Robotics Topic 6 – The Internet of Robotic Things

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1 Introduction

In this topic, we will examine the interaction of humans and machines by introducing the concept of the ‘Robosphere’. We will look at the Internet of Things (IoT) and how it interacts with robotics to create an expanding Internet of Robotic Things (IoRT). We will consider some real-life and potential examples of IoRT systems. Finally, we will revisit the Robosphere and ask questions about where control really lies.

1.1 Learning outcomes

By the end of Topic 6 you should be able to:

- explain how robotic systems, human interactions, databases, telecommunications and AI systems are all interlinked in the ‘Robosphere’
- write a definition of the Internet of Things and explain how having many sensors can enhance the control and monitoring of a system
- explain the significance of the development of 5G as it relates to the IoT
- explain the interactions between robotics and the IoT to form the Internet of Robotic Things
- explain the difference between cloud, edge and on-board computing and be able to determine what type of processing is best suited for which environment
- describe some example IoRT systems such as swarm robots in a rescue situation, smart cities and autonomous vehicles
- explain why security is important in the IoRT and why there have been problems with it
- discuss the world-wide IoRT or how the Robosphere could be considered as a giant robotic system in which humans play a role.

2 Case study – Asama’s work break

Activity 2.1 Read

The following is a story about an imaginary person called Asama who works at an office. Read the following story and make a list of any devices that Asama uses either directly or through the use of a mobile phone app. We recommend familiarising yourself with the story by reading it through once without taking notes, then re-reading it and taking notes.

> Asama liked to give herself a twenty minute break at about 10:30am. There was usually coffee in the office canteen. She opened the app on her mobile and made her order. She knew the payment would come out of her account automatically and the coffee maker would have her cappuccino ready for her by the time she got there.
>
> She pinged her colleagues to meet her in 5 minutes and instantly got confirmations: coffee was an important event. Asama had just enough time to check the house. Her house app let her start the vacuum cleaner – although this was on automatic, she wanted to give the house floors an extra go over today as she was expecting visitors. Sam's parents were coming for tea; they hadn't visited for some time and she knew his father would be looking to see how clean the house was. Although the cats were in the house, the vacuum cleaner would avoid bumping into them as it did its work. The app let her know that the temperature in the house was 15 degrees, which was warm enough for the cats; the heating profile would ensure that the temperature rose to a comfortable 20 degrees before any of the family got home.
>
> Asama checked the door cam but there was no sign of the package she was expecting. Her house plant monitor showed that the plants in the conservatory had been watered automatically that morning but that she might need to attend to those in the living room. Sam had insisted that they could not run water-pipes into the living room for the houseplants, not even micro-piping.
>
> She was surprised to find that the lamp in the back room was on: it was meant to turn off when no one was in the room. She found the sensor had been over-ridden, so she reset it and noted that the lamp duly turned off. The app informed her that her heating bill was likely to be higher than normal based on the data it had gathered so far. It suggested the cause was the stretch of cold weather they had experienced the month before.
>
> Satisfied that everything was in order, Asama closed the app and went to collect her cappuccino and meet her friends.

There are several devices mentioned in the story and although the word 'robot' isn't used, there are several systems that could be considered to be robotic in nature. Go back to the notes you made and identify any robots, and the sensors and actuators used. While Asama can see and program some of the systems remotely over the Internet using an app, identify those that have autonomy.

SAQ 2.1

How autonomous are the systems in Asama's world?

Hide answer

Answer

The office coffee maker could just be a person, but the story implies it is a machine. So it will have sensors for fluid volume, cup position, and water, coffee and milk temperatures. It will have actuators to select the cup, heat the ingredients, dispense the cups and so on. It might make decisions such as ordering in ingredients that were running low, but these are more likely to be automatic functions (when each ingredient starts to run out an order is made).

Robotic vacuum cleaners are readily available and are smart enough to avoid obstacles (such as wandering cats!). They may have proximity sensors, and motors to drive and to pick up dust. They do make decisions in collision avoidance and will have to return to a docking station when their batteries are running low, so have some degree of autonomy.

Temperature control can be said to be robotic: there will be one or more temperature sensors and either a simple on/off thermostat or a more sophisticated control system. The actuator in this case will be the heating system – a gas burner for example.

Plant-watering systems detect moisture in soil and turn on or off water pumps. At the time of writing there are systems on sale that will supply up to 15 indoor potted plants, though not in response to moisture levels and not connected to an app. However, there are apps available to remind the owner when to water their plants so it should be possible to combine this information with an automatic system so that the app could add a layer of control. If moisture detectors are also added then the system will again have a degree of autonomy.

Automatic lighting systems that come on when a proximity infrared (PIR) sensor detects someone in the room are available and could easily be connected to an app. A number of home automation systems allow lighting to be controlled from apps and over the Internet. So Asama's system is realistic and partially automatic.

An interesting point at the end of the story relates to a prediction that Asama's electricity bill is likely to be higher than normal. A central system had monitored the outside temperatures as well as the energy usage and made a connection. The collection of data from networked devices and the analysis of that data are very important developments in the field known as the Internet of Things that we will study in Section 4. In this case the information is presented to Asama for her to make a decision, but a robotic system could equally have made a decision and lowered the heating by a small amount to save energy until the next meter reading was due.

3 The Robosphere

3.1 A comparison with the Biosphere

The Biosphere is the intersection of those areas on the planet where life exists, whether in the air, on (or under) the land, or in water (Figure 3.1). As long as cosmonauts and astronauts are aboard the International Space Station, we could consider that near space is part of the Biosphere as well. The term is also used to encompass the many interactions between life forms and their environment and interactions between the life forms. Just two examples of biosphere interactions are the influence of the Amazon rainforest on atmospheric carbon dioxide levels and the formation and maintenance of a coastal food web between seabirds, molluscs and fish.

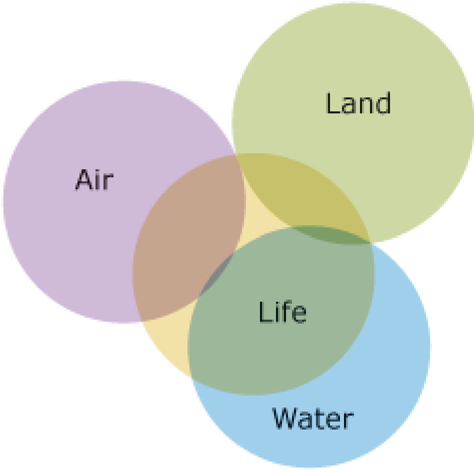

Figure 3.1 The Biosphere – life on planet Earth

Hide description

The figure shows three circles that partially overlap. The circles are labelled ‘air’, ‘land’ and ‘water’. The section where the three circles overlap is labelled ‘life’.

In a similar way we could think of the ‘Robosphere’ as being the intersection of robotic systems with other systems on Earth. Robotic systems interact with humans both directly and indirectly. They also interact with one another, with communication systems and with other computer systems such as artifical intelligences, databases and security systems. Robots might also interact with the natural environment; for example, a solar-powered robot, by drawing power from light, interacts with the Sun.

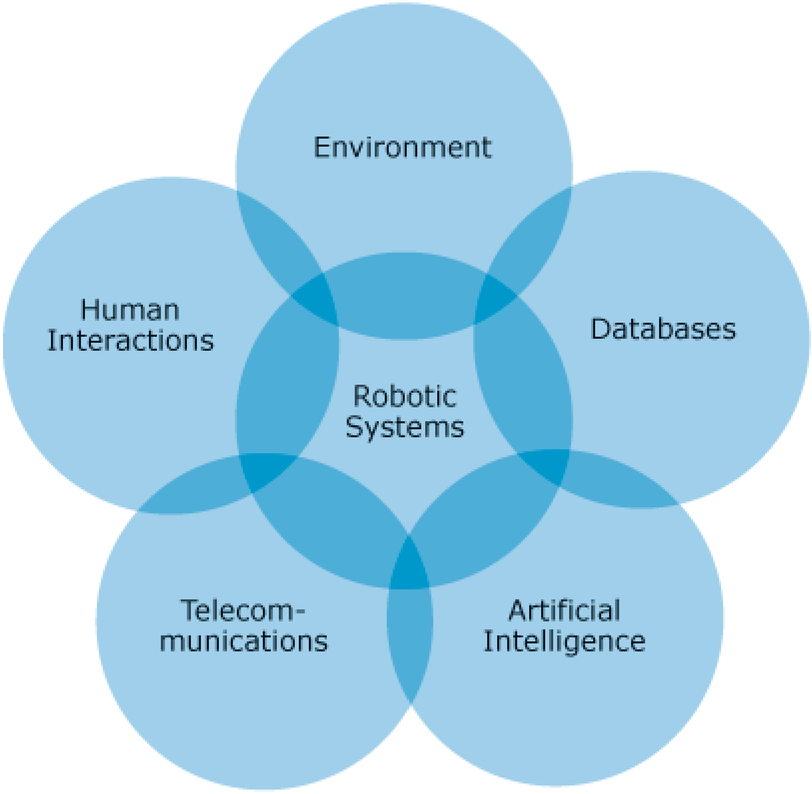

Figure 3.2 The Robosphere

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The figure shows six circles that partially overlap. The central circle is labelled ‘Robotic Systems’. Starting at the top and working clockwise, the following circles overlap with the central ‘Robotic Systems’ circle: ‘Environment’, ‘Databases’, ‘Artificial Intelligence’, ‘Telecommunications’, ‘Human Interactions’. All of the outside circles also overlap with the circles either side of it.

Figure 3.2 helps illustrate the Robosphere. It shows some of the interconnected systems and how they overlap. For example, consider a robotised warehouse where robots pack customers’ orders (such as those used by Amazon and Ocado), shown in Figure 3.3. This involves the robots interacting with humans in a shared environment. The robots need to use their AI algorithms, drawing on the warehouse databases, to maximise their efficiency.

Figure 3.3 Robots moving and packing groceries in the Ocado warehouse

Show description

3.2 Warehouse robotics

Activity 3.1 Research

Search online for a video of robots at a robotic warehouse such as at Ocado or Amazon. Watch the video and answer the following questions. Don't spend more than 15 minutes searching and watching videos.

a. What sensors do the robots have?
b. What actuators do the robots have?
c. Do humans and robots share the same area?
d. How do the robots communicate?

Hide answer

Answer

a. The robots are likely to have proximity detectors to stop them from colliding with each other or the walls. One video I saw stated that the robots avoided collisions by communicating with one another. Some robots navigated by scanning floor-mounted QR codes with their cameras.
b. The robots have motorised wheels and inside the warehouse can move using a coordinate grid. There are different methods of changing direction: in some warehouses, robots rotated through 90 degrees, whilst in others the robots changed direction by swapping wheelsets –

lifting the unwanted set out of the way. The robots moved crates around, delivering them to other robots or to humans for finishing the orders.

c. The robots don't share the same space as humans. This prevents accidents. At the time of writing there was an indication that more collaborative robots were to be incorporated in some warehouses.
d. At the time of writing, the Ocado robots communicate using the 4G network.

We have seen that the Robosphere can be considered as the region where robotic systems interact with many other computer systems and with life on Earth. To understand the interactions with current computer systems, the next few sections will consider the so-called Internet of Things (IoT): how it makes a difference to industrial systems and how the 5G network is designed with the IoT in mind. Then we will look at how robotic systems and the IoT can work together to form the Internet of Robotic Things (IoRT).

4 The Internet of Things

In 1991, Mark Weiser, a researcher working at Xerox PARC in California, published an article in the magazine *Scientific American* which went on to change the world (Weiser, 1991). 'The Computer for the 21st Century' imagined a world of 'ubiquitous computers' where the PCs of the late twentieth century were replaced by countless computers embedded in almost every manufactured object from houses and cars to ID cards, watches and furniture. Thirty years ago, Weiser not only predicted but also built prototypes of many technologies we are starting to use today.

Weiser's work influenced countless researchers, one of whom was Kevin Ashton, perhaps the first person to use the phrase 'the Internet of Things', in a presentation he gave to managers at Procter and Gamble in 1999 (Ashton, 2009). He persuaded his managers that Procter and Gamble's products needed to be tracked so that supermarkets could be sure that they were stocking them on the shelves. Ashton later worked at the Massachusetts Institute of Technology (MIT) where he helped develop a standard for radio-frequency identity (RFID) tags which can be used to track products. RFID allows almost any item to carry a small computer chip which, when queried using a compatible radio signal, transmits its unique serial number. Since every product has a unique number, a stock-control system can keep track of every product (*The Bottom Line*, 2019). You may have used RFID in applications such as pet identification chips, passports, security tags in shops, employee badges and public transport passes.

Today the definition of IoT has been extended to include devices that interact with the Internet (and other devices on the Internet). Unlike Ashton's RFID tags, modern IoT devices are capable of sending and receiving information as well as processing data to perform some task.

4.1 Evolution of a heating system

To understand the implications of the IoT we will explore the three stages in the evolution of a domestic heating system.

Stage 1

A traditional, simple domestic heating system contains a sensor, in the form of a thermostat, and a boiler. When the temperature falls below a certain threshold the thermostat is triggered and turns on the boiler. The boiler heats water, which is pumped through radiators to warm the house. When the temperature reaches the upper limit set by the householder, the thermostat switches off the boiler. Figure 4.1 shows a process diagram for this system. The action of the thermostat is shown as a comparison between the desired temperature and the actual temperature. This comparison creates a signal which starts and shuts down the boiler.

Although an analysis of different control techniques is beyond the scope of this module, it is worth pointing out the difference between an *open loop* and a *closed loop* system.

- In an 'open loop' control system, there is no feedback between the control and the output. An example would be a light switch used to turn on or off a light, or a switch to turn on a heating element in an electric heater. There is no sensor to detect the output has come on or reached a certain level.
- In a 'closed loop', feedback is used to operate the control. The measurement system in Figure 4.1 'closes the loop' and provides a way to control the output in a more intelligent way.

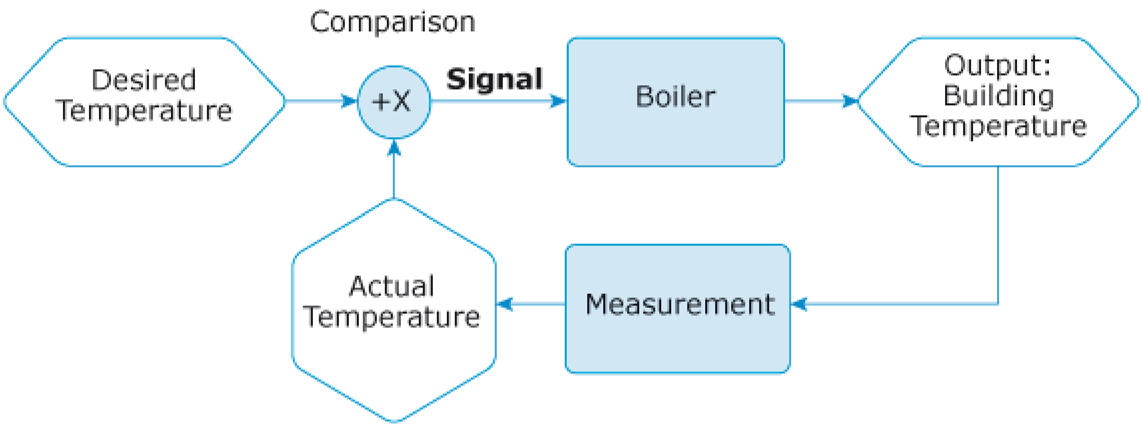

Figure 4.1 A simple temperature closed-loop control system

Hide description

A flow diagram. We start by entering a desired temperature to the thermostat. If this temperature is not the same as the current temperature, then a signal is sent to the boiler which increases or decreases the building's temperature. This is measured through a sensor which reports the current temperature to the thermostat.

This simple heating system could be extended by the addition of a timing system which would allow the boiler to turn on only during specific periods of the day. You may be familiar with a drawback of fixed timers: if a householder were to come home earlier or stay away longer than expected, then they would come home to a cold house or one where energy had been wasted heating an empty home.

Stage 2

Connecting the domestic heating system to the Internet of Things allows a householder to remotely log on and monitor the temperature of their house. It also allows them to remotely change the settings so that if they were coming home earlier, they could switch on the system at an earlier time.

Such a system requires that the sensor and the boiler controller are connected to the Internet. In the past, the thermostat could have been a simple heat-operated switch (such as a bimetallic strip) but in the IoT world the temperature sensor must convert the temperature to an electronic signal which can be relayed through an Internet Protocol (IP)-connected device to the household router. Similarly, the controller must also have an electronically operated switch connected to an IP-connected device and from there to the router.

This system only requires a small volume of information to flow between sensors, the central controller, the router and the householder's smartphone. Nor does this flow of information need to be continuous: instead, it can be transferred at fixed intervals or when the situation changes (e.g. when the temperature drops). Low-bandwidth connections are typical of many IoT systems. Figure 4.2 shows a possible layout of an IoT household heating system.

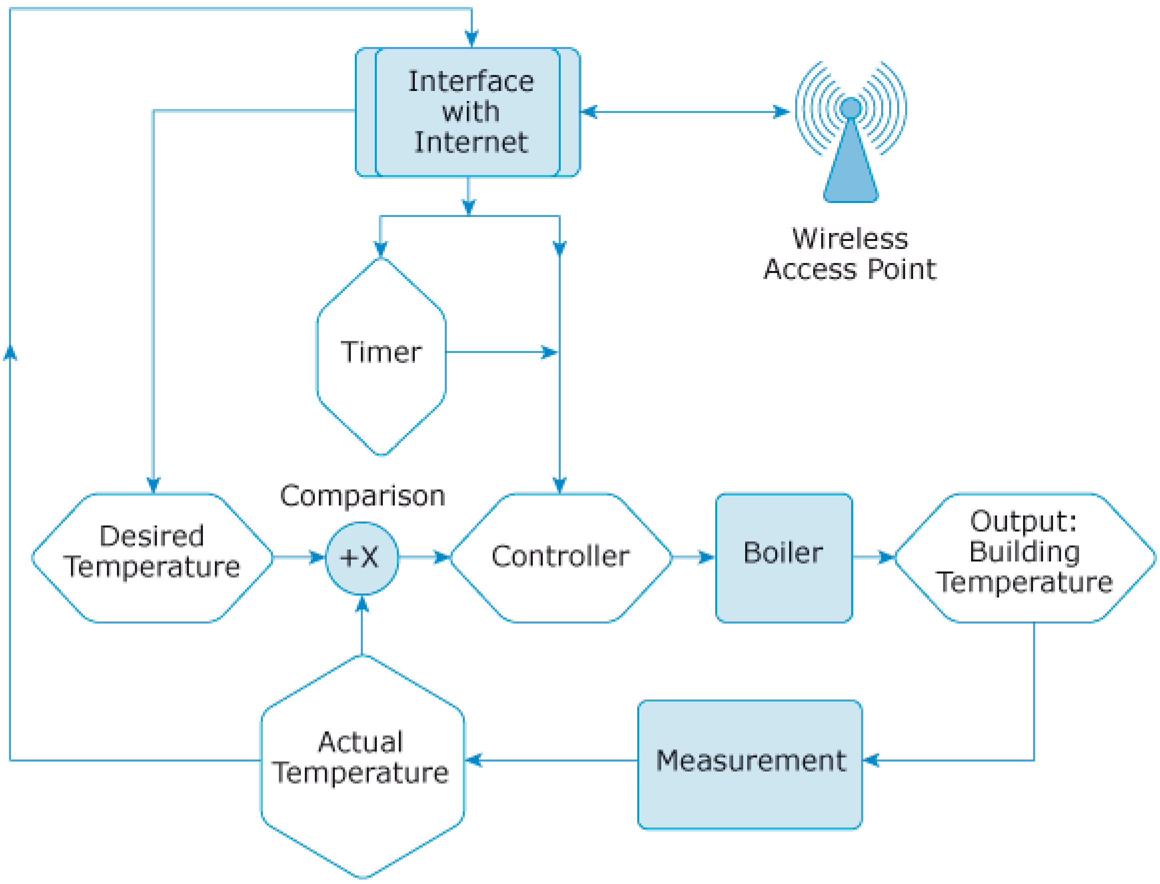

Figure 4.2 An Internet-connected heating system

Hide description

A flow diagram. We start by entering a desired temperature to the thermostat. If this temperature is not the same as the current temperature, then a signal is sent to the boiler which increases or decreases the building's temperature. This is measured through a sensor which reports the current temperature to the thermostat.

In addition, there is an Internet-enabled interface allowing the user to send a signal to the controller to the make the boiler to adjust the temperature.

Stage 3

The addition of an artificial intelligence module to the IoT system creates a system capable of anticipating the user's needs. For example, a central system tracks the location of the householder's phone and has knowledge of their typical commuter journeys. As the householder travels home from work, the system waits until they are 30 minutes away (based on previous journeys and the mobile phone location) before switching the heating on. When the householder is at home, the system would use its knowledge of previous days to anticipate which rooms are likely to be used at particular times, adjusting the valves on each radiator as required. Figure 4.3 shows this system; thick lines illustrate the parallel flow of multiple pieces of information.

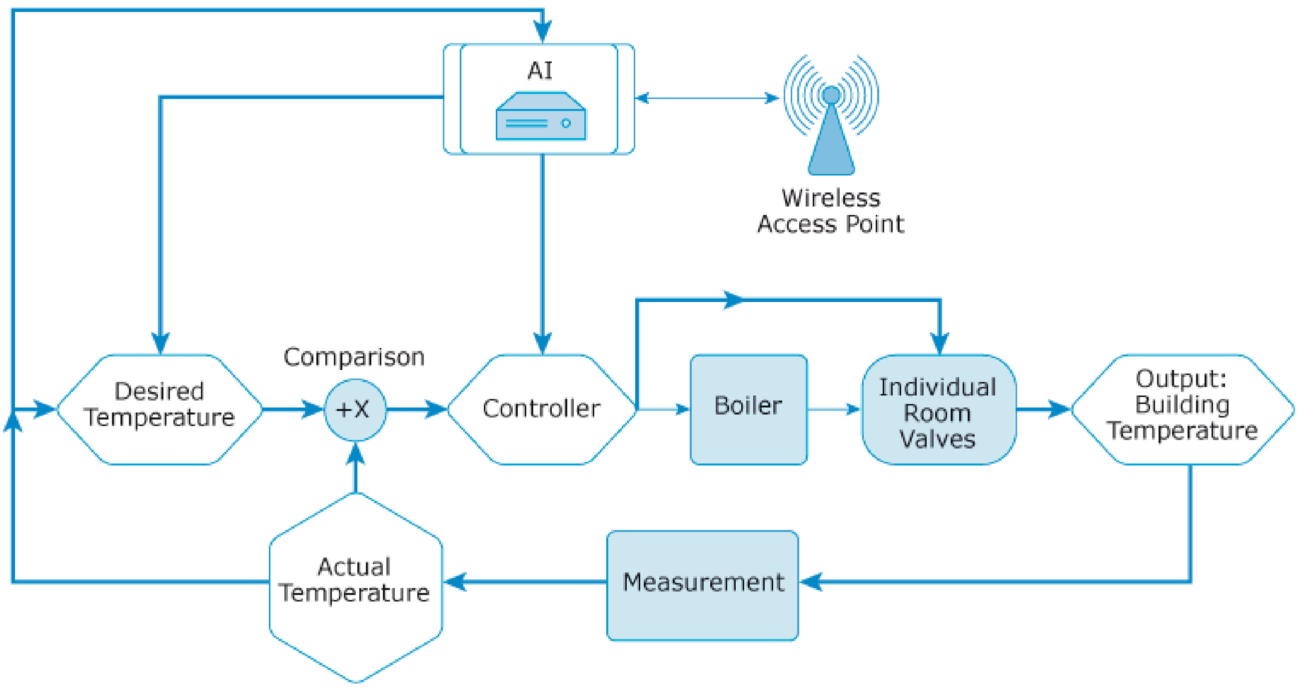

Figure 4.3 AI algorithms make decisions based on input from the system and the Internet

Hide description

A flow diagram. We start by entering a desired temperature to the thermostat. If this temperature is not the same as the current temperature, then a signal is sent to the boiler which increases or decreases the building's temperature. This is measured through a sensor which reports the current temperature to the thermostat.

In addition, there is an Internet-enabled interface monitoring a timer and the user's behaviour. Depending on their status, the controller may send a signal to the boiler to adjust the temperature.

Introduced in 2011, the Nest Learning Thermostat is an example of an IoT device for controlling household heating and air conditioning. The Nest replaces a conventional thermostat with a smart Internet-connected device. For a couple of weeks after it is installed, the Nest monitors how users change their heating and cooling requirements throughout the day, using machine learning to predict their future behaviour. The Nest also uses proximity sensors and mobile phone detection to monitor activity in the house, switching to energy saving measures when no one is home.

Figure 4.4 The Nest thermostat is an example of an Internet of Things device used to control household heating and air conditioning

Hide description

A round device, attached to a wall. The front of the device is a circular screen, with a dial around the edge and a large number 20 in the centre of the screen.

4.2 IoT examples

IoT technologies can transform systems containing sensors, each sending information to a central location for capture and processing. Consider a large factory where there are different spaces for different purposes. Sensors can monitor temperatures in warehouses and offices and give feedback to a centralised heating control system; RFID sensors can monitor raw materials or stock levels in each part of the factory and feed that information to a system that can order new materials or alert a team that a product needs to be moved or is ready for export.

Embedded sensors and the IoT allows for the monitoring and control of industrial processes such as supervising conveyor belts, temperatures, weights, detecting gas leaks, monitoring water temperature and purity, pressure in reaction chambers, and so on. In a similar way, sensors in agriculture are able to measure temperature and humidity in animal sheds; monitor soil temperature, moisture, and acidity; measure oxygen and carbon dioxide levels in greenhouses, and so on. And as we will see later, sensors in a city can measure light levels, traffic flow, air pollution and noise levels.

All this sensory information can be rapidly processed to provide immediate action and control. In the longer term, the data can be stored and processed by combining it with time stamps and other information to form enormous data collections that can be analysed to reveal long-term trends and effects. This is often referred to as ‘big data analytics’. Later we will talk about computer power in the cloud and how this is a useful place to perform such analysis.

4.3 IoT communications

As we have seen, one of the main aims of the Internet of Things is to collect information from sensor arrays. IoT sensors tend to use low-frequency, low-speed transmission systems and only periodically transmit data to central servers. There are two main reasons for this:

1. information about variables such as temperature, humidity and atmospheric pressure do not change very fast so there is no need for the data to be sent either continuously or at high rates
2. sensors may be in remote or hard-to-reach to locations and rely on batteries (perhaps recharged by solar power); if the device only transmits small amounts of data at regular intervals, then the batteries can last much longer than if they were in continuous communication.

Some IoT devices communicate through the mobile phone network, namely the 2G GSM (Global System for Mobile Communications), 3G, 4G and (at the time of writing) upcoming 5G networks. Each new generation offers increased bandwidth and more rapid access to information than previous systems. This latter attribute is called *latency*: the delay between a user trying to connect and actually connecting and receiving a reply. A long delay or high latency is undesirable as it can lead to ‘jittering’ on video, and a lag in communication.

Study note – Latency

High latency (sometimes called ‘lag’ or a high ‘ping time’) is especially annoying for online gamers who in a one-to-one shoot-out may find their opponent is always quicker ‘on the draw’ than they are!

Table 4.1 uses data from Ofcom and the IET (Institution of Engineering and Technology) to compare 3G, 4G and 5G networks. Speeds and latency figures are averages and tend to be lower than those quoted by manufacturers or mobile network providers; theoretical speeds are much higher (and latency times lower) than in real-life operating conditions. Speeds tend to be higher for static users as opposed to those travelling at speed (for example, in a car). As we will see later, this can be important in the consideration of connected autonomous vehicles.

In general, the higher the frequency of the radio wave carrying the signal, the faster the speed of the connection. However, these higher-frequency radio waves are less able to penetrate solid objects, such as walls of houses. Have a look and see what frequency ranges your Wi-Fi router uses. Mine uses 2.4 GHz and 5 GHz. I have some Wi-Fi devices connected to it that only work on the lower frequency; some prefer the higher frequency.

Table 4.1 A comparison of GSM network systems (Ofcom, 2015; Hayes, 2020)

Network	Speed (Mbps)	Latency (milliseconds)	Frequency spectrum
3G	5.9	60	850 MHz, 2100 MHz
4G	14.7	50	800 MHz, 1.8 GHz, 2.6 GHz
5G	500	10	700 MHz, 2.3 GHz, 3.7 GHz, 24 GHz

There are several other systems that exist for IoT devices to communicate through, but their details are beyond the scope of our interest.

5 Robots and the Internet of Things

Having established what is meant by the Internet of Things, we can now consider how it applies to robotic systems. How can the IoT help a robot to complete a task? And how can a robot help the IoT to complete a certain function?

One of the primary functions of the IoT is to provide a wealth of sensory information about an environment to a robotic system. Here are two examples.

1. Low-cost sensors can be deployed in a chemical factory to measure temperature and pressure in different reaction chambers. This data is sent to a central computer for analysis and monitoring to ensure steady production as well as anticipating hazards or problems – for example, a reaction overheating. Meanwhile, other IoT technologies such as RFID tags and readers can keep track of product locations and warehouse inventories. This makes the chemical factory a robot, with sensors (temperature, pressure, product location) and actuators (controlling the manufacture of the chemicals).
2. In agriculture, sensors can monitor air and soil quality on different parts of a farm. This data can be broadcast via mobile phone or satellite networks to a remote computer responsible for tasks such as monitoring crop growth or recording changes in soil condition. This data can then be used in autonomous vehicles for weeding or spreading fertiliser or water. This makes the farm a robot, with sensors (air and soil quality) and actuators (autonomous vehicles).

The IoT can provide information to help a robot fulfil its functions. Let us consider a hospital in the not too distant future where robots are fulfilling tasks such as

- collecting medication from the pharmacy and delivering it to wards for the patients
- carrying emergency equipment (such as a defibrillator) to any incidents
- cleaning floors
- moving round the hospital at night checking on patients by monitoring noise and carrying a camera so that a remote worker can track several at once
- carrying a camera and a screen so that specialist doctors and consultants can remotely check-in on patients with some telepresence.

Such robots can better perform their tasks if they are given information from a centralised hospital monitoring system. For example, an IoT system monitoring the position of an assistive robot working in a hospital could anticipate that the robot needs to go through a door to a private room and open the door ready for it. It could be that the door is not accessible to members of the public and so a general automatic door opening system is not in use. As the assistive robot approaches the door, its movements are caught on camera. This, together with an identification signal sent by the robot itself could trigger a system to open the door.

In another example, the hospital monitoring system might be instructed that several wards on the hospital need to be resupplied with specific medicines. A dedicated robot could receive that information, travel to the pharmacy, collect the appropriate medicines from a medicine-dispensing robot, and deliver the medicines to the wards.

These scenarios may seem far-fetched, but if you consider the definitions of robots that we discussed in Topic 1, then you should be able to note that many IoT systems help enable large areas – from a room in a house to an entire farm – to act as a single robot.

5.1 Search and rescue swarms

Moving beyond how the IoT is transforming physical spaces into robotic systems, this section considers how the IoT enables increased collaboration between robots.

In a search-and-rescue situation after an earthquake or other environmental disaster, local infrastructure is often compromised. For example, power lines may have been brought down so electricity cannot reach the affected region. This will not only affect homes and hospitals that don't have emergency generators, but also render mobile networks inoperative. Without a mobile phone network, rescue workers are forced to rely on either line-of-sight VHF (very high frequency) transceivers, more commonly known as walkie-talkies, or sophisticated satellite phones. Walkie-talkies have a reasonable range as long as the users can see each other because the higher-frequency radio waves cannot penetrate buildings or heavy vegetation. Modern satellite phones can be purchased that are much the same size as mobile phones and these can provide better coverage in uneven terrain. However, there are several problems with them including the fact that they are illegal in some countries and satellite mobile communication traffic can be become congested as satellites tend to cover a large area with a restricted number of voice channels.

One solution to the communication problem is to set up an ad hoc mobile network using a swarm of flying robots. Each robot can carry a communication node and – provided that they stay within range of each other – a readily-expandable communications network would be available to rescue workers on the ground.

In a swarm of robots, there needs to be communication between each robot so that each one maintains a reasonably constant position in the network. However, battery power is limited, and it is likely that each UAV (unmanned aerial vehicle, or drone) will have to return to base for charging at regular intervals. A UAV may not be able to fly for more than about 30 minutes without needing to be recharged (Gupta *et al.*, 2016). This means communication nodes will continuously change. Sending the drones to the right positions in the first place is also a challenge, especially as spaces in the network are changing dynamically as drones with low power are constantly returning to base. Another complication is with uneven terrain, for example, the presence of hills or mountains, or of dangerous areas such as large-scale bush fires.

6 Cloud, edge and fog computing

Cloud computing is a term used to describe the implementation of computer services at a distance from the operator. A simple example is the storage of photographs 'in the cloud' as a way to back-up and therefore safeguard the pictures. An advantage is that photographs taken on one device, such as a mobile phone, can be saved to the cloud and accessed from a laptop or desktop for editing or incorporation into a presentation.

Cloud computing can also be used by companies to run a portion of their computer needs. A company might use a cloud provider to host their web pages, process large volumes of data or to store data. Companies that have a seasonal demand may hire computer processing power at peak times. This means that they don't have to purchase computer equipment that will not be used for most of the year. An example might be an online retailer who does a lot of business in December but less in the summer. Such a company might struggle at peak times to process all the online orders and meet all the website requests. By outsourcing processing power to the cloud at peak times the company can cope with this demand.

Another example of a cloud service is in the voice recognition software available on home 'smart speakers' such as the Amazon Echo, Apple HomePod and Google Home. These devices carry a certain amount of processing power so that they can communicate with the Internet. They also contain enough processing power to recognise when the user has said the 'wake word' (be that 'Alexa', 'Siri', 'OK Google' etc.). They do *not* contain enough processing power to analyse any other portion of speech. So, when a user says the wake word, the smart speaker recognises that and then listens for whatever is spoken afterwards. That phrase or sentence is recorded and sent over the Internet to the cloud. The phase or sentence is analysed by a remote server or computer in the cloud and the answer sent back via the Internet again.

6.1 Edge and fog computing

Edge computing (or just edge) is a term used to describe processing power which occurs in the vicinity of the IoT device but not in the device itself. According to David Linthicum of Cisco, 'fog computing' refers to a type of computer network where large amounts of processing and storage are performed by the edge close to the user whilst retaining an interconnection with central cloud-based computers (Linthicum, no date). To help explain the difference between edge and fog computing, Linthicum uses the example of sensors embedded in a jet engine which can produce up to 10 GB of data a second:

- Edge computing is performed by a processor in, or near, the engine. It analyses the performance of the engine and immediately alerts the pilot of potential faults such as over-heating. Being local to the engine allows immediate data processing without worrying about network availability issues that may limit data transfer to or from the plane.
- At the same time, engine data can be sent to the cloud for deep-data analysis. Engine makers and airlines can analyse this data to find more efficient methods of operation or maintenance. This analysis is not critical to the immediate running of the plane and requires a lot of computing power and so can be performed later, at a distance, by powerful cloud servers.

6.2 Security

Security is an issue for IoT and IoRT systems. Consider the following security scenarios.

1. A hacker gains access to sensors and manipulates them to feed false information to the monitoring computer.
2. A hacker gains access to an autonomous car and deliberately causes a crash.
3. A system is compromised, and sensors are fooled into secretly sending their data to an industrial rival as well as to the intended recipient.

The first of these situations could lead to incorrect decisions being taken in the short or long term. For example, if city-wide sensors incorrectly indicate that pollution levels are lower than they actually are, then sufficient steps to protect vulnerable people from high nitrogen dioxide or particulate levels may not be taken leading to more illness and perhaps fatalities.

The second scenario is more dramatic, but it does show the importance of having a secure system.

The third scenario is about privacy and the need for protection.

Unfortunately, early IoT sensors were renowned for their lack of security. This was because they were low power (usually battery operated) devices with minimal on-board computing power. Encryption and error detection take up processor time and battery resources. Security was considered less important than it should have been, perhaps in a desire to get products to market quickly and making devices simple to install and use. Default passwords were sometime hard-wired into early IoT devices and could not be changed. Another problem was the inability of some IoT sensors to update their software (called 'firmware'; see the note below). Some firmware had problems that allowed hackers to add malicious code written in such a way as to fool the sensor into seeing it as a legitimate firmware update.

Study note – Firmware

Firmware is software that provides low-level control, rather like a simple operating system. It is saved to a special type of read-only memory (ROM), although it is now possible for firmware to be updated.

There isn't space in this section to look further at the security issues and solutions, but manufacturers of newer IoT and IoRT devices are much more security conscious. However, millions of legacy, insecure devices are still in use; and even those devices where security updates have been made available often remain unpatched. Some of these issues are explored in more depth in Block 3 of the module TM112.

6.3 Smart cities

A smart city is one which uses information from sensors to help deliver city services. For example, information about traffic congestion in one part of the city can be used to readjust traffic lights in neighbouring areas to help vehicles to move out of the congested area. Such systems rely on IoT devices communicating across the city using cloud, edge and fog networks.

Various cities in the United Kingdom have started to implement smart city technology. At the time of writing, the most advanced is Hull in Yorkshire. In 2018 a plan was developed to collect data from cities from the North of England and use that data to change the way that council services were operated (Ballard, 2018; Ingham, 2019). In 2019 the plan was to develop a city-wide operating system (CityOS) which would process data from waste management, smart lighting, parking and traffic. This data could be analysed not only to improve services but also to provide real-time information for residents on where best to park and what transport and traffic conditions are like in the area.

In China a system called 'City Brain', developed by Alibaba, uses artificial intelligence and computing power in the cloud to control traffic signals in Hanzhou (Alibaba Clouder, 2019). The effect is an increase in average traffic speed through the city (*E&T*, 2018). The system has been employed in other cities in China and is being rolled out in Malaysia. According to Alibaba, the system can help enable such diverse situations as allowing ambulances to travel to hospitals more quickly and enabling people to make bookings at hotels more efficiently, as well as allowing airports and rail networks to improve connectivity.

Paralleling the development of smart cities, advances are being made in autonomous vehicles as we shall discuss in more depth in Topic 7. Autonomous vehicles are being trialled in various parts of the world, but in all the trials the autonomous vehicles rely solely on on-board computing power. The vehicle's computer processes sensory data from video cameras, radar, ultrasonic sensors and lidar (light detection and ranging – used for measuring distances). This information is combined with geographical routing software to allow the vehicle to travel safely to the chosen destination – avoiding obstacles and keeping within the speed limit on the way.

In the near future, it is likely that smart cities will share sensory data with autonomous vehicles. Cars will use 5G networks to access relevant data gathered by the city's IoT, while the city will obtain further data from vehicles' sensors. The smart city and vehicles will collaborate to anticipate and avoid congestion: the city will use information from autonomous vehicles to identify congested routes and take steps, such as managing traffic signals, to alleviate it; vehicles will be routed around congested areas.

Given this diverse set of sensors and control systems, to what extent do you think we can think of a smart city as a robot?

Activity 6.1 Watch

In this video, Professor Lyudmila Mihaylova from the University of Sheffield talks about her research into using sensors to predict pedestrian movements in airports and train stations. She talks about how ‘connected vehicles’ are easier to put in place than truly autonomous cars. She also refers to pods that take passengers from one specific point – for example one terminal of an airport – to another (a second terminal).

Make a note of the types of data that might be gathered and fed into a smart city system. How long does she predict it will be before councils start to accept and utilise the technology?

Hide answer

Answer

Professor Mihaylova talks about the data from the pedestrian monitoring system at the start and then mentions the traffic loop and video camera feeds in the city centre of Birmingham. She also talks about GSM data and data from bus stations, taxis and social networks. She goes on to talk about how weather and traffic status in the city could be accessed by people using the real-time data from the city.

She hopes that the technologies would be accepted within two or three years. Given that this video was made in around 2017 we would expect that some of these technologies would be available or being planned to be available now.

6.4 Networked autonomous vehicles

In the previous section we looked at how autonomous cars could share data with a smart city network. In this section we will look more closely at some of the requirements to make such a collaboration useful and how autonomous cars can themselves be nodes in a network.

On-board, edge or cloud resources?

In Topic 4 we saw that vehicular autonomy can be categorised into six levels (0–5) with 0 being no automation at all and 5 being fully automated. For full automation, the car must be able to navigate safely from start to finish, obey street signs, stay within speed limits, avoid collisions, drive with 'due care' (so that other road users can predict what they are doing) and keep the occupants safe. Sharing information with other autonomous cars and with the smart city can give a vehicle advance warning about congestion or an accident ahead giving options to slow down or take an alternative route. For imminent hazards such as encountering an obstacle on the road – whether it be a pedestrian, an animal or a vehicle on the wrong side of the road – the autonomous vehicle may need to make a decision to apply the brakes or swerve to avoid the obstacle very quickly.

This is an example where latency and processing speed become important in the design of the autonomous vehicle infrastructure. We have discussed the differences between on-board, edge (and fog) and cloud computing.

SAQ 6.1

An autonomous vehicle receives sensory data from on-board sensors. It is in communication with roadside edge nodes which themselves have some computing power and which also connect to a cloud server. Assume that latency (the delay between sending a message and receiving an answer) is higher for communication with the cloud server than for an edge node – but the processing power in the cloud is much greater than that available in an edge node or the on-board processor.

Consider which type of processing is best suited for each of the five example situations below.

1

The vehicle is given a destination and needs to calculate the best route.

- ◯ Cloud server
- ◯ Roadside node (edge processor)
- ◯ On-board processor

Check your answer | Reveal answer

2

An accident has occurred half a mile ahead on a motorway and there are no intervening slip roads.

- Cloud server
- Roadside node (edge processor)
- On-board processor

Check your answer Reveal answer

3

A pedestrian walks out onto a city street without looking, less than 5 m from the vehicle which is driving at 28 mph.

- Cloud server
- Roadside node (edge processor)
- On-board processor

Check your answer Reveal answer

4

Another car wants to overtake the vehicle on a dual-carriageway.

- Cloud server
- Roadside node (edge processor)
- On-board processor

Check your answer Reveal answer

5

A city is experiencing severe congestion in one area and needs to divert oncoming traffic.

- Cloud server
- Roadside node (edge processor)
- On-board processor

Check your answer Reveal answer

7 The Robosphere revisited

The complexity of IoT robotic systems, with their combination of cloud computing, AI algorithms and sensors spread across a large geographic space, makes such systems extremely sophisticated. To an extent, we might consider that there is one giant Robosphere in which we live, and which takes sensory input from us along with data from the environment to analyse and plan.

For example, the connected heating system we considered at the start of this topic can be thought of as part of a robotic system: it has inputs, is able to make decisions, and uses these to drive its actuators. When connected to other distributed heating systems across a city, humanity is starting to take on the roles of the sensors and collaborative actuators of a world-wide robotic organism that partially guides our activities under robot control.

To what extent is our behaviour already influenced, guided or even controlled by computers and the physical environment?

Just consider the Internet itself: it mostly runs without direct human supervision and has been designed for great autonomy. The protocols that manage how data flows across the Internet are defined in such a way that we don't necessarily know what route any individual data packet (piece of information) will take as it moves from one computer, such as the web server that hosts this web page, to another, such as the computer you are using to read this page. The computers that run the network make autonomous decisions about how best to manage the flow of traffic across the network. And the Internet can perform its function in the presence of great uncertainty, so we could consider it to be intelligent.

The Internet is already fast becoming one of the most complex artificial systems on Earth. It is a gigantic swarm of computers, each being more or less autonomous, and each being more or less intelligent. If we now add on the Internet of Robotic Things, the Robosphere so to speak, then could the interactions of all these machines – sensors, intelligent nodes, the cloud, artificial intelligent systems and actuators that can physically interact with the environment – cause emergent behaviour be produced that no-one planned? Can this huge system be considered to be a robot?

7.1 The Robosphere in literature as a guide to the future

In 1909 E. M. Forester wrote a short story called *The Machine Stops* in which he predicted an all-pervasive system called the 'Machine' through which people communicate with each other and that can provide their every need. It is a dystopian novel in that the Machine eventually breaks down. In the story the scientists and engineers who had built the Machine had done such a good job that it was able to work for a time independently. However, as time passed there was no longer anyone who actually knew how the system fully worked and so when it started to fail, those in charge tried to cover up their ignorance with the result that the Machine and the civilisation that relied on it came to an end.

Activity 7.1 considers a different author's exploration of all-powerful machines.

Activity 7.1 Read

Read Chapter 9, ‘The Evitable Conflict’, of Asimov’s book *I, Robot* and then answer the following SAQ.

SAQ 7.1

a. What is the story about?
b. What is the main issue raised by the story?
c. Is this a source of concern?

Hide answer

Answer

a. The story is about the way the world is run, supported by ‘the Machines’: ‘The Earth’s economy is stable, and will *remain* stable, because it is based upon the decisions of calculating machines that have the good of humanity at heart through the overwhelming force of the First Law of robotics.’ The Machines have positronic brains and ‘in their own particular province of collecting and analysing a nearly infinite number of data and relationships thereof, in nearly infinitesimal time, they have progressed beyond the possibility of detailed human control.’

   Dr Susan Calvin, the robopsychologist, talks to the Controller, Stephen Byerley, about small imbalances: World Steel is overproducing, the Mexican Canal is behind schedule and there are other similar problems. The Machines seem to be making inexplicable errors, even though this is theoretically impossible.

   Susan Calvin suggests that the problem is related to the Society for Humanity, an organisation that hates the Machines. Each of the corporations that is performing badly has people belonging to the Society. There are tensions between the sectors of the world, and the Northern Region where the Society is based, is in danger of losing influence. The suggestion is that these people are trying to destabilise the world to prevent this.

   However, the Machines know that their instructions are being disobeyed and that humanity is in danger of economic disruption. So it is they that are causing the problems, in order to shake the anti-Machine people from their positions of power: ‘Their first care, therefore, is to preserve themselves, for us. And so they are quietly taking care of the only elements left that threaten them. It is not the ‘Society for Humanity’ which is shaking the boat so that the Machines may be destroyed. You have been looking at the reverse of the picture. Say rather that the Machine is shaking the boat – very slightly – just enough to shake loose those few which cling to the side for purposes the Machines consider harmful to Humanity.’

b. The main issue of the story is that the Machines are running the human world, and humans don't understand how they are doing it and cannot control it. Those who resist, like members of the Society for Humanity, are gently pushed out of their positions of power and neutralised. Stephen Byerley says, 'But you are telling me, Susan, that the 'Society for Humanity' is right; and that Mankind has lost its own say in its future', to which she replies: 'It never had any, really. It was always at the mercy of economic and sociological forces it did not understand – at the whims of climate, and the fortunes of war. Now the Machines understand them; and no one can stop them, since the Machines will deal with them as they are dealing with the Society – having, as they do, the greatest of weapons at their disposal, the absolute control of our economy. … Think, that for all time, all conflicts are finally evitable [avoidable, not inevitable]. Only the Machines, from now on, are inevitable.'
c. Viewed one way, this is a source of concern for humanity. To what extent are humans really in control of the human world? As suggested in this topic, to what extent are we already living in a great Internet-connected robot, serving it as its sensors and actuators? Our machines are getting progressively more intelligent all the time, and even now no one really understands the details of what makes our socio-technical world work.

   Viewed another way, this may not be a source for concern. We already live in this environment and most of us don't find that it undermines our humanity. However, our machines don't have positronic brains with the First Law built into them, so we cannot be sure that they will work towards the greater good of humanity. This suggests that, although there is no immediate threat of our machines taking over either actively or by default, we should be vigilant to make sure that humans retain control.

Asimov's story of the machines that run everything was remarkably prophetic, given that he wrote it at a time when the earliest computers were just being built by pioneers like Alan Turing. At that time there were no office PCs and no computer networks. By contrast, life without computers today seems impossible, and many organisations could not function without them.

To what extent is modern society like the machines in this story? Our society is wired up, with millions of machines networked to each other. A huge amount of information is constantly being distributed between these machines; and these machines are increasingly making decisions that affect our lives. The IoT is just one example of how these machines are networked to other parts of our physical infrastructure – the roads, railways and even the 'machines' we live in that are our homes.

In some ways we are the hands and eyes of a massive autonomous system that has a life of its own. But should we be concerned? We may not feel that our individuality is challenged by being part of this enormous socio-technical system. Even though machines do a lot of things autonomously, we can still feel that we are in control of our lives.

These two short stories – *The Machine Stops* by E. M. Forster and *The Evitable Conflict* by Isaac Asimov – end in different ways. In one, the Machine breaks down and in the other it continues and shapes the destiny of humanity. In both stories, people on Earth lost their independence which became subsumed by the needs of the robotic system. What do you envisage as the future of the Robosphere? It seems to me that humanity is already dependent on robotic systems and the Internet but that at least for now we are able to make it serve us rather than the other way around!

8 Practical activities

Activity 8.1 Robot practical activities

Follow the instructions on this week of the study planner and carry out the activities.

9 Summary

In this topic, we have examined how robots can exist as distributed networks of sensors and actuators across large geographic areas. Such a perspective is very distinct from what we may typically think of as a robot. However, by the definitions we explored in Topic 1, such systems – supported by the IoT – firmly fit into our concept of robotic systems. At the end of the topic we raised some uncomfortable questions about where control really lies in such systems – something we will explore next week when we discuss the ethical implications of robots in our daily lives. Having studied this topic you should be able to:

- explain how robotic systems, human interactions, databases, telecommunications and AI systems are all interlinked in the 'Robosphere'
- write a definition of the Internet of Things and explain how having many sensors can enhance the control and monitoring of a system
- explain the difference between cloud, edge and on-board computing and be able to determine what type of processing is best suited for which environment
- describe some example robot systems that use the IoT.

Where next

This is the end of Topic 6.

Topic 7 looks at the ethics around the use of robotics and AI systems.

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Figure 4.4: Taken from: https://store.google.com/product/nest_learning_thermostat_3rd_gen

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