6

Why accelerate the development and deployment of robots?

Robots are an iconic technology of the digital era, whose sophistication and diversity are growing rapidly. Autonomous vehicles, drones and automated vacuum cleaners are all widely known. Laboratory robots; collaborative industrial robots; ocean-going, space-faring, search-and-rescue robots; and robot surgeons, among many others, are less widely known. Progress in robotics is essential to make life easier, cleaner, healthier and richer. Robots have also aided the response to COVID-19, but their potential to help manage a range of crises is just beginning to be tapped. Robotics could play a major role in healthcare, increasing the resilience of health systems. Their role in combating future waves of the virus, or entirely new contagions, should be recognised and supported. Governments should scale up investment in research and development for robotics, support the wider diffusion of robots, and develop standards and innovation-friendly regulation. This chapter examines frontier developments in robotics, emerging applications across society and the diverse impacts of robots. Governments can use a number of tools to accelerate the deployment of socially valuable robot systems. They should act now.

Key findings

- **Robots can help to combat infectious disease and increase the resilience of health systems. In some applications, like elder care, better robots are likely to become essential. But good policy is needed to realise these aims**. Governments should: create a portfolio of targeted innovation prizes, which have features well-suited to advancing robotics; deploy tools such as regulatory sandboxes to help companies adapt to a particularly complex regulatory landscape; accelerate deployment of existing robot solutions in health systems, for instance by providing platforms that highlight leading-edge solutions; help develop and share useful data for training AI-enabled robots, especially in niche applications where data samples are small; and support the development of healthcare innovation hubs that bring together healthcare providers, research and academia, industry and regulators.
- **Despite often negative public perceptions, robots could make life richer, healthier, safer and easier, and governments can do much to accelerate these beneficial outcomes**. Governments should: invest in the R&D needed to solve widely identified research problems; help to broker and support public-private research partnerships, and support technology transfer; support robot uptake in firms, especially SMEs; deploy tools such as test-beds to help companies de-risk investments; facilitate SME participation in standards processes; and support digital connectivity, particularly 5G broadband.
- **Over time, advances in robotics could increase many aspects of societal resilience – from responding to the effects of natural disasters, to coping with population ageing**. To this end, governments should: encourage innovation in education and training initiatives; increase awareness in government of the current and potential uses of robotics – which will also help prepare for more effective uses of robots in future crises; advance research in systems for protecting and operating critical infrastructures and for crisis response; adopt a positive stance on the role of robots in advancing the public good; and, strengthen the security of cyber-physical systems.

Introduction

This chapter examines frontier developments in robotics and the applications of robots across the economy and society. It considers robots' diverse impacts, and the science and technology policies that can focus these impacts for maximum social benefit. It pays particular attention to the roles of robots in healthcare. These include laboratory robots, robot surgeons, robots that help reduce injuries to nurses (which exceed those of any other class of manual worker) and robots that assist people with autism spectrum disorder. Robots have so far played a minor role in the COVID-19 pandemic, and their uses in health systems are far below their potential. This reflects general unfamiliarity with potential robot applications, the high cost of leading-edge robot systems, institutional inertia and the incipient nature of some uses. Low wages, especially among care workers, also discourage investments in assistive robots. However, with suitable policies in place, robots could provide significant support in addressing future crises – including new contagions – while increasing the overall resilience of health systems and society.

The promise of robotics

Robots are an iconic technology of the digital era,[1] sitting at the centre of many topics in science and technology policy. Advances in many fields of science, digital technology and artificial intelligence (AI) are increasing the sophistication and diversity of robots. Their development and future impacts will be shaped by policies on basic and applied research and development (R&D), as well as taxation, public-private partnerships, technology diffusion, regulation and legal frameworks, technical standards, and digital connectivity and security. Indeed, some major recent advances in robotics trace directly to public policy, such as the challenge prizes run by the Defense Advanced Research Projects Agency (DARPA) in the United States.

The economic and social impact of robots is expected to increase greatly in coming years.[2] With the exception of surgical robots, exoskeletons and advanced prosthetics, and systems to aid rehabilitation, most robots used in healthcare today serve relatively simple functions, such as delivering medicines and transporting waste. Wider diffusion and more sophisticated applications will be spurred by advancing technologies. Among many current developments, cell-sized robot prototypes can traverse the body's circulatory system, gathering information and downloading it after a task is performed; using AI and cameras to precisely apply nasal swabs, a newly developed robot can improve sample quality and lower infection exposure for nurses; and robot surgeons are set to provide human surgeons with feedback during operations. If more lethal or contagious pathogens than COVID-19 arise in the future, new robot systems could confer greater resilience on society as a whole. They might, for example, operate essential services such as waste treatment, power generation and public transport, which in the current crisis have only functioned thanks to risk-exposed workers.

Robots also occupy a unique place in the public imagination. Humans react differently to objects in physical space than to objects on screens. Experiments show that people unconsciously treat robots as if they were human (Fussell et al., 2008[1]).[3] As robots come to possess more social attributes than current systems, how they are used, and how people interact with them, is set to change in possibly surprising ways. Autonomous vehicles, drones, vacuum cleaners and lawn mowers are all widely known. Less familiar systems include laboratory robots; collaborative industrial robots; ocean-going, space-faring, and search-and-rescue robots; and robot surgeons.

Robots also represent the most significant interface between AI and the physical world. Developments in both fields have been deeply intertwined. Advances in machine vision and AI were initially spurred by the goal of better robot navigation; in turn, robots served as platforms for demonstrating more capable AIs. Some consider that robots provide the best setting for tackling some crucial challenges of AI research. They argue that using AI in systems with a human-like form is more likely to allow research to find how to create AIs with human-like attributes, such as “common sense”. At the very least, the so-called “Moravec paradox” – that robots often easily do things that humans find difficult, and vice versa – points to fertile terrain for discovery. Beyond research, it is also through the actions of robots that many questions in AI governance will arise and require solutions.

Robots as a strategic technology

Some governments attribute strategic importance to robotics. Although national priorities vary, a common concern is the impact of robots on competitiveness. Because they are faster, stronger, more precise and consistent than workers, robots have vastly raised productivity in critical parts of the economy, such as the automotive industry. They will do so again in an expanding range of sectors and processes, as robotics advances.

Advanced robotics is also important to counteract sluggish labour productivity growth in many countries for the past decades. Progress in robotics creates global market opportunities, which some countries plan to supply. Accordingly, governments frequently voice concerns when leading robotics companies pass into foreign ownership, as openly expressed in a number of national robot strategies (e.g. in Japan and the United States). As Box 6.1 shows, the People’s Republic of China is perhaps pre-eminent in terms of its strategic ambition in robotics.

Box 6.1. China’s development of a world-class robotics sector

No country is more active than China in developing an advanced robotics industry. Among other measures, China has acquired established robotics companies abroad, with support from central and provincial governments. The acquisitions have often been esteemed German and Italian robot manufacturers and integrators (i.e. companies that assist others to deploy robots). Examples include Germany’s robot integrator KraussMaffei, acquired in 2016 by a consortium led by the state-owned China National Chemical Corporation, and the jewel in the crown of European robot manufacturers, Germany’s Kuka AG, acquired in 2016 by China’s home appliance maker Midea.

China’s National Development Plan for Robotics (2016-20) announced its goal of developing a domestic industrial robot sector technically equal to the leading international competitors, which would supply at least 45% of the domestic market, and expand production of robots for seniors and medical care.

A national robotics roadmap was prepared after the launch of the strategic manufacturing plan “Made in China 2025”, issued in 2015. It identifies key technologies and components for industrial and service robots; opportunities to strengthen co-ordination between research and application; and initiatives for standardisation, quality assessment and certification. In November 2016, China announced its first robot-certification scheme, and issued the first certificates. China has also become a leader in patent filings for robotics.

Compared to countries such as Japan and Korea, robot density in China is low. However, Chinese regions that lead in manufacturing mechanical and electrical products, such as the southeast provinces, have initiated large-scale “Robots Replace Humans” programmes. Many provincial governments also subsidise firms that buy robots.

Emerging robot capabilities

Robots are not a single technology. Rather, they embody combinations of technologies, some of which are developing faster than others. Some of the building blocks of progress in robotics include advances in sensors, such as laser systems with improved range and angle resolution; control systems, such as cloud-based robots and predictive control; actuators, such as dexterous grippers; and materials science, e.g. to help robots harvest energy from their surroundings.

Progress in manufacturing technology, such as laser sintering (a form of 3D printing) and micro-scale moulding, lowers costs and helps build more capabilities into robots. The proliferation of robot types and capacities also come from advances in basic and applied science. Neuroscience, biomechanics, materials science, computer science and mathematics are just some of the relevant fields. New fields, such as computational psychiatry, will also contribute to progress in robotics. Robots have even become tools of basic science in their own right, for instance, by helping to understand better how humans walk.

This section reviews some emerging developments in robotics. Many are recent research achievements or prototypes, which could be some years from commercial use. Others are just beginning to find commercial applications. These developments suggest the nature of future possibilities.

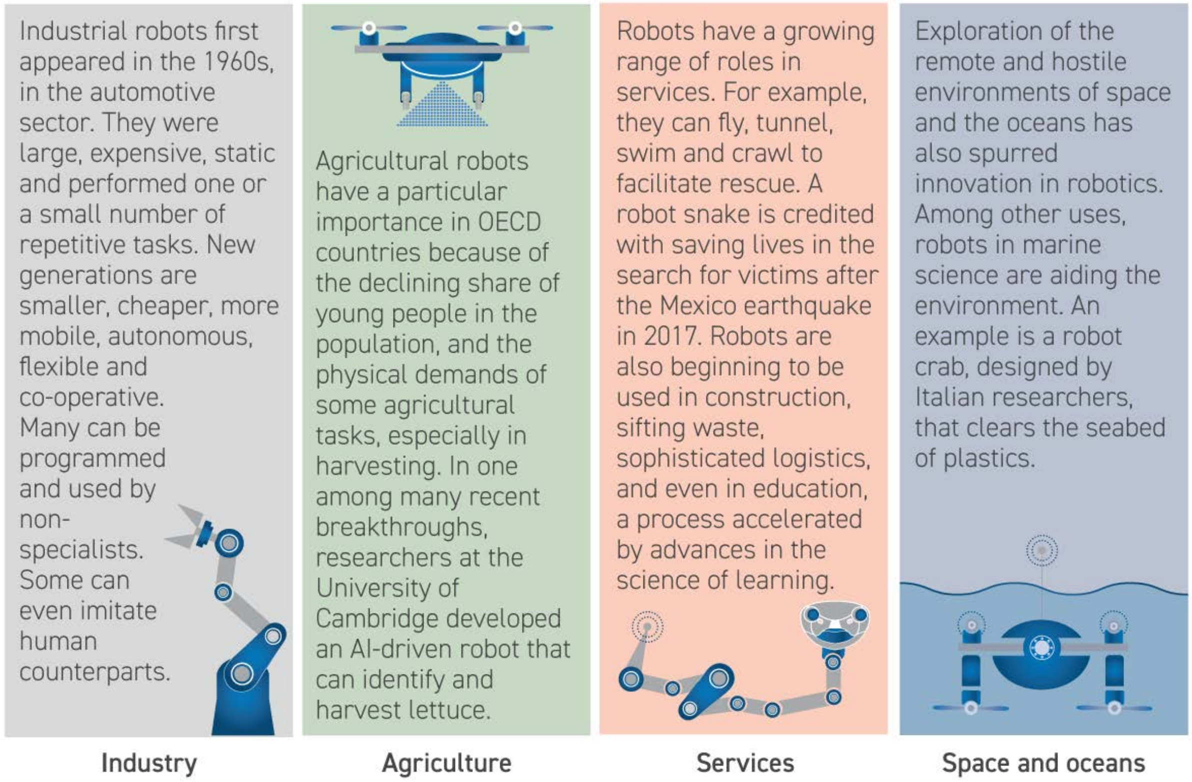
Soft robotics: until recently, robots were physically rigid. Advances in fields such as materials science, actuators (forms of motor that converts energy into work), sensing and modelling have produced an emerging class of deformable and compliant robots that can squeeze, stretch, climb, shape-change and self-heal (Terryn et al., 2017[2]). Research in soft robotics aims to further develop abilities to grow, evolve, self-heal and biodegrade (Laschi, Mazzolai and Cianchetti, 2016[3]). Many developments in soft robotics are inspired by examples from the natural world.

Miniaturisation: together with advanced fabrication, Moore’s Law has helped engineers build ever-smaller robots.[4] In one of the most striking examples of miniaturisation to date, researchers at MIT recently built self-powered robots the size of a human cell. These robots are able to follow pre-programmed instructions, as well as sense, record and store information about their environment, gathering data that can be downloaded once a task is completed. While these robots are at the laboratory stage, potential uses exist in medical diagnostics and industry (Chandler, 2018[4]).

Increased intelligence: in the late 1990s, most robots possessed only insect-grade intelligence. Today, progress in AI, particularly machine learning, is revolutionising robotics. Combining AI with other innovations is conferring a myriad of new capabilities on robots, including greater autonomy. Major developments include better vision, learning transfer between robots and across robot swarms, learning in virtual environments, learning by doing, learning by curiosity, emotional awareness, better object manipulation and more collaborative robots (“cobots”).

Thanks to these growing capabilities, robots have current and potential applications in many areas of the economy (Figure 6.1).

Figure 6.1. Current and emerging robot applications span the economy



Industrial robots first appeared in the 1960s, in the automotive sector. They were large, expensive, static and performed one or a small number of repetitive tasks. New generations are smaller, cheaper, more mobile, autonomous, flexible and co-operative. Many can be programmed and used by non-specialists. Some can even imitate human counterparts.

Agricultural robots have a particular importance in OECD countries because of the declining share of young people in the population, and the physical demands of some agricultural tasks, especially in harvesting. In one among many recent breakthroughs, researchers at the University of Cambridge developed an AI-driven robot that can identify and harvest lettuce.

Robots have a growing range of roles in services. For example, they can fly, tunnel, swim and crawl to facilitate rescue. A robot snake is credited with saving lives in the search for victims after the Mexico earthquake in 2017. Robots are also beginning to be used in construction, sifting waste, sophisticated logistics, and even in education, a process accelerated by advances in the science of learning.

Exploration of the remote and hostile environments of space and the oceans has also spurred innovation in robotics. Among other uses, robots in marine science are aiding the environment. An example is a robot crab, designed by Italian researchers, that clears the seabed of plastics.

Sources: Haridy (2020[5]), "Machine Learning helps robot harvest lettuce for the first time", https://newatlas.com/robot-harvest-lettuce-vegetable-machine-learning-agriculture/60465/; Hutson (2017[6]), "Searching for survivors of the Mexico earthquake – with snake robots", https://www.sciencemag.org/news/2017/10/searching-survivors-mexico-earthquake-snake-robots; Ridden (2019[7]). "Plastic hunting robot crab takes its first dive", https://newatlas.com/silver-2-plastic-hunting-robot-crab/60097/

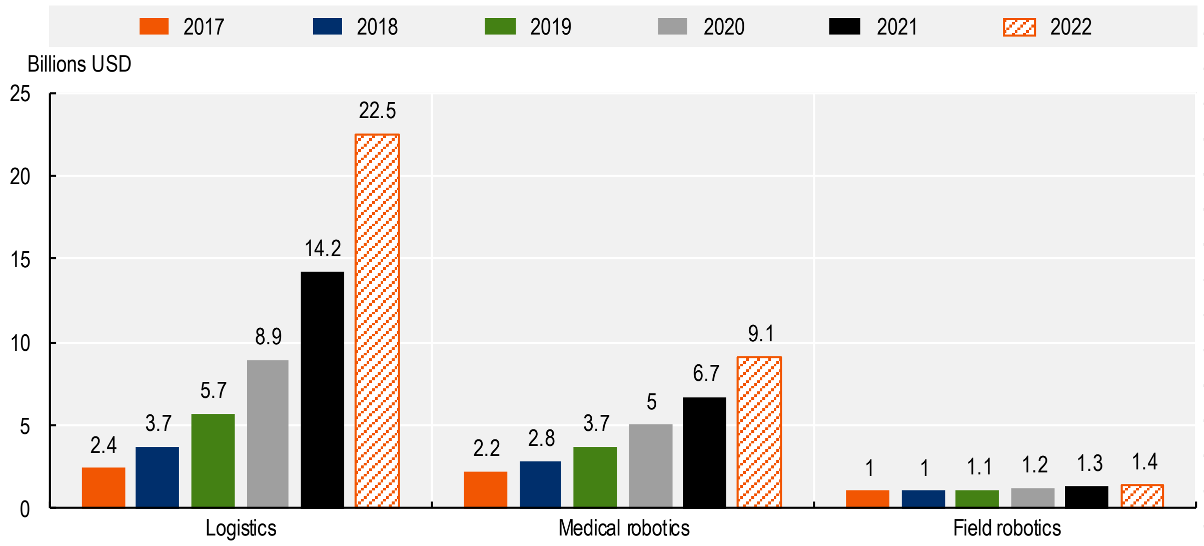
Robots and jobs

Machine-driven substitution of workers is the subject of a large and growing literature, which this chapter does not aim to assess. However, industrial robots – especially the more recent models – differ in important ways from other types of automation, such as computer numerical control systems. For instance, they can be reprogrammed and flexibly applied to diverse tasks. Atkinson (2019[8]) reviews the robot-specific research. He shows that many firm-level studies find only limited job destruction or loss of total hours worked attributable to robots. In some cases, significant increases in manufacturing employment are seen a few years after adoption, often because of increased product demand. When industrial robots are shown to have reduced the hours worked, this has applied primarily to low-skilled workers; the declines are less pronounced for workers with mid-level skills. Although little studied to date, robots in the health sector are unlikely to have major impacts on job numbers as they mainly augment the capabilities of health workers (e.g. by lowering injury risk), rather than substituting for them. The opportunity to work with robots might in fact make some health-sector jobs more attractive, especially among the younger population.

Current and emerging uses of robots in healthcare

This chapter pays particular attention to robots in healthcare, given the possible role of robots in ameliorating the current COVID-19 crisis or future outbreaks of infectious diseases. In 2018, global sales of medical robots reached USD 2.8 billion. Some 5 100 units were sold in 2018, a number that is forecast to rise to 19 700 units by 2022 (IFR, 2019[9]) (Figure 6.2). Robots have many roles in healthcare; some are well established, but others are just beginning to appear in health systems. Applications range from aiding laboratory research, surgery and physical rehabilitation, to delivering medicines, transporting waste, combating loneliness, and improving medical diagnostics and treatments. Moreover, by improving working conditions in many occupations outside of healthcare, robots can alleviate expensive medical problems, benefitting firms and society more broadly.

Figure 6.2. Global purchases and main applications of service robots for professional use, 2017-22



Note: Field robots are non-factory robots designed for unstructured and often dynamic environments on land, sea and air, e.g. in mining, agriculture and underwater exploration.
Source: IFR (2019[9]), World Robotics 2019, https://ifr.org (accessed September 2019).

StatLink https://doi.org/10.1787/888934223536

COVID-19 has focused attention on how robots might reduce infection risks and stress among frontline health workers. As the crisis escalated, leading roboticists wrote an editorial in *Science Robotics*, a journal of the American Association for the Advancement of Science, stressing the potential of robots to combat the COVID-19 pandemic and infectious diseases more generally. To enhance preparedness, the authors called on governments to target and fund multidisciplinary basic and applied science, bringing together scientists, engineers and infectious disease professionals to work in partnership with government agencies and industry (Yang et al., 2020[10]).

With a few notable exceptions, (e.g. surgical robots), most uses of robots in healthcare today are relatively simple (e.g. drones for delivering medicines). As technologies advance, broader diffusion and more sophisticated applications are set to emerge, potentially increasing the resilience of health systems to new diseases. Over a longer period, comprehensive use of robot systems in elderly care is likely to become essential as the global population ages.

The remainder of this section considers the main categories of robot use in healthcare, with an emphasis on COVID-19. It also highlights some of the existing challenges to progress.

Robots in the laboratory

Laboratory automation is increasingly essential in many fields of science. Robots have helped automate routine laboratory processes for some years. Today, AI-driven laboratory robots can go beyond this mechanical task, executing closed-loop cycles of testing, hypothesis generation and renewed testing. Hundreds of hypotheses can be generated and tested in parallel. Such systems can also automatically record experimental procedures and associated metadata, which are important for reproducing research. In 2009, “Adam”, a laboratory robot developed by researchers at the universities of Aberystwyth and Cambridge in the United Kingdom, became the first such system to make an independent scientific discovery (concerning the genomics of baker’s yeast). Such robots can greatly speed experimentation, e.g. by screening and testing thousands of pharmaceutical compounds per day. As well as contributing to research, laboratory robots have also helped accelerate testing for COVID-19. For example, the VIB-VUB Centre for Structural Biology in Brussels uses its KingFisher robot to perform an additional 1 000 tests per day (euRobotics, 2020[11]). On the downside, laboratory robots remain costly and difficult to use.

However, adding AI to robots is not enough to improve the entire process of laboratory testing, especially in a crisis. Greater flexibility in handling, combining vision, gripping tools, and grip sensing, is also needed. During the first wave of the COVID-19 pandemic, laboratories faced shortages of test kits, and medical practitioners sent patient samples in many types of containers, with no standardised shapes and sizes. Human dexterity was needed to handle, open and extract the samples for testing. Most automated processes could not have dealt with this variance. Some robot systems could have done this, but were not used owing to the high costs of installation, programming and peripheral sensing. This manipulation challenge is a generic problem in robotics and requires further progress.

Robots in patient screening and initial care

In the second quarter of 2020, during the first COVID-19 peak, patients arriving at Antwerp’s University Hospital in Belgium were met by a robot that checked whether they were wearing masks, ensured these were properly positioned, screened for signs of fever and admitted those who could safely attend an appointment. The system, which speaks 35 languages, reduces crowding among waiting patients and lowers infection risk for staff (Parrock, 2020[12]).

Nasal and throat swabs are currently the standard for initial diagnostic testing for COVID-19. This requires qualified personnel, whose time is scarce when demand is high. In response, researchers have developed a fully automated robot that performs the delicate task of taking coronavirus swabs. Using AI and cameras to apply the swab precisely, it can improve sample quality and lower infection exposure for nurses (Filks and Skydsgaard, 2020[13]).

Researchers aim to achieve greater functionality for remote interaction with patients, such as through high-resolution cameras to measure pulse rate from the skin. Since drawing blood carries a high risk of exposure for medical staff, engineers are examining ultrasound imaging of veins for robotic venepuncture (Yang et al., 2018[14]). Assisting emergency medical technicians (EMTs) is even more challenging. EMTs perform complex cognitive and physical tasks, such as rapid assessment of a patient’s condition or inserting breathing tubes. If AI-enabled robots could assist EMTs, more attention might shift to the most urgent procedures.

Robot surgeons

The first documented use of a robot assisting surgeons occurred in 1985, when a robot arm helped to biopsy neurological tissue. Surgical robots are now categorised under three broad types: active systems that perform pre-programmed tasks under human supervision; semi-active systems, where a surgeon complements an active system; and systems under a surgeon’s sole control which precisely reproduce the surgeon's hand movements (Lane, 2018[15]). Most experts consider fully autonomous robot surgeons a distant prospect.

Several thousand prostate operations using minimally invasive robots are performed every year in the United States. The robotic procedures reportedly lead to shorter admission periods, fewer infections and faster recovery (CCC/CRA, 2009[16]). Robotic kidney transplantation is increasing at transplant centres around the world. The first surgery with the patient and the surgeon in different countries took place in 2001. Some systems allow the surgeon a physical sensation of what the robot touches. Non-invasive abdominal surgery, kidney surgery, orthopaedic surgery and neurosurgery are now all part of the medical robotics market.

To complement the work of surgeons, robots can be designed with more limbs, digits and freedom of movement than a human. They do not tire or get distracted, and they can operate with extreme and consistent accuracy. A new system, the Microsure Musa, developed for super-microsurgery, can even compensate for human traits such as hand tremor. Thus, robots may help to lower the frequency of preventable surgical errors.

The main challenge in surgical robotics is achieving greater autonomy. The predictability in which industrial robots work is not available to surgical robots. Vastly greater variation and uncertainty exist in patients' bodies and surgical needs, and in the actual implementation of surgical procedures. Beyond traditional but limited clinical decision-support tools – such as decision trees – engineers are attempting to integrate the most synergistic features of human and machine intelligence, with humans and machines collaborating to enhance *in situ* surgical decision-making (Loftus et al., 2020[17]). Among many other topics, research is examining how robot surgeons might learn from the human surgeon, follow the surgeon's gaze, share control of some steps in an operation, and even record and provide feedback to the surgeon.

Another research challenge concerns the clinical efficacy and secondary outcomes of robotic surgery. Claims of efficacy in some procedures are contested. In some circumstances, the need to reconfigure the robot's tools during surgery could lengthen the time spent by the patient under anaesthesia. Cost-benefit analyses on the use of surgical robots might also miss some variables relevant to a crisis like COVID-19, such as the value of treating patients with greater than usual speed when hospital beds are scarce.

Robotic exoskeletons

An exoskeleton is a hard or soft structure that fits around one or more body parts, affording physical support. Wearable exoskeletons, for instance, can reduce a surgeon's fatigue during long operations. Passive exoskeletons, which only give static support, are now complemented by active systems that amplify some aspect(s) of the wearer's abilities.

One use of exoskeletons is physical rehabilitation. Systems can interpret the kinetic properties of a person's movements, helping patients such as stroke victims perform therapeutic movements precisely. Some exoskeletons give performance and motivational feedback, adjusting the difficulty of therapeutic tasks. A notable recent breakthrough comes from the French Alternative Energies and Atomic Commission, which developed a brain-controlled exoskeleton that allows a subject with four paralysed limbs to walk, achieving control over arms and legs. This achievement stems partly from progress in "neurobotics", the study of the brain in conjunction with technology.

Robots in the supply chain

In a growing number of Chinese towns and cities, drones are being used to share information (over loudspeakers), spray disinfectant, deliver medical supplies and even take people's temperatures (using thermal imaging). Drones routinely fly to the centre for disease control in Xinchang County, traversing China's first anti-epidemic "urban air transport channel" (Cozzens, 2020[18]). Such systems could also help deliver medical supplies to remote regions. For instance, companies in the United Kingdom have partnered to deliver COVID-19 tests to a remote island off the Scottish coast. Drones could also be helpful in developing countries, where road coverage may be limited and/or roads are poorly maintained.

Autonomous hospital-delivery robots

Robots are freeing the time of hospital staff by autonomously transporting hazardous materials, laboratory specimens, medications and meals for persons in quarantine. Many hospital robots can respond to requests placed through touchscreen interfaces, performing tasks and returning independently to charging points. Robots are also being designed to perform tasks in hospital kitchens and pantries.

Robot disinfectors

Hospital-acquired (nosocomial) infections are a leading cause of death in OECD countries, also imposing major costs on health systems. Short-wave highly energetic ultra-violet (UV) light can destroy genetic material in bacteria and viruses. Robots using high-intensity UV light can disinfect frequently touched areas, creating more sanitary conditions, lowering the workload for hospital staff and reducing risk exposure compared to manual disinfection. In response to COVID-19, Bucharest Robots deployed a UV-based robot that disinfected a hospital space spanning 7 500 m^2 in just a few hours (euRobotics, 2020[11]). Robotic disinfection systems have existed for many years but are not yet widely deployed, partly because of their limited ability to navigate in uncertain environments, as well as detect and reach shadow areas. Progress in such areas is needed.

Micro-robots for drug delivery

There exist two main classes of medical micro-robots – man-made and bio-hybrid. In the man-made category, robots are just emerging that sense and record information about micro-scale environments in the body, and move under their own power. Bio-hybrid systems, for their part, integrate biological and man-made components (such as nano-tubes, nano-particles and micro-machines). The biological components have functionalities that complement the man-made parts. Bacteria, for example, can self-propel in ways that most man-made systems cannot, leading researchers to examine if bacteria swarms can be used to push man-made drug delivery devices. Bacterial micro-robots have been the main object of research in the field of bio-hybrid systems, and have begun to be used more widely in drug delivery.

Research priorities for micro-robotic drug delivery include developing biodegradable and non-toxic systems capable of high autonomy and intelligent targeting, catheter-based robot delivery near disease targets, monitoring and controlling of swarms of micro-robots, and therapies best suited for robotic delivery (Yang et al., 2018[14]).

Robots supporting mental health

Research has recently begun on robots and mental health. Loneliness is a growing problem in OECD countries, and the isolation felt by many during the COVID-19 lockdowns has itself created mental stress. Robot systems can diminish loneliness in some people. Research has shown that a robot speaking encouraging phrases can positively affect a subject’s mood and game-playing performance. Interaction with the PARO therapeutic robot – which looks like a seal – has improved the mood of dementia patients and reduced feelings of isolation (Robinson, Broadbent and MacDonald, 2015[19]).

Autism spectrum disorder (ASD), which affects around 1 in 160 children worldwide, is another target for research. For example, to study if they could improve social skills in children with ASD, (Scassellati et al., 2018[20]) took robots out of the laboratory setting, where experiments are usually brief, and into homes and longer-term interactions. The robots helped to teach social skills such as taking turns, seeing the perspective of others and making eye contact. The research showed that personalized therapeutic robotics could eventually aid parents and therapists and provide children with ASD with more comprehensive care.

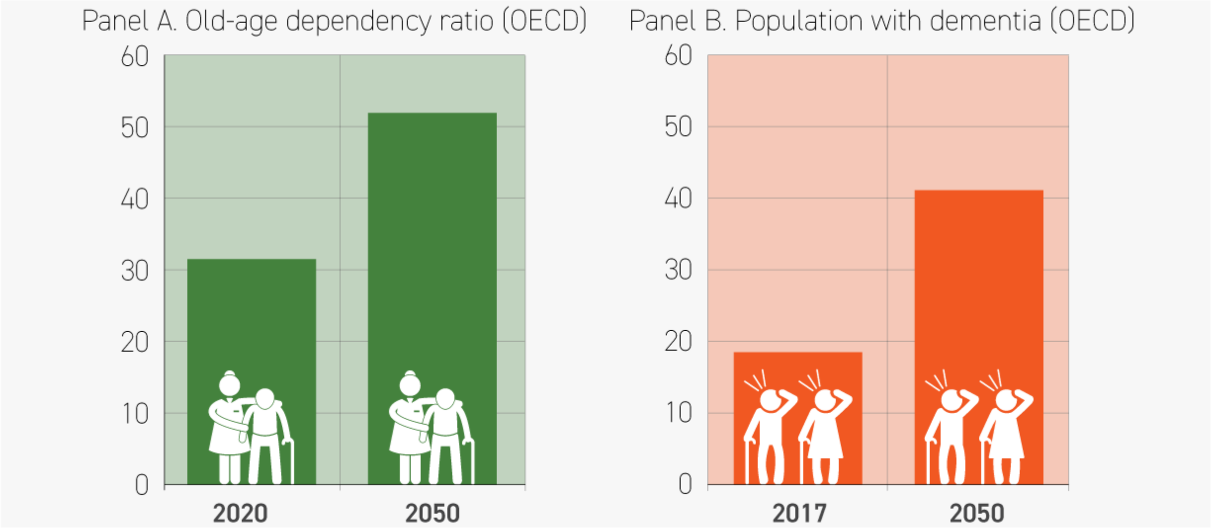
Research is needed to develop more effective social robots. Such robots would build and maintain multidimensional models of human counterparts, understanding more of what they know, believe, feel and intend, while also accounting for context (Yang et al., 2018[14]). Contributing to this goal, Canada's National Research Council aims to help develop robots that process emotional responses.

Robots in elderly care and nursing homes

Population ageing in OECD countries and the ensuing prospect of widespread age-related physical, cognitive and socio-emotional decline (Figure 6.3) have spurred interest in how robots might help. With the world's oldest population, Japan is the global leader in robotics for elder care. One priority is how robots might complement the caregiver workforce, which is projected to grow significantly. The United States alone could need 2.5 million additional long-term care workers by 2030 (Bryant, 2017[21]). Various companies make social robots for elder care. These perform basic non-medical tasks, such as reminding the elderly to take medications, while also providing cognitive stimulation and a form of companionship. A related development is systems that connect users to navigable mobile robots, allowing them to experience sights and sounds in the robot's environment. These systems, which provide telepresence, are proliferating thanks to their simplicity and wide range of uses, including helping convalescent or immobile patients interact with family members at home, young patients attend school and persons of any age visit museums. One drawback to such robots is their cost. Hence, some companies have developed simpler designs that interface with the user's own tablet computer.

Elder care raises particular challenges for robot systems. For instance, older people – especially the most impaired – interact with caregivers differently from younger adults. Robotic care for individuals requires better understanding and modelling of verbal and non-verbal communication between the elderly, human carers and robot systems. More research is also required on the outcomes of older persons' interactions with social robots. Another need is lowering costs while ensuring safety.

Figure 6.3. Increasing old-age dependency and growing share of the population with dementia



Note: In Panel A, the old-age dependency ratio is defined as the number of individuals older than 65 years for every 100 persons of working age (20 to 64 years).

Sources: OECD (2019[22]), *Pensions at a Glance 2019: OECD and G20 Indicators*, OECD Publishing, Paris, https://doi.org/10.1787/b6d3dcfc-en (Panel A); OECD (2018[23]), "Care Needed: Improving the Lives of People with Dementia", *OECD Health Policy Studies*, OECD Publishing, Paris, http://dx.doi.org/10.1787/9789264085107-en (Panel B).

Robots and public policy

This section examines selected public policies that are relevant to the development of robotics, and the use of robots in firms and public services (the full range of policies includes topics such as connectivity and cybersecurity, not covered here) (Nolan, forthcoming[24]). The section also considers options for governments to influence the direction of future developments in order to meet short- and long-term societal challenges. Several governments have national robotics strategies in place (Box 6.2).

Box 6.2. Examples of national robotics strategies

Led by China, Japan, Germany, Korea and the United States, all robotics-related strategies aim to increase applications in industry, with differences however in funding priorities.

Japan was the world's leading industrial robot manufacturer in 2018, delivering 52% of the global supply. Under the New Robot Strategy, the country increased its R&D budget for robotics to USD 351 million in 2019, with the aim of making Japan the world leader in robotics innovation.

Korea's Intelligent Robot Development and Supply Promotion Act focuses on the role of robots in advanced manufacturing. The country's 2019 Basic Plan for Intelligent Robots proposed targeting public and private support at promising areas of robot development and use.

The European Union's Horizon 2020 programme supports many fields of robotics R&D, including manufacturing, healthcare, transportation, agriculture and consumer technologies. The European Commission committed EUR 780 million (euros) over seven years, beginning in 2014. The European Union's 2018-2020 Work Programme includes funding for robotics in industry and core technologies such as AI and cognition, cognitive mechatronics, socially co-operative human-robot interaction, and model-based design and configuration tools.

The United Kingdom's 2020 Robotics and Autonomous Systems programme is a national strategy to capture value across the industrial and innovation system through co-ordinated development of assets, challenges, clusters and skills.[5]

Although the United States does not possess an overall industrial or automation policy, there have been efforts to develop national strategies for robotics, AI, drones and autonomous vehicles. The National Robotics Initiative (NRI) supports robotics R&D. NRI-2.0 focuses on cobots and encourages collaboration between academia, industry, non-profits and other organisations, in the same vein as the Advanced Robots for Manufacturing Institute and regional robotics clusters. At USD 35 million, the NRI budget for 2019 was relatively small.

Source: Demaitre (2020[25]), "Robotics R&D still driven by government initiatives worldwide, says IFR report", https://www.therobotreport.com/robotics-rnd-still-driven-government-support-worldwide-says-ifr/.

Interdisciplinarity in robotics research

Addressing research challenges in robotics requires interdisciplinary collaborations, for example among physicists, mathematicians, materials scientists, engineers and biologists, in both public and private-sector organisations. Policy needs to ensure robotics is not hindered by obstacles to cross-disciplinary research, such as hiring, promotion and tenure policies, and by funding systems favouring traditional disciplines (see Chapter 3). Ethical, legal and social implications of robotics, which are often hard to foresee, also need to be a part of research.

Robotics research needs public-private partnerships

The complexity of some research challenges may exceed the research capacities of even the largest individual institutions, necessitating a spectrum of public-private research partnerships (see Chapter 5). In terms of resources and focus, such partnerships can help create synergies between basic and applied research. Partnerships should also involve engineers, who usually play a major role in finding the best ways to implement robotic solutions. The Advanced Robotics for Manufacturing Institute (ARM) in the United States is one example of a research partnership model. ARM aims to create and deploy robotic technology by integrating industry practices and institutional knowledge across many disciplines, from materials science to human and machine behaviour modelling. Another example is euRobotics, the private-sector pillar of the Partnership for Robotics in Europe (SPARC). With EUR 700 million in funding from the European Commission over 2014-20 and triple that amount from European industry, SPARC is the largest civilian-funded robotics innovation programme in the world.

Support for technology transfer

Policy might also direct the trajectory of robotics development by providing targeted support for technology commercialisation. Many institutional settings affect knowledge transfer and commercialisation, from licensing and patenting arrangements, to the *modus operandi* of intermediary organisations (e.g. technology transfer offices). Policy should aim to optimise this ecosystem regardless of the type of technology. Where social priorities are urgent, however, technology transfer in specific fields might be facilitated. For example, a mobile disinfection robot was awarded the euRobotics Technology Transfer Award 2020.

Moonshots for robotics in society

Grants, R&D-based procurement and innovation prizes all have a role to play in tackling research “grand challenges” for robotics, and aligning robotics with societal needs. Public- and private-sector challenge prizes have played a prominent role in the recent development of robotics. In the United States, DARPA, the Office of Naval Research and the National Aeronautics Space Administration (NASA) have all run challenge prizes in robotics. From a policy perspective, challenge prizes are attractive because of the relatively small public investments involved: the NASA Space Robotics Challenge awarded the winning team a total of USD 300 000. Summed across all competitors, the R&D effort elicited by such a prize might dwarf the prize money. Moreover, competitions can help identify talented individuals and teams, drawing attention to ideas that deserve a second chance.

Challenge competitions in robotics could be envisaged for a range of major social goals, such as helping older adults to live longer and with more autonomy in their own homes. A portfolio of challenge competitions could also be considered for healthcare, and more specifically COVID-19 and infectious diseases. Some competitions could focus on critical safety and efficacy-enhancing tasks that cannot yet be performed by robots. Comprehensive consultation with health workers and other stakeholders might help identify and prioritise competition goals.

Diffusion of robots in healthcare

General unfamiliarity with the potential uses of robots, combined with the high cost of leading-edge robot systems, institutional inertia and the incipient nature of some applications, has constrained the application of robots in health systems. Low wages, especially among care workers, also discourage investments in assistive robots.

Among other steps, governments could examine how to accelerate the deployment of existing robot solutions, e.g. by providing platforms that highlight leading-edge solutions. The evidence indicates that public reporting of technology use by hospitals can accelerate the pace of adoption (Skinner and Staiger, 2015[26]). A high level of familiarity with robot technologies could have another positive consequence in a crisis situation, in that it could increase readiness to rapidly repurpose or innovate with currently available robot solutions. This might be quicker and more effective than relying on older robots stockpiled in preparation for a crisis. During the Fukushima disaster, for example, stockpiled robots were reportedly less suitable than routinely used commercial models. The specific capabilities (e.g. radiation resistance and advanced mobility) of older robots designed for interventions in nuclear facilities were outweighed by their slow speed and limited energy storage.

Education and training

Workforce skills are the most critical variable in an institution's ability to adopt new technology. Populations with broad and strong generic skills – i.e. literacy, numeracy and problem solving – are better positioned to acquire fast-changing technical knowledge. More specifically, some countries are rapidly developing curricula relevant to education and training in robotics at all levels. China, for instance, is developing robotics education tailored to primary schools.

Skill-related needs are also in flux. As robots are deployed more widely, demand will likely rise for roles such as "robot co-ordinators" who oversee robots and respond to malfunctions. Not all robot-related jobs are software jobs – many concern hardware. Training could help open such jobs to workers who possess mechanical skills taught in vocational courses. Many of the necessary skills do not require a four-year degree. Shorter courses could help, especially if delivered at scale. In the United States, for example, the intensive 12-week Rockwell programme trains and certifies underemployed veterans as instrumentation, control and automation technicians.

Regulation

Regulating robotics is an increasingly complex endeavour, owing to rapid technical change, growing robot capabilities and novel forms of human-robot interaction. For example, as intelligent robots become more widely used in care facilities or domestic settings, they might gather sensitive personal data, e.g. on religious or political views. Technically, such data could also be shared across robots, or with third parties (the OECD is currently working with independent experts to develop practical guidelines for implementing the OECD AI Principles; among other topics, it is examining how regulatory authorities can best address the challenges raised by AI).[6] Regulation has multifaceted goals, i.e. to provide producers with certainty, protect consumers and facilitate innovation. The aim is to create a regulatory framework that best balances all three goals. The space available in this chapter is not sufficient to review the differences across jurisdictions, the intricacies of legal scholarship and the comparative merits of competing legal proposals. Thus, this section only touches on some main challenges, drawing heavily on (Holder et al., 2016[27]).

An obvious concern is that the field of robotics changes faster than regulatory frameworks (see Chapter 8). While existing laws are often adequate to resolve potential legal disputes arising from the use of robots, some changes may be necessary. For instance, while it is now technically feasible for a surgeon to operate on a patient in another country, legal frameworks do not yet stipulate which country's laws would apply in the case of a mishap.

Another new issue regulation may need to address is the human-like appearance of some robots. If people unconsciously attribute an especially high degree of agency to humanoid robots, they might be less prone to question the instructions or behaviour of such systems. This could have implications for the protection of consumers, who might overly trust human-like robots and become more susceptible to misleading information. For the same reason, the safety of some critical systems could also be impaired when human operators deal with humanoid robots. Safeguards may therefore be needed in the future so that robots are not overly anthropomorphic.

A central question for wider robot use – and the insurance industry – concerns legal liability. The major legal conundrum relates to machine learning in the field. Today, if an unintelligent robot is programmed incorrectly and harms someone, liability lies with the user, not the robot manufacturer. In the case of robots with AI-enabled control functions, two possibilities exist:

1. The robot goes to school before being deployed, i.e. learning takes place at the manufacturer.
2. The robot learns during operation, including new tasks not imagined by the manufacturer.

The first option presents a technical challenge for manufacturers of AI-enabled robots as they ponder how to guarantee that the learning process will not produce unforeseen consequences, without testing the robot exhaustively in every situation. The second option may be simpler (provided the first option cannot be solved). Clearly, the manufacturer cannot be held responsible for the robot's actions if it does not control the environment in which it is used, the situations it learns from, and so on. A possible solution might be to certify a robot's baseline learned capabilities; once the user unlocks a learning process, however, the warranty is void.

Autonomy levels for road vehicles exists on a scale from 1 to 5. For medical robots, there exists no established definition of autonomy levels. Such a definition is more complicated to achieve: the range of tasks, working environments, technologies and risks to be considered is much greater than for road vehicles. Defined levels of autonomy effectively allocate technologies to different regulatory approval procedures, which vary in stringency, cost and time. A categorisation of autonomy for medical robots is necessary for the entire sector (Yang et al., 2018[14]).

It is also important to examine whether regulation hinders new robotic solutions. In a crisis situation such as COVID-19, regulation for some robot applications might justifiably de-emphasise risk avoidance and lower liability for innovators. A case in point could be regulations governing robotic delivery systems, which present fewer safety implications if a population is in lockdown.

Lastly, complex regulation can hinder robot adoption, particularly in small and medium-size firms, which typically lack teams specialising in regulatory compliance. Public programmes exist to help such firms deploy robots when regulation is hard to interpret.[7] However, a better solution would be to begin with a more amenable regulatory framework.

Conclusion

Progress in robotics could increase standards of living, quality of life and societal resilience, as well as strengthen healthcare systems. The potential of robotics is vast, but has only begun to be achieved. Governments possess a number of tools to accelerate the deployment of socially valuable robots. Support for both public R&D and public-private partnerships is essential, and the community of robot scientists and engineers broadly agrees on priorities (Nolan, forthcoming[24]). Policy makers can shape the course of future of developments to better meet challenges in areas such as healthcare, productivity growth, disruptive effects on labour markets, and new or increased skill needs. As with many digital technologies (even mature technologies such as cloud computing), the diffusion of robots across the economy and health systems is vastly below potential. This shortfall has a variety of causes, all of which can be influenced through public policy. As robots acquire new capabilities, they raise new policy issues, from privacy to legal liability. Robots can do more for society than is the case today, but active policy is a prerequisite.

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Notes

[1] The Oxford English Dictionary defines a robot in two ways. The first definition is “a machine capable of carrying out a complex series of actions automatically, especially one programmable by a computer.” Under this definition, smart phones are robots: they perceive something (through microphones, cameras and text input), and they act on their perceptions (putting appointments in calendars, sending money, etc.). The second definition – although the distinction between the two is not strictly technical – is “a machine resembling a human being and able to replicate certain human movements and functions automatically.” This chapter focuses on machines that more closely accord with the second sense.

[2] As Colin Angle, co-founder of iRobot, the world’s most successful consumer robotics company, recently put it, “we are just about none of the way to achieving the potential of robotics”.

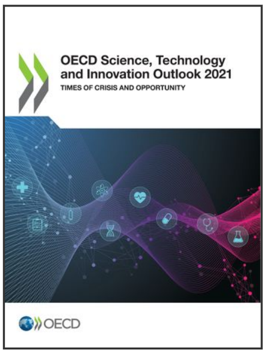
[3] When they first appeared, YouTube clips of Boston Dynamic’s “Atlas” robot performing backflips and appearing eerily human went viral. In 2015, MIT demonstrated the quadruped robot “Cheetah” leaping untethered over obstacles at a speed of 23 kilometres per hour. Here again, the images were unprecedented and arrestingly lifelike.

[4] The term “Moore’s Law” refers to a trend of exponential shrinking of transistors on integrated circuits, described by Gordon Moore in 1965.

[5] www.ukras.org.

[6] https://oecd.ai/.

[7] See, for example, the EU-funded COVR project (www.safearoundrobots.com).



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