific Tasks	Vehicle/crane/digger automation		
	Physical work via autonomous system (e.g. move A to B) – the GO-FOR, natural language understanding	Moving to "apprentice". Requires learning and anticipation	
	Complexity of environment (scale, people, weather, etc.)		
	Construction is turning into manufacturing – pre-fab, etc. Hence see the manufacturing capability map		

Defence Sector

Area	5 year	10 year	15 year
High Altitude Unmanned ISR Systems	Long-endurance surveillance operations over the ocean. The Triton also enables persistent maritime patrol and other intelligence, surveillance and reconnaissance tasks over a broad area. Triton's operations will be closely coordinated with that of the Poseidon maritime surveillance and response aircraft		
Intelligence Systems	Collecting and analysing intelligence, with a focus on strengthening intelligence capabilities in support of deployed forces (for example to support increased use of unmanned systems)		
	Generating intelligence and mission data for pre-programming advanced platforms		
	Defence will develop systems, sensors and networks to deliver effective air and space situational awareness around Australia and in deployed locations. A new, more sophisticated command, control, communications, computer and intelligence system will also be required to be able to fuse information from multiple sources		

Area	5 year	10 year	15 year
ISR Information, Integration and Optimisation	Processing, exploiting and disseminating the large volumes of data that will be generated by sophisticated platforms - such as unmanned intelligence, surveillance, and reconnaissance systems (including Triton)		
	Space-based and ground-based intelligence, surveillance and reconnaissance systems; and …command, control, communications, computer and intelligence capabilities		
Common Operating Picture Capability Program	Success in all operations is dependent on providing tailored and near real-time situational awareness to commanders. In the operations sphere this is provided by generating a trusted common operating picture.		
Digital Topological Systems Upgrade	Management of maritime military geospatial information and to support national tasking for surveys…. increase the throughput of both national and military hydrographic information		
Joint Electronic Warfare Integration Program	Force-level, electronic warfare capability, to achieve high levels of information fusion and comprehensive planning across the joint force and Defence intelligence agencies… improve the ADF's ability to control the electronic environment and where necessary, deny or degrade the electronic systems of adversaries		
Long-range Electronic Warfare Integration Program	EW support aircraft acquisition		
Satellite Imagery Capability	Increasing the capacity for imagery analysis		
Cyber Security Capability Improvement	Enhanced cyber capabilities		
Airfield Capital Works-Multiple Bases General Ranges and Testing Areas Womera Redevelopment Tracking Ranges	Modifying the Defence estate footprint to accommodate our new high technology capabilities and larger platforms, and to ensure that we are appropriately placed to meet future strategic requirements. Over the next 50 years, this will involve developing new bases, wharves, airfields and training and weapons testing ranges. Training range upgrades will include a variety of estate infrastructure, communications and environmental controls to manage training activities sustainably; new instrumentation, targets and threat simulation		
Pilot Training Systems Helicopter Aircrew Training Systems Defence Simulation & Collective Training Air Combat Officer Training Systems	The pilot and air combat officer training systems will be upgraded to support more complex aircraft and aviation systems, including unmanned aircraft, and the increasing number of aerial platforms in the future force		
NGT - Trusted Autonomous Systems Defence CRC Fishermans Bend Redevelopment and Laboratories	Trusted autonomous systems - researching developments in trusted autonomous systems that may have the potential to support ADF capability in the future, such as the use of autonomous vehicles for resupply		
Long-range Combat Search and Rescue Aircraft	Defence will explore options for a long-range, aero-medical evacuation and combat search and rescue aircraft to provide enhanced support to ADF operations, including operating with the amphibious ships		
Replenishment Ships	The new replenishment ships will be fitted with situational awareness and communications capabilities along with semi-autonomous point-defence against air and surface weapons threats and torpedo defences		
Future Submarine Program - Design and Construction	The new submarines will have advanced communications systems to link with other Navy ships and aircraft to conduct anti-submarine warfare operations		
Future Frigate Program - Design and Construction	Upgrade self-protection systems and unmanned tactical intelligence, surveillance, and reconnaissance systems		
	The future frigates will be required to conduct a range of missions, with a focus on anti-submarine warfare		
	The Hobart Class ships and future frigates will operate embarked helicopters and tactical unmanned systems as integral components of their combat systems		

Area	5 year	10 year	15 year
Maritime Surveillance and Response Aircraft Program	The existing AP-3C Orion aircraft are being replaced by the P-8A Poseidon aircraft to support maritime surveillance and response together with the MQ-4C Triton unmanned aircraft		
Maritime Tactical Unmanned Aircraft	Tactical unmanned ISR aircraft systems to be deployed from a range of ships. To improve the situational awareness of ships on operations, we will acquire a new tactical unmanned intelligence, surveillance, and reconnaissance aircraft system that will complement other sensors and systems by extending the area able to be held under surveillance		
Maritime Anti-Ship Missiles and Deployable Land-based Capability	New deployable land-based anti-ship missile systems from the mid-2020s. This new capability of engaging ships from land will enhance sea control and force protection for ADF deployments. It could also contribute to protecting vital offshore assets such as oil and natural gas platforms		
Offshore Patrol Vessel - Design and Construction	Focused on border security and resource protection. They will also be capable of more extended operations		
	Larger patrol vessels will be able to embark unmanned aerial, underwater and surface vehicles and operate larger sea boats		
Mine Countermeasures systems	Modernised mine countermeasures and an efficient combination of military and commercial hydrographic survey capabilities. Develop and evaluate remotely operated mine countermeasures and bathymetric collection systems to inform capability development. This could include the potential future option of a modular, mine countermeasures system that could be deployed from a range of non-specialist vessels		
Hydrographic Data Collection Capability	Oceanographic survey capabilities to deliver the required capacity... enhanced hydrographic capabilities from non-specialist vessels suitable for tasks including rapid environmental assessment in support of operations		
	Laser Airborne Depth Sounder could be replaced from around 2019... with a commensurate high-volume space and/or air-based bathymetry collection systems, and contracted ship-based, and remotely operated, underwater vehicle-based sensors		
Air Combat Capability - Fourth Squadron	The Super Hornet fleet has been extended beyond its initial bridging capability timeframe and is now planned to be replaced by around 2030. Its replacement could include either a fourth operational squadron of Joint Strike Fighters r possibly a yet to be developed unmanned combat aerial vehicle		
Tactical Air and Missile Defence	Future with a gun system capable of engaging a range of threats as the last line of defence against rocket and missile attacks		
Infantry - soldier systems	Indirect weapons - such as mortars		
Canberra Class Ship - Amphibious Integration	Semi-autonomous self-defence capabilities		
Special Operations - Enhancements and Development Program	Respond to high-risk threats in unpredictable and uncertain environments		
Combat, Construction and Support Engineer Capability (Bridging and Crossing)	Geospatial support - reconnaissance and analysis of terrain		
Armed Reconnaissance Helicopter Replacement	A future armed reconnaissance capability to replace the Tiger, which could include manned or unmanned systems or a combination of both, to be introduced from the mid-2020s		
Armed intelligence, surveillance, reconnaissance unmanned aircraft	Grow the ADF's existing capability through acquisition of an advanced armed, medium-altitude, long-endurance unmanned aircraft for an integrated and persistent intelligence, surveillance, reconnaissance and attack capability to support ADF and coalition forces A fully integrated armed, medium-altitude unmanned aircraft for an integrated and persistent intelligence, surveillance, reconnaissance and attack capability to support ADF and coalition forces A fully integrated armed, medium-altitude unmanned aircraft capability supported by intelligence analysts will facilitate the timely delivery of accurate information to commanders at all levels, providing superior situational awareness to inform decision-making. This system's intelligence, surveillance and reconnaissance capability will also enhance the ADF's counter-terrorism support capability overseas and could augment search and rescue, humanitarian assistance and disaster relief and coastal surveillance tasks The new armed, medium-altitude, long-endurance unmanned aircraft will require some enhancements to our command and control capabilities, along with facilities, including a ground control station and fixed and deployable launch and recovery elements		

Area	5 year	10 year	15 year
Land tactical intelligence, surveillance and reconnaissance	The systems that contribute to land tactical intelligence, surveillance, and reconnaissance in this context are ground-based sensors, small unmanned aircraft and joint integration to enable access to situational awareness. Ground-based sensing systems include laser range finders, weapons sights, thermal imaging and ground surveillance radar and some specialised surveillance systems employed with combat reconnaissance platforms. In addition to the in-service Shadow unmanned aircraft, new capabilities such as smaller, hand-launched systems will be introduced to complement ground-based sensing and provide tactical commanders with organic, responsive systems		
Deployable Land Networks and Command Systems	Enable the land force to communicate across the battlespace including within and between formations on the ground, with aircraft and ships, with headquarters and other agencies or partners. The capability includes... mobile elements... able to continue operating while moving around the battlespace		
Deployable Battlefield Logistics	Supply and distribution - the introduction into theatre and movement of stores such as ammunition, rations, and fuel transport - vehicles such as trucks, water transport, and handling equipment like forklifts Maintenance and recovery - maintenance of equipment and recovery of damaged equipment		
Riverine Patrol Craft	Deliver a fleet of lightly armed boats from around 2022 to allow operation in a wide range of estuarine environments		

Infrastructure Sector

	5 year	10 year	15 year
Mobility	Navigation on relatively less complex - reasonably flat surfaces With rigid links, bulky actuators, sensors and power sources Climbing robots, UAVs for bridge inspection, tower and underwater pile inspection robots, underwater diving robots	Navigation on complex 3D surfaces where general wheeled robots cannot navigate With biologically inspired robotics, advancement in materials and manufacturing technology for miniaturised sensors and actuators	Navigation on highly complex environments where humans can navigate. This may also include, swimming, flying With new paradigms - integrated actuator, sensor, soft links approach - like human body (with soft polymers, composite structures, 3D printing)
Dexterity	Grasping standard objects in highly engineered environments With rigid links, bulky actuators, sensors and power sources	Grasping more complex objects With advancement in materials and manufacturing technology for miniaturised sensors and actuators	Comparative dexterity, similar to human hands in handling objects With new paradigms - integrated actuator, sensor, soft links approach - like human hands (with soft polymers, composite structures, 3D printing)
Perception (highly impactful)	Perception in Autonomous cars etc., Currently mostly based on 2D representations, can do "where" things are, not very much "what" things are Bulky and power-hungry sensors, recognition of task relevant characteristics	Advanced machine learning, data fusion, parallel sensing to achieve 3D representations, semantics and object affordances, adaptation to changes for extended operation, miniaturised sensors, new sensing techniques which can work in harsh environments (grit blasting chamber, bad weather, fog, dust, day/night)	Highly advanced perception with massively parallel sensors (human skin), static and dynamic sensors networks, identifying new objects and adaptation, low cost, miniaturised, low power sensors, new sensing modalities, actuator-links integrated sensors
Human Robot Collaboration	Basic human intention recognition, safety, basic collaborations (helping grit blaster, exoskeletons, as force multipliers)	Advanced shared autonomy, help when needed, when to take over in specific tasks	Advanced interactions with complex user behaviours and actions, robots predicting contingencies and user error, taking actions on reducing user effort, varying level of autonomy as necessary while communicating with the user
Control and Path Planning	Real time algorithms for simple tasks - structured environments, simple multi robot operations	Realistic scenarios in structured environments. Working with greater uncertainty, incomplete, intermittent data, working in simple unstructured environments, constrained environments	Realistic tasks in unstructured environment

12 Conclusion

Robotics will advance economic productivity and quality of life when used appropriately. This document describes the current state of robotic technologies, their applications by key sectors of the Australian economy, and the choices of paths forward.

Image courtesy of QUT

Like any roadmap, it doesn't prescribe a destination, but it shows the starting points across industries and describes how to reach them. The impact of these technologies will depend on many factors, some of them still unknown.

The intersection of all technology with artificial intelligence, machine learning and the data collected through the exponential growth of sensors will find new problems and identify new opportunities.

How we respond to this, both as a nation and as a planet, will determine the outcomes. There are five categories of players who will influence these responses. This roadmap includes detailed recommendations to inform these responses, as listed in Chapter 1.

The priorities for each of the key groups of players can be summarised in this way:

Governments: Creating ethical legislation and flexible regulations and standards encouraging investment in robotics and automation, identifying and supporting the local robotics industry, clearing the pathway to commercialisation, supporting skills development, directly investing in research, establishing testbeds for robotic technologies and ensuring these are implemented in public sector functions;

Industry (both users of technology and the developers of new technology): Attracting and prioritising investment, building new business, recruiting for and managing workforce change and skills development, direct investment in research, application of new technologies to existing functions.

Education Providers: Building national capability, collaborating with end users, developing talent and providing easy access to opportunities to upskill.

Research Institutions: Forming clusters of excellence, identifying and managing research priorities, attracting investment, improving design thinking and pathways to commercialisation and encouraging interdisciplinary research.

The Australian Public: Awareness of change, building skills to benefit from technological change, developing workforce flexibility.

As in all major reforms, all of the successful players must find ways to co-operate if full advantage is to be taken of what is possible. This will involve give-and-take but, if managed properly, could see benefits spread across the community.

By describing what is possible and what is desirable, this roadmap aims to create the grounds for the necessary co-operation to allow robots to help unlock human potential, modernise the economy, and build national health, well-being, and sustainability.

13 | References

Child experimenting with coding using Code-A-Bot. Image courtesy of QUT

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14 | Appendices

Image courtesy of Reach Robotics

14.1 Challenges

One way to harness the robotic talent of Australia is to deploy it towards solving national challenges. Several Roadmap co-chairs developed challenges specific to industry sectors that could lead to step-changes in how technologies are applied in these sectors. These challenges could be used to fast-track the development of robotic technologies in Australia.

Challenge – Create Commercial Robot Businesses

Do you have an idea for a robot companion pet for the elderly, or robots that could save people from disaster, eliminate feral pests, or help redistribute coral spawn for the Great Barrier reef?

People have asked “Where are all the robots?” but maybe the most pertinent question is “Where are all the Australian robotics companies?”

What would be needed to achieve several Australian icon companies in robotics in the next five years?

The challenge will help entrepreneurs start up, incubate, venture fund and plan the scale-up of companies to realise their dream. It will also help Government to better understand the policy changes needed for the future to achieve “scale up” companies in Australia in robotics and autonomous systems.

The challenge will seek proposals from entrepreneurs who have great ideas for commercial robotics that they would like to pursue. It will provide an incubator environment with national and international experts to develop their ideas to the stage of business plans to be pitched to national investors and build business networks.

(Underground) Mining Disaster Response Challenge

Scenario:

In a remote part of Australia, an underground mine tunnel has collapsed, trapping miners inside.
No communication to the miners is possible, and there is no indication of the miners' condition. Due to the collapse the area has become inaccessible.

Part 0 (optional):

A robot autonomously drills a borehole to access the collapsed tunnel, while ensuring it is not compromising the structural integrity of the tunnel or the rest of the mine.

Part 1:

A relatively small borehole (dimensions TBD) freshly drilled is the only possible access. Participants need to deploy a robot through this hole (might be a UAV, a ground vehicle or both) to assess the situation:

- Map the area as completely and accurately as possible (compared to ground truth only available to the judges),
- Identify risks such as hazards from the environment. Or unstable areas (geotechnical risk)
- Locate all miners (being confident none have been missed, but the number of them is unknown a priori)
- Optional: Assess their medical status/conditions as much as possible (see other challenge on remote doctor, or remote health diagnosis)
- Communicate all this information to the base station

Notes:

- The area is large enough that the teams might need to setup some communication relays etc. (all autonomously)
- Robots may/will have to move some rocks/debris around to be able to reach victims and be able to assess their conditions
- Robots may also have to act on the infrastructure
- Variant: the robot could be already there? And get the people out?
- The structure could be modular: e.g, teams could solve just the remote health diagnosis part, or just the borehole drilling part

Part 2:

Robots need to get the people out

1-day Apprentice / Innovation / Multi-functional kit

Scenario

A serious incident has occurred in an isolated location and little situation information is available. The team is able to drop in a safe zone with transportable cases and a single on-site operator. The challenge is to perform a given task at a location distant from the safe zone.

Summary specifications

Limited (~10) job scenarios one or a combination, but not limited to

Building sites

Manufacturing/industrial sites

Defence scenarios (drug delivery)

Bush fire estimation

Cyclone survivor discovery

Unknown weather conditions

Limited (~10) situational/site scenarios (known, semi-structured, unstructured)

Semi-autonomous or remote control and fully autonomous scenarios (random and permanent dark spots)

Single person or robot assembly of system

Fly-in scenario: limited to packing case size but not the number of cases...some cases might be taken away on arrival (unsuccessful airdrop simulation)

Requirements

The teams will be required to assemble their system, assess the scenario, identify the issues and methods in which to perform the task. The team will be given 1 hour to assemble their system(s) and prepare for the mission. The team will be given 6 further hours to perform their task (including task modelling, simulation, rehearsals, learnings, refinements, modifications, etc)

Applicability of Challenge:

- First responder to disasters
- Military support/scenarios
- Rapid reconfiguration of functionality
- Coordination of man/machine
- Remote medical scenarios
- Remote access.

Part of the challenge could be to require teaming up with other groups and/or capabilities.

Biosecurity Challenge - Pests and native species management

1. Robotic identification and removal of feral animals (e.g., cats, pigs, cane toads, rabbits). Develop methods of identifying infestation (sound, visual, impact on environment/animals) and deliver sterilisation systems etc.
2. Control/behaviour of native animals, keep out of crops etc. Identifying overlap of animal territory and crop, providing safe incentive to move to non-farm location.
3. Provide guardian to protect vulnerable species (e.g., sugar glider/ Gilberts Potoroo). Development of “Robotic shepherds’.

Aged Care and Hospitals Challenge

Socially assistive robots in Hospitals and Aged Care

The challenge is to demonstrate a social robot entering a room in a hospital or aged care facility, identifying the roles and activities of the people present, and interacting appropriately with them. The robot will be able to enter an unfamiliar room, and understand whether the occupant is asleep, eating, reading, etc. making measurements of health signals, deliver companionship and encourage their patient to make healthy safe choices.

Australia spends $AU115b annually on health and 13% of our workforce is deployed in the healthcare sector, yet most aged care patients miss out on 88 minutes of necessary care every day [WI16]. 40% of people in care, especially those with varying degrees of dementia, receive no visitors [WY17] and our ageing population is growing, with 3.7m people over 65 currently in Australia. Social robots can provide a source of interaction, or can be used to check on human wellbeing and to encourage positive health outcomes. For example, they might assist in control of infectious diseases or to encourage patients to follow medical advice.

Social robots are an emerging and disruptive innovation and also one ideal to showcase robotic vision capabilities. Social robots are currently limited in their application because they do not move around, or navigate well, and have very limited understanding of their environment. A demonstrator showing a social robot seamlessly moving from room to room and making sensible decisions to solve the challenge of robots operating in unstructured environments and under uncertainty.

Remote Medical Access Challenge

In Australia, expenditure on healthcare represents just over 10% of the economy (by GDP [HE16]). Access to this is not uniform. In regional areas, for example, male life expectancy is 2.5 years less than in the city [ABC15].

While the over-arching challenge before us is to deliver better health outcomes to all, the immediate challenge is to facilitate better access to healthcare in a manner than transcends distance and delay. This will not only allow a patient to be treated more rapidly (before small issues become major complications), but also to allow professionals in the one area to help patients in another – which could be particularly helpful in the disaster's aftermath.

While virtual health and telemedicine ("Dr. Skype" [ABC16]) are already commercial, the challenge is to literally "reach out and touch someone". The challenge is to build and readily a "robot" that can work with the patient (and their partner) to touch the patient – ranging from perform a palpation, to taking a blood sample, to even performing CPR. It could be a kit (like a "super first aid kit") or a machine that is deployed on demand and it has to work with current power/network infrastructure found in a typical Australian home.

Urban City Challenge

More than 54% of the world population (almost 4 billion people) live in cities. This number is expected to grow to 6 billion people by 2045 [CO18].

Cities are like those who live in them, they are ageing! If not properly maintained, they are silent killers. It is not feasible to rely on demolishing and building new infrastructure as it comes with a huge price tag with monetary, social, legal and insurance consequences. The choice that we have is to find efficient and cost effective ways to inspect, assess and to perform timely intervention. The infrastructure issues can include, bridges, roads, buildings, towers, water pipes, sewer pipes to name a few.

This grand challenge is to address this silent killer problem by advanced robotics and automation solutions. A mock up city is to be created with many challenging infrastructure to exploit the triathlon of robotic challenges: air, ground and underwater navigation with multi-modal perception. The teams are to design robotic solutions to provide a comprehensive inspection report on the entire infrastructure – by using a single robot or a swarm of robots.

Natural Disasters Challenge - First Respondent

During a natural disaster, there is a role for the first respondent, to be able to survey the region, gather intelligence and offer initial support.

Challenge

- Survey
  - Locate people in the designated area
- Gather intelligence
  - Obtain environmental data
- Initial Support
  - Offer support for the people

The solution could be a combination of a drone with sensors to locate people, and gather basic environmental data (ie: temperature at the location in a bushfire; wind speed in a cyclone), an autonomous vehicle to travel to the location, and a robot to deliver basic support (ie: water & blanket in a bushfire,) and gather information (ie: person's name, where they are from, details of others in the area, vision

Variations

The concept can be adapted to other challenges, like terrorism, war zones, finding people lost in the outback

Agriculture Challenge "Daisybot"

The challenge is to demonstrate an unmanned dairy farm in operation.

The robot or robot team will maintain the farming operation and undertake appropriate actions, e.g., turn on the water to refill drinking troughs, supply the correct amount of feed to cattle, check fences, livestock health, control the entry and exit of cattle to the robotic milking stations, coordinate the pick-up of milk and any other tasks required to maintain the farm at standard production level while also looking for opportunities for improvement.

Australia's farming population is ageing and many people choose not to enter the industry. There are also high levels of mental health issues in rural Australia often attributed to the pressures of maintaining a labour intensive, isolated lifestyle. It is often difficult for farmers to have holidays because of the lack of availability of replacement care. Demonstrating a robot or robot team that can manage a farm in the farmer's absence will address two issues, the lack of people available to do the work and the necessity for farmers' to be on call 365 days per year.

Bushfire Challenge

Bushfires have accounted for over 800 deaths in Australia since 1851 and the total accumulated cost is estimated at $AU1.6 billion. Furthermore, Australia's climate has been trending toward more bushfire weather over the last 30 years.

First-responders are routinely exposed to dangerous hazards and unpredictable conditions, such as canopy fires, power lines, collapsing roofs, moving vehicles and even hazardous materials or exploding gas tanks.

Fighting bushfires involves highly communicative teams of people operating vehicles and equipment according to a general plan with tactical decisions made in real-time.

The challenge is to automate fire containment using a team of ground and/or air robots cooperating with fire fighting personnel to do one or more of, provide situational awareness, identify people trapped in houses, clear debris and brush to control fire spread, and apply direct fire suppression methods.

The robots should be able to participate as valued members in a firefighting team, autonomously planning and executing operations while being able to take commands from firefighter commanders and respond to dynamic changes in the situation in a risk-aware manner.

Tasks:

- Suppression
- Clearing
- Exploration and Assessment
- Phased Challenge
- Start with simulation

Challenges:

High winds

Heat

Sensing

Manipulation

Combined situational awareness from UAVs and ground robots

Multi-agent planning navigation and control

Risk aware planning

Human robot interaction

Natural Language Communication

Sensor fusion

Imagine Australia sending its robots around the world to help people fight fires [ABC172, ABC173]

Great Barrier Reef Challenge

The Great Barrier Reef is almost unarguably Australia's most significant World Heritage Listed entity. Its economic value has been conservatively estimated at around $6b per annum, but this figure is based only around its value as a tourist destination.

Monitoring and improving the health of the reef, because of its size, location, and diversity is crucial. A current threat is the significant loss of coral due to climate change, pests and weather (bleaching, COTS, cyclones) which has adversely impacted approximately 50% of the reef's entire coral cover. Researchers across Australia are embarking on an ambition plan to adaptively restore large areas of coral reef through harvesting, and transplanting technologies. However, the shear scale of the reef means that this is an impossible task without automation.

Coral transplanting is a technique whereby thumb-sized pieces of coral are "harvested" from health growths, nurtured to much larger healthy corals over a year or more, then "replanted".

This challenge is to create an underwater robot that can perform harvest and replanting of corals to upscale reef restoration. The challenge will involve a series of tasks:

1. Navigate to a reef (4 points)
2. Find a designated species of coral and capture images (and other sensory information) (4 points)
3. Capture a 3D model of an individual coral
4. Acquire thumb-sized piece
5. Return to base (4 points)
6. Identify/map an area for transplant
7. Prepare a specific site
8. "Plant" the coral

14.2 Defence Development Plan

The following table maps the key attributes from the Defence White Paper to the capability streams that are to follow.

Key Attributes	Defence Capability Streams
Decision-making Capability	• Intelligence, surveillance, reconnaissance, electronic warfare, space and cyber
Enabled, mobile and sustainable forces	• Key enablers • Air and sea lift
Potent and agile offensive response	• Maritime and anti-submarine warfare • Strike and air combat • Land combat and amphibious warfare

The following table breaks down capability streams by function, program, active development years and investment range, with a narrative specific to robotics, computer vision and trusted autonomous systems, and with reference to the relevant Integrated Investment Plan section.

Defence Capability Stream	Function	Program	Start (year)	Value ($B) Range (min, max)		Capability Sought (direct quotes from IIP)	Ref (IIP)
Intelligence, surveillance, reconnaissance, electronic warfare, space and cyber	ISR	High Altitude Unmanned ISR System (initial phase)	Scheduled for approval	0.1	0.1	New and enhanced unmanned intelligence, surveillance and reconnaissance capabilities (including the MQ-4C Triton unmanned aircraft system)	1.3
	ISR	High Altitude Unmanned ISR System	2017-2030	3	4	...long-endurance surveillance operations over the ocean. The Triton also enables persistent maritime patrol and other intelligence, surveillance and reconnaissance tasks over a broad area. Triton's operations will be closely coordinated with that of the Poseidon maritime surveillance and response aircraft.	1.12
	Intelligence	Intelligence Systems	2016-2031	2	3	Collecting and analysing intelligence, with a particular focus on strengthening intelligence capabilities in support of deployed forces (for example to support increased use of unmanned systems)	1.7
	ISR	ISR Information Integration and Optimisation	2016-2029	0.3	0.4	Processing, exploiting and disseminating the large volumes of data that will be generated by sophisticated platforms - such as unmanned intelligence, surveillance, and reconnaissance systems (including Triton)	1.7
	Intelligence	Intelligence Systems	2016-2031	2	3	Generating intelligence and mission data for pre-programming advanced platforms	1.7
	ISR	Intelligence Systems	2016-2031	2	3	Defence will develop systems, sensors and networks to deliver effective air and space situational awareness around Australia and in deployed locations. A new, more sophisticated command, control, communications, computer and intelligence system will also be required to be able to fuse information from multiple sources.	1.8
	Situation awareness	Common Operating Picture Capability Program	2017-2033	0.5	0.6	Success in all operations is dependent on providing tailored and near real-time situational awareness to commanders. In the operational sphere this is provided by generating a trusted common operating picture.	1.9
	Maritime geospatial data management systems	Digital Topological Systems Upgrade	Approved	0.087	0.087	Management of maritime military geospatial information and to support national tasking for surveys. ...increase the throughput of both national and military hydrographic information.	1.18
	Electronic warfare	Joint Electronic Warfare Integration Program	2016-2033	0.4	0.5	Force-level, electronic warfare capability, ...to achieve high levels of information fusion and comprehensive planning across the joint force and Defence intelligence agencies. ...improve the ADF's ability to control the electronic environment and where necessary, deny or degrade the electronic systems of adversaries.	1.19
	Long-range electronic warfare support	Long-range Electronic Warfare Support Aircraft	2017-2024	2	3	EW support aircraft acquisition	1.20
	Space	ISR Information Integration and Optimisation	2016-2029	0.3	0.4	space-based and ground-based intelligence, surveillance and reconnaissance systems; and ...command, control, communications and intelligence capabilities	1.21
	imagery	Satellite Imagery Capability	2023-2039	3	4	Increasing the capacity for imagery analysis	1.22
	cyber	Cyber Security Capability Improvement	2016-2025	0.3	0.4	enhanced cyber capabilities	1.25

Defence Capability Stream	Function	Program	Start (year)	Value ($B) Range (min, max)		Capability Sought (direct quotes from IIP)	Ref (IIP)
Key enablers	ranges - infrastructure investment & facilities	Airfield Capital Works-Multiple Bases	2018-2035	2	3	modifying the Defence estate footprint to accommodate our new high technology capabilities and larger platforms, and to ensure that we are appropriately placed to meet future strategic requirements. Over the next 50 years, this will involve developing new bases, wharves, airfields and training and weapons testing ranges. Training range upgrades will include a variety of estate infrastructure; communications and environmental controls to manage training activities sustainably; new instrumentation, targets and threat simulation.	2.10 2.21
		General Ranges and Testing Areas	2017-2027	1	2		
		Woomera Redevelopment	2018-2027	0.5	0.75		
		Tracking Ranges	2018-2025	0.3	0.4		
Air and sea lift	air lift & combat search/rescue	Long-range Combat Search and Rescue Aircraft	2023-2032	2	3	Defence will explore options for a long-range aero-medical evacuation and combat search and rescue aircraft to provide enhanced support to ADF operations, including operating with the amphibious ships	3.23
	self-protection	Replenishment Ships	Scheduled for approval	1	2	The new replenishment ships will be fitted with situational awareness and communications capabilities along with semi-autonomous point-defence against air and surface weapon threats and torpedo defences.	3.26
Maritime and Anti-Submarine Warfare (ASW)	ASW	Future Submarine Program - Design and Construction	2018-2057	50	50	The new submarines will have advanced communications systems to link with other Navy ships and aircraft to conduct anti-submarine warfare operations.	4.13
	ASuW	Future Frigate Program - Design and Construction	2017-2040	30	30	Upgrade self-protection systems and unmanned tactical intelligence, surveillance, and reconnaissance systems	4.21
	ASW	Future Frigate Program - Design and Construction	2017-2040	30	30	The future frigates will be required to conduct a range of missions, with a particular focus on anti-submarine warfare.	4.23
	AAW	Future Frigate Program - Design and Construction	2017-2040	30	30	The Hobart Class ships and future frigates will operate embarked helicopters and tactical unmanned systems as integral components of their combat systems.	4.24
	ISR, ASW, ASuW	Maritime Surveillance and Response Aircraft Program	2017-2027	1	2	The existing AP-3C Orion aircraft are being replaced by the P-8A Poseidon aircraft to support maritime surveillance and response together with the MQ-4C Triton unmanned aircraft.	4.28
						While the primary role of the maritime surveillance and response aircraft is intelligence, surveillance and reconnaissance in support of maritime operations, it can also undertake offensive operations against submarines and ships, and support search and rescue operations.	4.29
	ISR	Maritime Tactical Unmanned Aircraft	2018-2030	0.5	0.75	Tactical unmanned ISR aircraft systems to be deployed from a range of ships. To improve the situational awareness of ships on operations, we will acquire a new tactical unmanned intelligence, surveillance and reconnaissance aircraft system that will complement other sensors and systems by extending the area able to be held under surveillance.	4.9 4.32
	Force Protection	Maritime Anti-Ship Missiles and Deployable Land-based Capability	2018-2037	4	5	New deployable land-based anti-ship missile system from the mid-2020s. This new capability to engage ships from land will enhance sea control and force protection for ADF deployments. It could also contribute to protecting vital offshore assets such as oil and natural gas platforms.	4.34

Defence Capability Stream	Function	Program	Start (year)	Value ($B) Range (min, max)		Capability Sought (direct quotes from IIP)	Ref (IIP)
Maritime and Anti-Submarine Warfare (ASW)	Resource Protection	Offshore Patrol Vessel - Design and Construction	2016-2033	3	4	Focused on border security and resource protection. They will also be capable of more extended operations.	4.36
	ISR	Offshore Patrol Vessel - Design and Construction	2016-2033	3	4	Larger patrol vessels will be able to embark unmanned aerial, underwater and surface vehicles and operate larger sea boats.	4.37
	ISR, MCM	Mine countermeasures systems	2016-2035	1	2	Modernised mine countermeasures and an efficient combination of military and commercial hydrographic survey capabilities. Develop and evaluate remotely operated mine countermeasures and bathymetric collection systems to inform capability development. This could include the potential future option of a modular, mine countermeasures system that could be deployed from a range of non-specialist vessels.	4.4 4.39
	ISR	Hydrographic Data Collection Capability	2016-2026	1	2	Oceanographic survey capabilities to deliver the required capacity. ...enhanced hydrographic capabilities from non-specialist vessels suitable for tasks including rapid environmental assessment in support of operations.	4.40
	ISR	Hydrographic Data Collection Capability	2016-2026	1	2	Laser Airborne Depth Sounder could be replaced from around 2019. ...with a commensurate high volume space and/or air-based bathymetry collection system, and contracted ship-based, and remotely-operated, underwater vehicle-based sensors.	4.41
Strike and Air Combat	Multi-role UCAV	Air Combat Capability - Fourth Squadron	2025-2031	6	7	The Super Hornet fleet has been extended beyond its initial bridging capability timeframe and is now planned to be replaced by around 2030. Its replacement could include either a fourth operational squadron of Joint Strike Fighters or possibly a yet to be developed unmanned combat aerial vehicle.	5.11
	Self protection/ counter artillery	Tactical Air and Missile Defence	2016-2024	1	2	Future with a gun system capable of engaging a range of threats as the last line of defence against rocket and missile attacks.	5.28
Land Combat and Amphibious Warfare	Combat	Infantry - soldier systems	2016-2029	2	3	Indirect weapons - such as mortars.	6.12
	Force protection	Canberra Class Ship - Amphibious Integration	2019-2025	0.5	0.75	Semi-autonomous self-defence capabilities.	6.19
	Various	Special Operations - Enhancements and Development Program	2016-2038	2	3	Respond to high-risk threats in unpredictable and uncertain environments.	6.21
	ISR	Combat, Construction and Support Engineer Capability (Bridging and Crossing)	2018-2031	1	2	Geospatial support - reconnaissance and analysis of terrain	6.28
	ISR, EW, combat, force protection	Armed Reconnaissance Helicopter Replacement	2021-2030	5	6	A future armed reconnaissance capability to replace the Tiger, which could include manned or unmanned systems or a combination of both, to be introduced from the mid-2020s.	6.32

Defence Capability Stream	Function	Program	Start (year)	Value ($B) Range (min, max)		Capability Sought (direct quotes from IIP)	Ref (IIP)
Land Combat and Amphibious Warfare	ISR, combat	Armed intelligence, surveillance, reconnaissance unmanned aircraft	2018-2038	1	2	Grow the ADF's existing capability through acquisition of an advanced armed, medium-altitude, long-endurance unmanned aircraft for an integrated and persistent intelligence, surveillance, reconnaissance and attack capability to support ADF and coalition forces. A fully integrated armed, medium-altitude unmanned aircraft capability supported by intelligence analysts will facilitate the timely delivery of accurate information to commanders at all levels, providing superior situational awareness to inform decision-making. This system's intelligence, surveillance and reconnaissance capability will also enhance the ADF's counter-terrorism support capability overseas and could augment search and rescue, humanitarian assistance and disaster relief and coastal surveillance tasks. The new armed, medium-altitude, long-endurance unmanned aircraft will require some enhancements to our command and control capabilities, along with facilities, including a ground control station and fixed and deployable launch and recovery elements.	6.6 6.33 6.34 6.35
	Force protection, situation awareness	Land tactical intelligence, surveillance and reconnaissance	2021-2032	3	4	The systems that contribute to land tactical intelligence, surveillance and reconnaissance in this context are ground-based sensors, small unmanned aircraft and joint integration to enable access to situational awareness. Ground-based sensing systems include laser range finders, weapons sights, thermal imaging and ground surveillance radar and some specialised surveillance systems employed with combat reconnaissance platforms. In addition to the in-service Shadow unmanned aircraft, new capabilities such as smaller hand-launched systems will be introduced to complement ground-based sensing and provide tactical commanders with organic, responsive systems.	6.37
	Survivable communications	Deployable Land Networks and Command Systems	2021-2032	3	4	Enable the land force to communicate across the battlespace including within and between formations on the ground, with aircraft and ships, with headquarters and other agencies or partners. The capability includes ...mobile elements ...able to continue operating while moving around the battlespace.	6.40
	Logistics	Deployable Battlefield Logistics	2020-2027	0.3	0.4	Supply and distribution - the introduction into theatre and movement of stores such as ammunition, rations and fuel. Transport - vehicles such as trucks, water transport, and handling equipment like forklifts. Maintenance and recovery - maintenance of equipment and recovery of damaged equipment.	6.46
	ISR, combat	Riverine Patrol Craft	2018-2028	0.2	0.3	Deliver a fleet of lightly armed boats from around 2022 to allow operations in a wide range of estuarine environments.	6.48

Robotics in Australia

Australia was the first country in the world to automate its ports.

Australian companies are using robots in manufacturing to reshore jobs back to Australia.

Australian minesites already deploy self-driving haulage vehicles that transport tonnes of material each day.

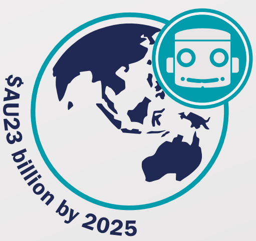
Australian scientists are developing flying and underwater robots to protect the Great Barrier Reef.

Australia won the Amazon Robotics Challenge in 2017, demonstrating our strength in robotic vision applied to logistics.

Australian group CanberraUAV are major contributors to the ArduPilot autopilot system used in UAVs all over the world.

The Opportunity:

$AU23 billion global market for robotics and autonomous systems by 2025.



Roadmap Recommendations

Industry

Ensure Australia's ongoing prosperity by stimulating formation of new hi-tech firms, encouraging global tech giants to invest in Australia, and reskilling Australian workers

Education

Equip all Australians with Industry 4.0 relevant skills

Government

Lead the region in catalysing robotics activity by setting ethical, legal and standards frameworks and adopting robotics in government services

R&D

Develop clusters of robotics activity, encourage VC investment, develop aspirational research challenges and encourage multidisciplinary problem-solving

Culture

Support an entrepreneurial culture around Australia's niche robotics capability and harness the nation's imagination through aspirational challenges that solve pressing needs for our nation

Australia's first Robotics Roadmap is a guide to how Australia can harness the benefits of a new robot economy. Building on Australia's strengths in robot talent and technologies in niche application areas, the roadmap acts as a guide to how Australia can support a vibrant robotics industry that supports automation across all sectors of the Australian economy.

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