Robotics Topic 8 – Futures

Prepared for the module team by Jeffrey Johnson and Tony Hirst, revised by Daniel Gooch, Tony Hirst and Jon Rosewell

1 Futures

In this topic we will consider the possible future of robotics and of societies which use robots and other intelligent systems. Robotics and AI systems are fast-moving fields; the aim of this topic is to help scaffold your ability to keep up with these changes. First, we will outline four different sources of information on discoveries in robotics, so that you are aware of how to keep up to date. Second, we will look at current technological developments to see how robotics might develop in the medium term. Then we will look at a particular domain – space – and explore what future improvements in robotics could help achieve. Finally, we will highlight three application areas where robotics is currently having an impact.

The application areas we have chosen – autonomous vehicles, industrial and agricultural, and health and social care robotics – are those where robot technologies are starting to emerge from the robot development labs and are making their way into everyday use. Since progress in these areas is fluid, we have not attempted to survey them in detail. Instead, we are giving you the opportunity to research current trends yourself. We have identified some questions that you can use to guide your exploration and have provided a few resources as starting points. Please add any interesting resources you find to the Robopedia wiki.

Study note – the TMA

The assignment that completes this block will ask you to report on some independent research. Therefore, we suggest that you skim this topic now to see what is covered and also look at the assignment. Then you can return to this topic to read the material in more detail, concentrating on those aspects that will help you with your assignment topic. You are not expected to read all the linked material in detail.

1.1 Learning outcomes

By the end of Topic 8 you should be able to:

- state some of the likely advances in robot technology
- undertake independent research
- discuss the implications for society of developments in robot technology.

2 Keeping up to date

Robotics and AI systems are large fields, covering everything from engineering improvements, developments in machine learning algorithms, new domain areas, improvements in human–robot interaction and everything in between.

To remain current and knowledgeable about any area, it is important to keep up with changes in the field. New discoveries and developments are being released at an incredible rate, and it is important for you to know how to access this information.

It is also a valuable skill to be able to gather, assess, analyse and summarise information you have researched. You will practise this later this week, in preparation for the TMA.

2.1 Sources of information

2.1.1 Research journals and conferences

For historical reasons, nearly all research developments are published as articles in either research journals or conference proceedings. These articles detail work that researchers have completed – typically including an explanation of the problem, the proposed solution, the means of evaluating the success of that solution, and the results. Both academic and industrial researchers publish their results in academic journals.

Before publication, these articles will go through a process of peer review: other experts will read the paper before publication to ensure that it has value, and that the evidence provided supports the claims being made. The paper is published only if the peer reviewers agree it is of a high standard, the evidence is compelling and the article makes a contribution to the field.

Journals and conferences are often run by academic bodies. In the areas of robotics and AI systems, the two main bodies are the Association for Computing Machinery (ACM) and the Institute of Electrical and Electronics Engineers (IEEE). Notable journals and conferences include the *ACM Transactions on Human-Robot Interaction*, the *IEEE Transactions on Robotics*, *The Journal of Machine Learning Research*, and the *IEEE/RSJ International Conference on Intelligent Robots and Systems*. All of these publish world-leading research developments.

Research papers can be somewhat challenging to read, particularly if you are only looking for a quick summary of how the field is changing. The IEEE publishes an excellent magazine, *Spectrum*, whose online version (see Figure 2.1) allows you to narrow your interests to robotics. If you are interested, please subscribe to receive updates, as the developments can be extremely interesting.

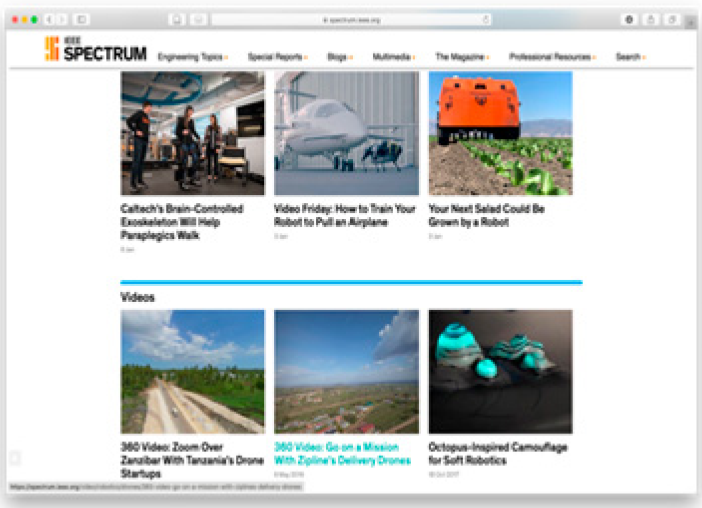

Figure 2.1 The robotics section of the *IEEE Spectrum* magazine

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A screenshot of the robotics section of the *IEEE Spectrum* magazine. The articles listed include:

- Caltech's Brain-Controlled Exoskeleton Will Help Paraplegics Walk
- Video Friday: How to Train Your Robot to Pull an Airplane
- Your Next Salad Could Be Grown by a Robot
- 360 Video: Zoom Over Zanzibar with Tanzania's Drone Startups
- 360 Video: Go on a Mission with Zipline's Delivery Drones
- Octopus-Inspired Camouflage for Soft Robotics

Activity 2.1 Research and discuss

Spend five to ten minutes exploring robotics on the *IEEE Spectrum* website.

Think about the different types of innovations being reported on and the domains in which robots are being developed.

Can you spot any patterns? If so, what are the patterns? If not, why do you think the innovations are so diverse?

Discuss your thoughts with others in your Cluster group forum.

2.1.2 Commercial venues

Commercial companies can be reluctant to publish academic papers for a number of reasons, including commercial sensitivity. The main reason is that it isn't necessarily in their interest – companies exist to sell products, rather than to release their research into the wild.

Therefore, in addition to academic sources of information, it can be insightful to explore what is happening in the commercial world.

One mechanism for doing so is to subscribe to the news coming from specific companies. For example, Boston Dynamics is a world-leading robotics company, with an intriguing YouTube channel that you can subscribe to, allowing you to keep up with the innovations they are developing.

However, maintaining an interest in all of the individual commercial companies would be incredibly time-consuming. A better approach would be to keep an eye on commercial trade shows. For example, CES (formerly the Consumer Electronics Show) is an excellent place to explore what companies are developing for consumers, while car shows such as the International Motor Show (IAA) are a great place to understand what is going on in the world of autonomous vehicles. It is worth remembering that at these events, companies will be presenting the best interpretation of their innovations, which may not exactly match with how those innovations will work once they are commercialised.

These trade shows, alongside other commercial developments, are often reported in the technology press through outlets such as the BBC or *Wired* magazine. However, these articles are curated by journalists (and thus may not cover everything at the show) and will by their nature be light on technical details to appeal to a wide audience.

2.1.3 Enabling legislation and incident reporting

As we have made clear throughout this block, the adoption and use of technical developments in robotics and AI systems are hugely influenced by societal factors. Therefore, it is also worth thinking about how to influence and keep up to date with how society is responding to technical developments. To keep things straightforward, we will be looking at this from a UK perspective.

UK Parliament

The parliamentary process in the UK is somewhat complicated, with both the government and backbenchers allowed to put forward legislation, and various select committees publishing reports in their specific areas. These efforts are often aided by expert testimony and advice.

The Parliamentary Office of Science and Technology is part of parliament, and offers an independent, balanced and accessible analysis of science-related issues. They commonly publish digestible reports which comment on the current state of the art, alongside the legal and societal implications this may have. The 'Preparing for a changing world' report (POST, 2019) contains everything from robot-surgery to robotic weapons.

Parliamentary select committees commonly hold public enquiries to explore outstanding issues, soliciting input from as many experts as possible. For example, the Science and Technology Committee has previously run an inquiry into robotics and artificial intelligence; the Education Committee had a robot ‘testify’ at their inquiry into the Fourth Industrial Revolution and the implications for education of developments in artificial intelligence; see Figure 2.2.

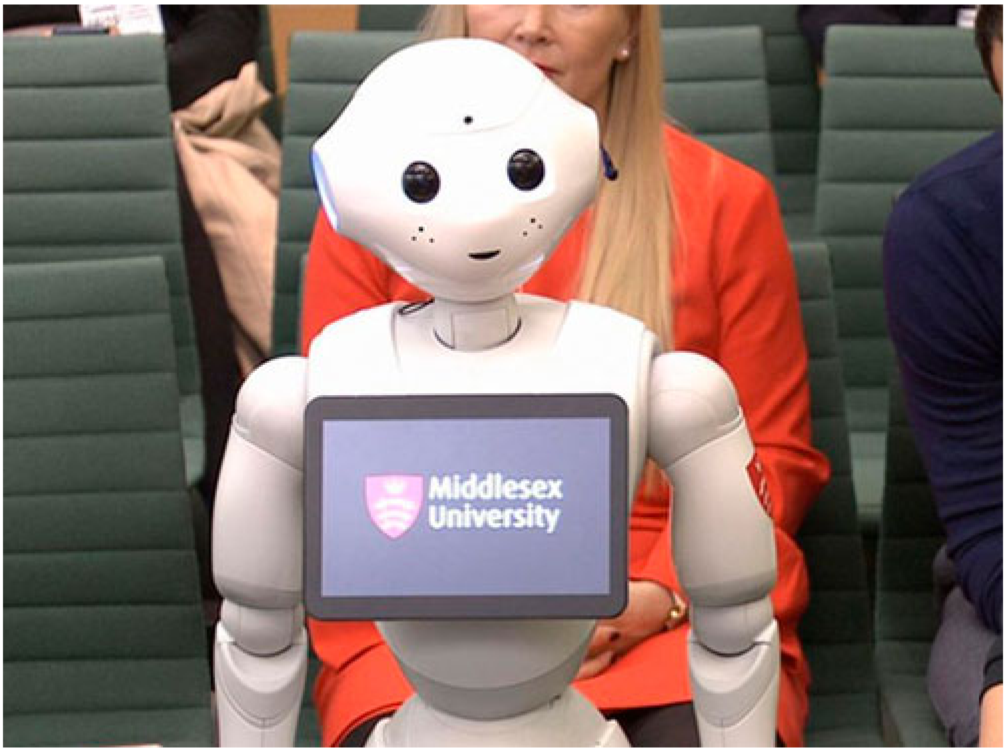

Figure 2.2 Pepper the robot, giving evidence at the Education Select Committee of the UK parliament

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An image of a Pepper robot. The robot stands about 4 foot (1.2 m) tall and is humanoid. Pepper appears to be looking at someone and is in a committee room within the UK parliamentary estate.

Parliamentary enquiries and select committees often start with calls for evidence, with those committees currently soliciting evidence listed online. Much of the evidence is publicly available and can make interesting reading – not least if you look at who is making a submission and what case they appear to be making. The reports from such enquiries and committees can often pre-empt legislation restricting or allowing certain activities to occur (such as the trialling of autonomous cars on public roads in the UK).

Other reports

Beyond parliament, there are other non-legislating organisations that are worth keeping up with. The Health and Safety Executive (HSE) is an independent regulator of UK workplace health and safety. It has a research branch that publishes reviews into how workplace changes may have an impact on safety (such as collision and injury criteria when working with collaborative robots). The HSE also investigates accidents that occur in the workplace. Both of these activities can highlight emerging concerns.

Finally, let us briefly discuss the International Organization for Standardization (ISO). ISO is responsible for developing and publishing standards which organisations ascribe to, ensuring the quality of work.

Keeping up with new proposed standards as well as recently adopted ones can be useful. The development of these standards often pre-empts mass adoption arising from standardisation, giving a potential insight into what will become mainstream in the short term.

Getting involved

One of the reasons for highlighting these different organisations is that as well as keeping up with what the law or a standard has suddenly enabled, *you* can influence the future. Parliamentary enquiries take written submissions, and ISO has a mechanism for gathering expert input. If you have interest and expertise in these areas, and have a strong opinion, then you should get involved.

Furthermore, looking at which companies are taking part in which consultations can also give you advance notice that they may have jobs in that area in the near future.

2.2 Competitions and challenges

One way in which research in robotics has been stimulated in recent years has been by the introduction of particular competitions and challenges. We will be focusing on the DARPA challenges as these have arguably had the greatest impact in recent years on robotic innovations. There are plenty of other competitions which have also stimulated innovation, but none to the extent of the DARPA challenges. These challenges were briefly mentioned in Topic 4.

DARPA – Grand and Urban Challenges

The progress that can be stimulated by challenges and competitions is vividly illustrated by the DARPA Grand Challenge, a competition for robotic cars sponsored by the US Government’s Defense Advanced Research Projects Agency (DARPA).

The challenge was to produce driverless vehicles that can travel long distances on standard roads. The first competition was held off-road in 2004: no vehicle managed the 150-mile route and the best performer travelled only seven miles. A year later, all but one of the entrants travelled further than this: five vehicles completed the 130-mile course, the winner averaging nearly 20 mph. In 2007 the DARPA Urban Challenge required robotic cars to obey the rules of the road while driving over 60 miles in traffic with other robotic and human-driven cars.

2.1 Watch

Watch this video clip of the second-place finisher Junior, the entry from Stanford Racing Team. The car is a 2006 Volkswagen Passat. The clip is from the qualifying run – handling 4-way intersections and road blocks.

The Grand Challenge/Urban Challenge was the first time DARPA had run a competition of this nature, and it was generally seen as a great success, stimulating interest and commercial opportunities for autonomous vehicles.

Study note – Further reading

If you're interested in learning more about the competitions and how they stimulated the commercialisation of autonomous cars, we recommend:

> Burns, L. (2019) *Autonomy: The Quest to Build the Driverless Car and How It Will Reshape Our World*. William Collins.

DARPA – Robotics Challenge

Moving on from autonomous vehicles, DARPA advertised the DARPA Robotics Challenge (DRC). The goal was to stimulate innovation in the development of human-supervised robotic technology for disaster-response operations.

The challenge culminated in the DRC finals, where robots had to complete a course consisting of eight tasks, including driving alone, walking through rubble, tripping circuit breakers, turning valves and climbing stairs. Twelve teams from around the globe reached the finals.

2.2 Watch

Watch this video clip of the highlights from the second day of the finals of the DARPA Robotics Challenge.

Note how different the robots are, from extremely humanoid competitors through to quadrupedal competitors.

DARPA – Current challenges

Activity 2.3 Research

Spend ten to fifteen minutes exploring the DARPA Prize Challenges website.

What challenges are currently being advertised? What kinds of innovations do you think these competitions might promote?

2.3 Dealing with a difficult-to-read article

Study note

Reading long official reports can often be a soul-destroying exercise – so where do you start? In this section, I describe how I dealt with one example, a European Commission report called *AI: The future of work? Work of the future! On how artificial intelligence, robotics and automation are transforming jobs and the economy in Europe* (Servoz, 2019).

This European Commission document is potentially important because such documents tend to drive both the funding of research programmes and the development of legislation. Unfortunately, bodies such as the European Commission tend to produce very long and difficult-to-read reports. However, there are several tricks to bear in mind when reading such reports that reduce the need to read them all.

The first is to use the contents list to find bits of the report that look as if they may be relevant. The second is to start off by reading just the introductory part of each section. Often this will give you a reasonable summary of the section, which you can use as a basis on which to decide whether or not the section contains information that is likely to be useful to you. Reading the first sentence of a paragraph can also tell you whether or not the rest of the paragraph is likely to be relevant to your needs; if it isn't then skip it. Being able to skim-read sections, looking for keywords and then reading the paragraph that contains them in more detail, can also help you work through a document at speed. Official documents can provide you with a useful stock of formal keywords and search terms that you can use as part of your own search strategy. So, using some of these tricks, what did I learn from the document?

From the first part of the introductory section I noted that three chapters looked particularly relevant to my interests: Chapter 2 (how automation is changing the economy), Chapter 5 (preconditions for developing viable AI ecosystems in Europe) and Chapter 7 (policy recommendations).

Skimming the section headings of Chapter 2, and focusing on the graphs, I found that Chapter 2 concentrated more on current changes within the economy, rather than analysing what changes may come about as a result of innovations which will not be coming to market for 5–10 years. As this was not really what I was looking for, I skimmed most of this chapter. I did note that 'AI has started to transform the organisation of companies, but this transformation process is by no means complete. As further elaborated in Section 3.3, the vast majority of firms are either running some pilot schemes, which do not end up getting incorporated into day-to-day activities, or are not considering taking up AI at all. An AI diffusion gap can thus be observed, with only about 20% of firms being early adopters of technologies such as AI'. This made me think that despite all of the interest in AI transformations, only a relatively small number of companies are currently exploring how it may assist their companies.

In the initial paragraphs of Chapter 5, I read the paragraph 'The challenges related to an increased uptake of AI by SMEs are almost as numerous as the benefits. In a world economy where data is the new oil, SMEs often struggle to access large datasets of good quality, which puts them at a competitive disadvantage with big (mostly US-owned) technology companies'. As I found this of greater interest, I read the remainder of the chapter in depth.

Finally, glancing over the chapter on policy recommendations, I focused on those areas I had the most interest in, particularly any investment into universities and research organisations.

In summary, the report was not quite as useful a resource as I thought it might be at first glance. However, because I didn't feel as if I had to read it all, I was able to skim through it and pull out some nuggets of information that made me slightly more informed about the subject, and which provided me with a set of useful search terms that could act as a starting point for a more refined search strategy.

3 Future technical developments in robotics

The future of robotics can be seen in terms of technical developments that improve performance and capabilities, and the ways that new types of robot will be used. Here, we will briefly review some of the technological advances that can be expected.

3.1 Physical aspects

As far as the physical aspects of robots are concerned, we can expect to see the following developments.

- **Sensors:** Robot sensors will get better, delivering not only the quality of information that we experience as humans, but also sensory information beyond the capabilities of our own sensors. For sensors to be useful in robots, they need to be made smaller and to consume less power. The reduction of noise and reduction of costs also remain important issues. Major technological progress remains to be made in sensor fusion – combining the outputs of a number of sensors – and the 'co-evolution' of sensors with sensor mounts, robot morphology and control systems.
- **Materials:** Robotics provides many challenges to materials science, and is driving developments forward. New materials will appear that combine strength with flexibility. It seems certain that new and better artificial skin will be developed, being both tough and rich in sensors. Space robotics will drive the search for strong, light materials. Another development we can expect to see is better artificial muscles. Major developments can be expected in the area of 'smart' materials, allowing more intelligence to be embedded inside robot bodies.
- **Structures:** The body of a robot plays a great part in its performance. We can expect to see many novel mechanical structures in the future, allowing robots to move in new ways with much greater dexterity. There will also be reconfigurable robots: robots built from relatively simple components that can autonomously configure and reconfigure themselves.
- **Power systems:** The problem of powering robots is so important that we can expect to see major developments in this area. Advances in battery technology will be important, combined with low-power electronics, and low-power motors and actuators. The development of non-battery technologies will also be important.
- **Nanotechnology:** Nanotechnology is set for a massive investment in research and development in the foreseeable future, and we can expect many innovative ideas. These range from microscopic motors and gearboxes to tiny sensors. Nanotechnology also permits much smaller subsystems to be built into larger robots. The impact of nanotechnology will, therefore, be very significant.
- **Embodied intelligence:** Biological systems such as the human body get much of their performance from the physical properties of their materials, such as rigid bones, elastic tendons and muscles. For example, if you hold your arm out straight and rotate your fist as far as you can, it will naturally twist back into place when you relax your muscles. Your arm does not need an intelligent controller to make it do this: this behaviour is an inherent property of the arm due to its materials and structure. 'Embodied intelligence' does not just mean that cognitive intelligence has to exist somewhere: it means that 'intelligence' is distributed throughout an intelligent system – just as it is in our bodies. This principle is set to influence robot design for the foreseeable future, and is likely to solve many problems that the sense–think–act model has not solved.

3.2 Cognition

As noted above, embodiment will become an important principle in robot design. Even so, the more abstract cognitive abilities of robots will remain important, and here we can also expect many developments, although sometimes the boundaries between sensing, cognition and actuation may become artificial. Research into AI systems will continue to examine problems that are theoretically difficult to analyse and solve algorithmically. Of the many advances related to cognition, we can expect the following.

- **Increased processing power:** Moore's law still has a long way to go, and we can expect a continuation in the dramatic increase of microprocessing power available. This will be combined with a better understanding of parallel computation. Quantum computers may also make a significant contribution to the processing power available to robot designers. Besides this, Wi-Fi and 5G provide connectivity to the huge processing capacity and data of the Internet, providing cloud computing resources to any robot.
- **Improved neural processing:** Neural information processing has proved to be very powerful and will be increasingly built into robots. Developments will include new chips and software support systems, which will include circuitry that can be reconfigured 'on the fly', making robots much more flexible.
- **Human–robot interaction:** There will be a greater understanding of how people can interact with robots, enabling better robot–human communication.
- **Data mining:** Data mining (gathering electronically stored information) is in its infancy, and there will be major developments in this area. In future, software agents will be able to inspect huge quantities of information and make connections much better than they do today. This will allow better use of information to make predictions and determine behaviour.
- **Reasoning:** Over the past 50 years there has been a lot of research into reasoning and the way humans do it so successfully. This has given rise to many developments, including so-called fuzzy logic, which does not restrict the robot to true and false, but allows truth to be weighted, and non-monotonic logic, which allows the truth of propositions to change over time. Better understanding of human reasoning may lead to more intelligent robots.
- **Learning:** It is increasingly realised that the robots of the future will learn and self-adapt rather than have everything programmed in. Intensive research in this area is likely to produce robots that are easier to make, more intelligent and better able to adapt to changing environments.
- **Pattern recognition:** Pattern recognition is fundamental in robotics, in both perception and cognition. Pattern recognition is still relatively poor in some areas, but it is likely to get much better in the future.
- **Control:** Robotics has generated many new ideas and novel control architectures. These include the use of neural networks to control actuators, and other learning techniques. It is certain that robot control will improve dramatically in future, as it must if humanoid robots are to become as mobile and dexterous as humans.
- **Planning and scheduling:** Great progress has been made in robot planning and scheduling, but in future this will be done at a more strategic level and often involve communities of robots and intelligent agents.
- **Social intelligence and swarm robots:** Robots of the future are likely to communicate with each other to achieve their tasks. Intensive research into the 'social intelligence' that emerges from the interaction of many robots will continue. There will be big improvements in our understanding of how to design swarm robots, robot teams and robot communities. Future robots may have autonomous parts (e.g. a robot arm and its gripper) which behave in a swarm-like way.

These improvements in sensing, cognition and actuation will enable much better robots to be built over the next 5–20 years. They will certainly contribute to the development of robots built to perform specific functions.

Activity 3.1 Discuss

Predicting the future is challenging. Rodney Brooks is the Panasonic Professor of Robotics (emeritus) at MIT, and has developed a series of predictions up to 1 January 2050 of when robotics and AI milestones will be met.

Spend five to ten minutes reading through his predictions in the most recent scorecard. You might like to think about:

a. which predictions you agree with
b. which predictions you disagree with.

Discuss your thoughts with others in your Cluster group forum.

4 Robots in space

Having looked in general at the range of improvements that could appear in robotic and AI systems in the medium term, let us focus on a particular domain: space.

Since the first Lunokhod rover was successfully landed on the Moon by the USSR in 1970, robots have played a critical role in our exploration of space.

Figure 4.1 A replica Lunokhod rover

Hide description

An eight-wheeled robot, around 2 m long and 1.5 m tall. The main body of the robot appears like a covered bath, with a parabolic dish containing solar cells attached to the rear of the rover.

Why are robots so useful in space? There are a variety of reasons including the following:

- Robots need neither food nor drink. Many can be indefinitely powered through solar power. This means that robots can operate for much longer than astronauts can, who require sustenance to be delivered from Earth.
- Robots can work in very inhospitable conditions, including high gravity and vacuums, which would be challenging for humans.
- It takes around 9 months to fly to Mars using state-of-the-art rockets; it takes longer to reach planets, asteroids and comets further away from Earth. While this has never been done with humans, placing a robot in a spaceship for months and years at a time causes fewer challenges.
- Robots can operate continuously; humans cannot. This is significant when trying to gather as much data as possible, for example from the surface of Mars.
- Space exploration is challenging; it is preferable to lose a robot than the life of an astronaut.

4.1 Challenges for space robots

On purely practical and economic grounds, space robots are often severely constrained in terms of their weight (mass) and size (volume), as payloads dictate whether or not a robot can even get a ride on a spacecraft. At the same time, they must be built to survive the stresses of the launch and potentially the landing on another planet, moon or asteroid. In space or on another planet, they must be able to endure very hostile environments. The robot must cope with extremes of temperature, light (and darkness), and exposure to high levels of radiation which can badly affect unshielded electronic systems. In addition to this, typical operating conditions for a space robot include working in a vacuum and little or no gravity. And all this, remember, is likely to be at a distance from the Earth so large that human control interventions may take minutes, or even hours, to reach the robot.

Operating in a vacuum

Operating in a vacuum raises several issues. For example, on Earth many robots use ultrasound sensors to detect obstacles. However, ultrasound does not work in the vacuum of space or on planets with very thin atmospheres. Laser range finders provide an alternative.

Thermal management is a major problem for a robot, or indeed any hardware, that operates in space. The robot may experience extremes of temperature, from intense solar radiation to the bitter cold of space. Some subsystems may require heating in order for them to work correctly. On the other hand, the spacecraft will also generate heat, from firing its engines or from running electronic systems. Disposing of this heat is a problem because the vacuum that surrounds the spacecraft acts as an insulator. Thermal management of the robot can use *passive* measures (such as reflective materials and insulation), *active* measures (such as radiators and heaters) or *avoidance* (that is, choosing systems and materials that are unaffected by extremes of temperature).

As well as extremes of temperature, there are extremes of pressure. In the vacuum of space, the pressure is effectively zero. However, on some of the planets in our solar system the pressure far exceeds that of the atmospheric pressure on Earth – another factor which must be addressed if we are to send robot explorers to such destinations.

Power

The issue of power is critical to the success of a space exploration mission. The limited power available restricts the number of electronic systems that can be supported and also limits the potential for transmitting data back from the robot.

Batteries can be used for short-term storage and then recharged through solar arrays. Many satellites rely on solar power, as did the Mars rover Curiosity. However, deep-space probes, such as the Cassini–Huygens mission to Saturn, operate at such extreme distances from the Sun that insufficient light is received to make solar cells viable. Instead, nuclear power supplies are used; these are thermoelectric generators powered by the heat of radioactive decay. The NASA Kilopower project is exploring the use of fission nuclear power, which could enable rovers to remain on planetary surfaces indefinitely and allow the powering of human outposts on the Moon and Mars by relying on resources in the local area.

SAQ 4.1

What makes space inhospitable for humans and robots?

Hide answer

Answer

Space is a hostile environment that goes from extreme to extreme in terms of temperature, pressure and light levels (for example, the dark side of the Moon is very dark!). Low or zero gravity conditions, as well as high g-forces as the rocket launcher accelerates, must also be accommodated. The lack of a breathable atmosphere means an astronaut must have access to an air supply at all times. Radiation is also a problem in space, where there is no Earth atmosphere to filter out some of the harmful rays.

Control and autonomy

Controlling robots in space remotely requires sending a radio signal. Although electromagnetic waves, like radio signals, travel very fast (about 300 million metres per second), they still take a finite time to travel between two points. In fact, it will take just under 3 seconds for a radio signal to do the 769,000 km ‘round trip’ from the Earth to the Moon and back, and between 3 and 21 minutes for a signal to travel from Earth to Mars, depending on the relative position of the planets. Given the round-trip travel time, real-time remote control is not possible.

This requires robots in remote locations to have a great deal of autonomy. As you’ve seen throughout this block, great strides are being made in constructing autonomous robots, and we can expect further progress to continue to be made.

SAQ 4.2

The speed of light is 0.3 million kilometres per second. What is the minimum time it would take a radio signal to travel to the Earth and back from the following planets:

a. Mercury – when it is 124 million kilometres from Earth
b. Venus – when it is 64 million kilometres from Earth
c. Mars – when it is 56 million kilometres from Earth
d. Jupiter – when it is 941 million kilometres from Earth?

Hide answer

Answer

a. Mercury – 827 seconds
b. Venus – 427 seconds
c. Mars – 373 seconds
d. Jupiter – 6273 seconds.

From this example, a radio communication from Mars to Earth and back takes over 6 minutes, making remote control impractical.

4.2 The future of robots in space

Having explored some of the challenges of using robots in space, let us consider some of the innovations that might occur in the near future. We will mainly be focusing on the efforts of NASA and the European Space Agency (ESA) due to their openness in releasing information publicly.

4.2.1 Robot astronauts

Ever since Yuri Gagarin became the first person to orbit the Earth in 1961, it has become too easy to forget how remarkable astronauts are. Fewer than 600 people have been to space – an extremely low number given how many people have been alive since 1961. While we haven't placed a person on the Moon since 1972, there have been other achievements – the International Space Station (ISS) for example has been continuously occupied since November 2000.

NASA has long been developing humanoid robots to help with space exploration. The Robonaut 2 (Figure 4.2) was sent to the ISS in 2011 where it was used to replace human astronauts in completing some simple, repetitive tasks (such as measuring air flow).

Figure 4.2 Robonaut 2 in the Destiny laboratory of the International Space Station

Hide description

Robonaut is a white robot with a golden humanoid head. It stands about six-foot (1.8 m) high and resembles an astronaut in a space suit and helmet. This image shows Robonaut 2 in a laboratory, with many wires hanging to its left. It stands on a pillar, appearing to have limited movement beyond its arms.

Work on developing humanoid robotic astronauts has continued, with the latest NASA robot, Valkyrie, born out of the Johnson Space Center entry to the DARPA Robotics Challenge discussed earlier.

Activity 4.3 Watch

Watch the clip from *Hyper Evolution: Rise of the Robots* episode 2.

The expectation is that as Valkyrie is further developed – through increased artificial intelligence and the refinement of the mechanics – it will be an invaluable tool in helping the Moon to Mars mission. This attempt to create a permanent human-occupied base on the Moon, in order to be able to send people to Mars, will require robots such as Valkyrie to undertake tasks that are too complicated, expensive or dangerous for human astronauts.

4.2.2 Planetary rovers

Planetary rovers have been around since the 1970s. Some of the tasks they have assisted with include:

- instrument deployment and sample manipulation
- surface exploration, where the robot may be expected to explore the planetary surface in the immediate vicinity of the lander
- identifying sites of scientific interest, and planning activities related to these.

In the near future, two significant rovers will be launched: NASA's Mars 2020 rover Perseverance and the ESA's ExoMars rover Rosalind Franklin.

The Mars 2020 rover Perseverance is car-sized, about 3 m long, 2.7 m wide, and 2.2 m tall. At 1050 kg, it weighs less than a compact car.

Activity 4.4 Watch

Watch the following clip of the Mars 2020 rover's first test drive in the Jet Propulsion Lab (JPL) at NASA.

The Mars 2020 rover forms part of an ongoing mission to explore Mars using rovers. According to NASA, the current mission priorities includes ‘opportunities to gather knowledge and demonstrate technologies that address the challenges of future human expeditions to Mars. These include testing a method for producing oxygen from the Martian atmosphere, identifying other resources (such as subsurface water), improving landing techniques, and characterizing weather, dust, and other potential environmental conditions that could affect future astronauts living and working on Mars’.

The ExoMars rover will be the first time the European Space Agency has sent a rover to Mars.

Figure 4.3 The ExoMars rover Rosalind Franklin

Hide description

A six wheeled rover. Above the rectangular base of the rover, a large pole stands attached to the front of the frame. On the top of the pole is a camera unit.

The ExoMars mission's main objective is for the rover to travel across the Martian surface to search for signs of life.

These improved rovers – alongside other ongoing developments of planetary rovers – help us to better explore planetary bodies. Improvements in the design of the robotics, and the AI systems that drive them, should ensure that the rovers can provide scientific data that we have not received before.

4.2.3 Space probes

Comets are composed of ice, dust, rock and frozen gasses, and they stream around outer space. The Open University played a significant part in the ESA Rosetta Mission, which was the first successful landing of a probe onto a comet.

Activity 4.5 Watch

Watch this summary of the ESA Rosetta Mission.

As the video concludes, ESA now plans to send probes to a variety of different comets, requiring the development of more advanced probes.

4.2.4 Autonomous landing platforms

We have discussed the robotics involved in space exploration, but have not discussed the route of getting such robots into space.

As part of an attempt to make space research more economical, NASA has partnered with a number of commercial organisations to deliver key services.

One of these companies is SpaceX. On Saturday 30 May 2020, its Falcon 9 rocket sent their Crew Dragon spacecraft carrying NASA astronauts Doug Hurley and Bob Behnken to the ISS.

One of the key design principles of the Falcon 9 was to ensure that the rocket engines were recoverable, and reusable, at minimal cost. Due to where space launches occur, and the flight path of rockets, the nearest landing location is always in the ocean (see Figure 4.4). This minimises the fuel the rocket has to have as it doesn't need additional fuel to return to the launchpad.

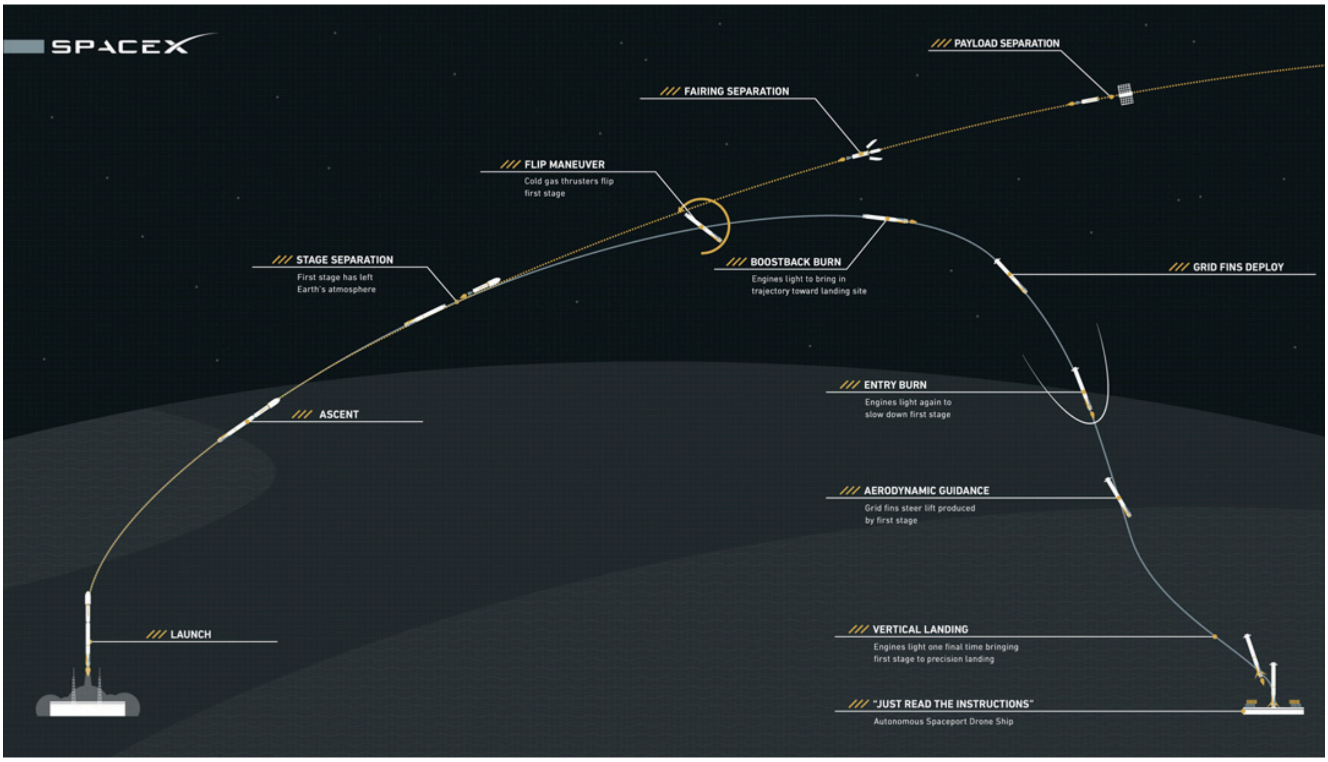

Figure 4.4 The route of a Falcon 9 rocket

Hide description

An image showing the launch route of a Falcon 9 rocket. Following a parabolic curve, the engines return to Earth, while the payload continues rising into orbit.

Having a crewed ship to land on would be significantly more expensive, so SpaceX have developed an autonomous landing platform that can reportedly keep itself in an exact position to facilitate recovery of the Falcon 9 engine. This was successfully achieved for the first time in April 2016.

Activity 4.6 Watch

Watch this clip of the SpaceX engines landing on an autonomous drone ship.

4.2.5 Soft robotics

Focusing away from application areas but on technical developments, soft robotics involves the construction of robots from flexible, compliant materials, rather than the more traditional rigid plastics and metals we are used to.

This is a relatively new research area; watch the summary clip in Activity 4.7 of why NASA is working on the development of soft robotics.

Activity 4.7 Watch

5 Further explorations

The aim of this section is to provide you with an opportunity to select and explore a particular question in one of several topics that interests you. We have chosen three broad application areas where there are interesting current developments. For each we provide a brief introduction, a series of questions that you could use to research the topic further and some resources that you might wish to use as starting points. We suggest that you quickly skim these sections to see what is covered and then carry out Activity 5.1.

If you would like to share any resources you discover in the forums or on the Robopedia wiki then please do so.

One of the questions in the TMA for this block asks you to investigate a particular topic, discover relevant resources and write a short article about it. You may find that following the process suggested in Activity 5.1 will help you approach the TMA question.

Study note – Completing a literature search

Searching through literature is an important study skill. It combines the need to find information and assess the usefulness, accuracy and limitations of any information you find. The OU Library provides a number of resources to help you develop these skills. Read their guide How do I do a literature search?.

Activity 5.1

Choose *one* question from Sections 5.1, 5.2 or 5.3 that interests you and then find some resources that help you frame an answer to this question. You might like to use my suggestions as a starting point. Make some notes and remember to keep track of the sources of your information. Have you answered the question to your own satisfaction? Would you be able to justify your answer to another student on this module? You might like to share what you have found in your Cluster group forum.

5.1 Autonomous vehicles

There has been a huge amount of hype of autonomous cars – with good reason. If widely deployed, they will completely reshape our transportation systems forever. Given that the early prototypes showed such promise, what is the state of autonomous cars today?

Of course, cars are only one form of transportation: from planes to ships to lorries, many other vehicles could benefit from automation. To what extent might the next generation of vehicles be robotic?

5.1.1 Questions and resources

Here are a number of questions that you may want to explore further. Do not feel as if you either need to read all these resources or limit your own reading to them. Try to pick resources that look relevant to your research question(s).

1. How close are we to seeing autonomous, driverless cars replacing human-driven cars?
2. What are the potential risks of pilotless, aerial vehicles in civilian airspace? What if these vehicles are carrying passengers?
3. What progress is being made with other forms of autonomous vehicles?
4. What are the social, legal, ethical and environmental implications of making vehicles autonomous?

Resources

Some of the resources included here were also discussed in Topic 7 when discussing the ethics of autonomous cars. They remain good starting points for exploring the questions we pose.

- While they have not had the high profile of autonomous cars, autonomous air vehicles have already arrived. They are being used to deliver blood to hospitals throughout Rwanda using cargo drones, and deliver groceries in the USA. Both Boeing and Airbus have active autonomous air vehicle programmes. This BBC report sheds some light on why we may never see autonomous passenger aircraft.

- We have already seen in Section 4.2.4 how autonomous ships are being used to collect space rocket engines. Autonomous boats are also being used to monitor weather conditions. Rolls-Royce has argued that the technology for autonomous cargo ships is already here, having already demonstrated their autonomous ferry.

- Focusing on the implications of autonomous vehicles, there is already concern over what the implications are for the hundreds of thousands of people who are involved in the transportation industry. The legal situation remains largely untested, despite the passing of legislation in the UK (Automated and Electric Vehicles Act 2018). The Law Commission is continuing to explore the regulatory environment to make the use of autonomous cars safe. There also remain huge questions over protecting the data generated by autonomous cars, as well as what the environmental implications are. The UK Centre for Connected and Autonomous Vehicles is a useful starting point for exploring what the UK government's response to autonomous vehicles will be.

5.2 Industrial and agricultural robotics

What is the state of industrial robots today? Low human labour costs have seen a lot of factory work move to China, rather than be taken over by robots. So has industrial robot development stalled, or are there commercial or technical challenges that are slowing the progress of industrial robots?

On the land, if you have ever watched a harvest then you may have noticed how human workers often work in tandem with machines. To what extent might the next generation of agricultural machinery be robotic?

5.2.1 Questions and resources

If you work in a particular industrial sector, then you may wish to take this opportunity to explore the extent to which automation and the use of robots are taking place in your industry (make sure to phrase one or two questions first to focus your research). Alternatively, here are a few other questions you may like to consider (feel free to come up with additional questions yourself, and maybe even share them in your Cluster group forum). As before, do not feel as if you have to research every question: each one might in its own right be the subject of a PhD!

1. What sorts of tasks are the latest industrial and agricultural robots being used to perform?
2. If the robots are replacing human workers, are the robots performing the task in the same way that humans used to, or has the task been re-engineered? Do opportunities for any new human tasks arise as a result?
3. Who owns the robots and who is responsible for operating and maintaining them?
4. Are the robots capable of learning? If so, what sort of training is required, and by whom?

Resources

Tracking down reliable resources is an important information skill. The following resources are drawn from a variety of sources that I would tend to trust. Note that in the case of published reports, rather than academic papers, you often need to check what sort of agenda or lobbying interests the producer of the report may have in promoting a particular viewpoint. As before, do not feel as if you either need to read all these resources or limit your own reading to them. Try to pick resources that look relevant to your research question(s).

- One industry where the use of robots has become mainstream is warehousing. Reports suggest that Amazon alone has deployed over 200,000 warehouse robots. As this *Wired* report notes, such a mass use of robots dramatically changes the nature of working in a warehouse, making it a collaboration with the robots. Depending on your interests, you could look deeper into the technology behind these warehousing robots, such as ‘Handle’ from Boston Dynamics. There are still outstanding research questions around the development of these robots that you could explore, including how to optimise their navigation systems. Alternatively, you could focus more on the human impact of the automation of work. The report ‘Automation and the future of work’ from the House of Commons Business, Energy and Industrial Strategy Committee is an interesting read, exploring both what the issues are, the benefits to businesses and what the implications are for society.

- Agriculture is an industry that is likely to see a huge increase in the use of robotics in the near future. Robot companies argue that the use of robots can increase yields while decreasing the mass use of chemicals. The Small Robot Company is currently running trials of their robots across the UK. Robots are not only being used to help with crops but, as *The Economist* reports, can also be used to help raise livestock. If you’re interested in what the current areas of interest are in the academic community, then a special issue on ‘Precision Agricultural Robotics and Autonomous Farming Technologies’ in the *IEEE Robotics and Automation Letters* is an excellent starting place. This website from the European Parliament has a set of interesting summaries on the impact robots may have on agriculture, ranging from the environmental impacts to the social and legal impacts.

- One final industry to consider is construction. This BBC article is a great starting point for understanding how robots may change the construction industry. One avenue is the 3D printing of buildings, including houses, by companies such as CyBe. The United Arab Emirates has the goal of 25% of Dubai’s buildings to be based on 3D printing by 2030. A different avenue is making construction equipment, such as diggers and bulldozers, autonomous. Companies such as Built Robotics are raising millions of pounds worth of funding to develop self-driving construction equipment. One final avenue to consider exploring is using robots to assist construction workers through the development of exoskeletons that will allow workers to lift much heavier weights safely.

5.3 Health & social care robotics

In this final personal research topic you will have the chance to reflect on the extent to which robots might play a role in our daily lives, in the home and for health care. You might also wish to explore how robot technologies can be used to enhance, or augment, humans directly.

5.3.1 Questions and resources

1. What sorts of tasks or roles do the latest generations of robots intended for supporting health perform?
2. How are robots currently being used in health and social care? How are they controlled?
3. To what extent are robots being used for supporting health today, and how? Who controls the robot?
4. To what extent might health-related robot technologies become ‘wearable’ by humans?

Resources

There are many possible avenues to explore in the area of the health applications of robotics, so you will need to focus your research on one or two quite specific areas. As before, do not feel as if you have to address every question and every resource, nor limit yourself to them. Choose your question or questions wisely, and limit your reading accordingly.

- This briefing report on Robotics in Social Care from the Parliamentary Office of Science and Technology is a good starting point for an exploration into how robots might support social care. It considers their current use, the barriers to adoption and the social, ethical and legal implications. It also contains an excellent set of references so is a good starting point for a literature search. Depending on the questions you want to explore, you could delve deeper into how these robots operate in field trials of robots designed to enable independent living, or to address loneliness in care homes.

- Robots are increasingly being used in surgery. This offers a variety of questions and areas to explore – a good starting point is this introduction from *The Economist*. You could look into the capabilities of commercial systems, such as the da Vinci surgery robot. Clinical commissioning policies for particular conditions – such as prostate cancer – detail the evidence base for the use of robots in particular surgeries. Robots are used by surgical teams, so it is also important to consider the adoption paths and social aspects from the surgical team. The robots also need to be controlled by the surgical team, so you could carry out a deeper exploration into how the robots are interacted with by surgeons, for example using manual gestures.

- Mobility is something that many of us take for granted. For people needing mobility rehabilitation, or for those who are paraplegic, robotic systems are starting to be developed that can dramatically change their mobility. The *IEEE Robotics and Automation Letters* special issue on 'Human Cooperative Wearable Robotic Systems' is a good starting place, with a broad range of papers covering everything from hand exoskeletons to wearable skin devices for haptic guidance. There is an excellent review of smart wheelchairs, which also highlights some potential areas of future research. This magazine article from *IEEE Spectrum* also provides a good introduction, with the ability to move on and explore the Caltech lab in more detail. If you are more interested in the perception of exoskeletons amongst older adults and clinicians, then this journal article from the *ACM Transactions on Human-Robot Interaction* is an excellent starting place.

- Robots are also helping children with various health needs. This BBC video clip provides an insight into how telepresence robots can help students attend school, even when they can't physically be in a classroom due to health concerns. Efforts have also been made to explore how social robots can make hospital visits for children less traumatic. For some children with long-term health issues, such as cancer, building a longer-term relationship with a social robot could be extremely helpful, although this requires a better understanding of how to develop that long-term child–robot bond. Of course, robots are not only useful to those children who have pre-existing health concerns: some researchers are focusing on developing robot assistants to help with physical exercise coaching.

6 Practical activities

Activity 6.1 Robot practical activities

Follow the instructions on this week of the study planner.

7 Summary

In this topic you have considered to what extent our lives are already dominated by machines, and how we may interact with machines in the future. Certainly the robots of the future will become much better and have a wider range of abilities than today's robots.

The main purpose of this topic has been to equip you with the skills to keep informed about the topics you are interested in. With that aim in mind, we took a look through different sources of information – academic, commercial and societal – as well as a brief exploration of how to read long documents.

After exploring some of the potential technical developments for robotic and AI systems, we focused on the use of robotics in space. Exploring how robots might help humans get to Mars will inspire some, and terrify others – although it would be a remarkable achievement either way.

We concluded this topic with a research activity – selecting a domain and exploring the future uses of robots in that domain. I hope that the initial resources we provided scaffolded your exploration of autonomous vehicles, industrial and agricultural robots, and health care robots. Hopefully you found the process interesting, and learned something along the way.

Where next

This is the end of Topic 8 and this block. Next week you will be focusing on completing your TMA.

We hope you have enjoyed learning about robotics and AI systems.

References

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Further reading

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Acknowledgements

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