Need to know: (New syllabus) 2023
• What each device does
• Why it does it
• When it might be used

hardware component that allow users to interact with a computer system

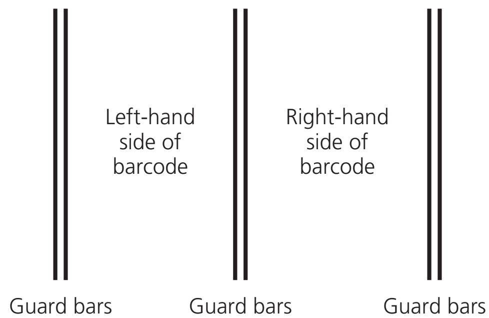
input data/commands into the system

3.2 Input and output devices

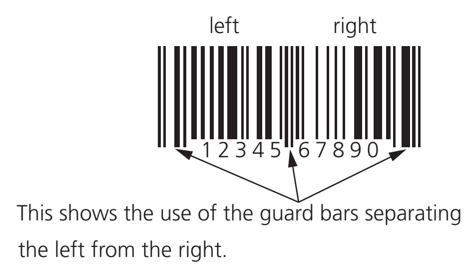
3.2.1 Input devices (8 for IGCSE)

① Barcode scanners (readers)

A **barcode** is a series of dark and light parallel lines of varying thickness. The numbers 0 to 9 are each represented by a unique series of lines. Various barcode methods for representing these digits exist. The example we shall use adopts different codes for digits appearing on the left and for digits appearing on the right of the barcode:

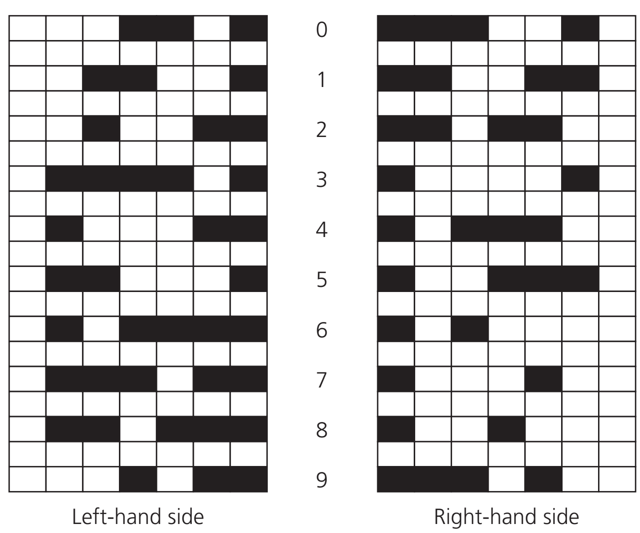


▲ **Figure 3.13** Diagram of guard bars



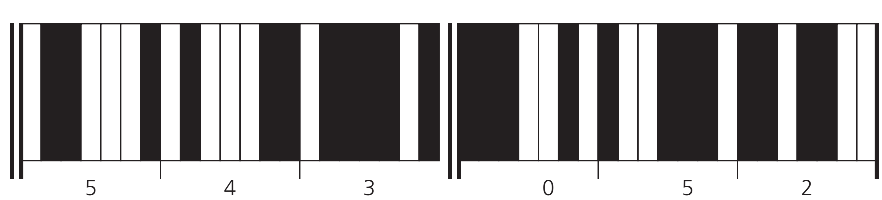
▲ **Figure 3.14** Sample barcode

Each digit in the barcode is represented by bars of 1 to 4 blocks thick as shown in Figure 3.15. Note there are different patterns for digits on the left-hand side and for digits on the right-hand side.



▲ **Figure 3.15** Barcode digit patterns

The section of barcode to represent the number 5 4 3 0 5 2 would therefore be:



▲ **Figure 3.16** Sample barcode section using patterns from Figure 3.15

Each digit is made up of 2 dark lines and two light lines. The width representing each digit is the same. The digits on the left have an odd number of dark elements and always begin with a light bar; the digits on the right have an even number of dark elements and always begin with a dark bar. This arrangement allows a barcode to be scanned in any direction.

So what happens when a barcode is scanned?

- the barcode is first of all read by a red laser or red LED (light emitting diode)
- light is reflected back off the barcode; the dark areas reflect little or no light, which allows the bars to be read
- the reflected light is read by sensors (photoelectric cells)
- as the laser or LED light is scanned across the barcode, a pattern is generated, which is converted into digital data – this allows the computer to understand the barcode
- for example: the digit '3' on the left generates the pattern: L D D D D L D
(where L = light and D = dark),
this has the binary equivalent of: 0 1 1 1 1 0 1
(where L = 0 and D = 1).

Barcodes are most commonly found at the checkout in supermarkets. There are several other input and output devices at the checkout:

▼ **Table 3.4** Input and output devices at a checkout

Input/output device	How it is used
keypad	to key in the number of same items bought; to key in a weight, to key in the number under the barcode if it cannot be read by the barcode reader/scanner
screen/monitor	to show the cost of an item and other information
speaker	to make a beeping sound every time a barcode is read correctly; but also to make another sound if there is an error when reading the barcode
printer	to print out a receipt/itemised list
card reader/chip and PIN	to read the customer's credit/debit card (either using PIN or contactless)
touchscreen	to select items by touching an icon (such as fresh fruit which may be sold loose without packaging)

So the barcode has been read, then what happens?

- the barcode number is looked up in the stock database (the barcode is known as the **key field** in the stock item record); this key field uniquely identifies each stock item
- when the barcode number is found, the stock item record is looked up
- the price and other stock item details are sent back to the checkout (or point of sale terminal (POS))
- the number of stock items in the record is reduced by 1 each time the barcode is read
- this new value for number of stock is written back to the stock item record
- the number of stock items is compared to the re-order level; if it is less than or equal to this value, more stock items are ***automatically*** ordered

- once an order for more stock items is generated, a flag is added to the record to stop re-ordering every time the stock item barcode is read
- when new stock items arrive, the stock levels are updated in the database.

Advantages to the management of using barcodes

- much easier and faster to change prices on stock items
- much better, more up-to-date sales information/sales trends
- no need to price every stock item on the shelves (this reduces time and cost to the management)
- allows for automatic stock control
- possible to check customer buying habits more easily by linking barcodes to, for example, customer loyalty cards.

Advantages to the customers of using barcodes

- faster checkout queues (staff don't need to remember/look up prices of items)
- errors in charging customers is reduced
- the customer is given an itemised bill
- cost savings can be passed on to the customer
- better track of 'sell by dates' so food should be fresher.

The barcode system is used in many other areas. For example, barcodes can be utilised in libraries where they are used in books and on the borrower's library card. Every time a book is taken out, the borrower is linked to the book automatically. This allows automatic checking of when the book is due to be returned.

QR code Scanner 2

▲ **Figure 3.17** Sample QR code

Quick response (QR) codes

Another type of barcode is the **quick response (QR) code**. This is made up of a matrix of filled-in dark squares on a light background. For example, the QR code in Figure 3.17 is a website advertising rock music merchandise. It includes a web address in the code.

QR codes can hold considerably more information than the more conventional barcodes described earlier.

Description of QR codes

- A QR code consists of a block of small squares (light and dark) known as pixels. It can presently hold up to 4296 characters (or up to 7089 digits) and also allows internet addresses to be encoded within the QR code. This compares to the 30 digits that is the maximum for a barcode. However, as more and more data is added, the structure of the QR code becomes more complex.
- The three large squares at the corners of the code function as a form of alignment; the remaining small corner square is used to ensure the correct size and correct angle of the camera shot when the QR code is read.

Because of modern smartphones and tablets, which allow internet access on the move, QR codes can be scanned anywhere. This gives rise to a number of uses:

- advertising products (for example, the QR code in Figure 3.17)
- giving automatic access to a website or contact telephone number
- storing boarding passes electronically at airports and train stations (Figure 3.18).

Figure 3.18 Sample boarding pass

By using the built-in camera on a mobile smartphone or tablet and by downloading a QR app (application), it is possible to read QR codes on the move using the following method:

- point the phone or tablet camera at the QR code
- the app will now process the image taken by the camera, converting the squares into readable data
- the browser software on the mobile phone or tablet automatically reads the data generated by the app; it will also decode any web addresses contained within the QR code
- the user will then be sent to a website automatically (or if a telephone number was embedded in the code, the user will be sent to the phone app)
- if the QR code contained a boarding pass, this will be automatically sent to the phone/tablet.

Advantages of QR codes compared to traditional barcodes

- They can hold much more information
- There will be fewer errors; the higher capacity of the QR code allows the use of built-in error-checking systems – normal barcodes contain almost no data redundancy (data which is duplicated) therefore it isn't possible to guard against badly printed or damaged barcodes
- QR codes are easier to read; they don't need expensive laser or LED (light emitting diode) scanners like barcodes – they can be read by the cameras on smartphones or tablets
- It is easy to transmit QR codes either as text messages or images
- It is also possible to encrypt QR codes which gives them greater protection than traditional barcodes.

Disadvantages of QR codes compared to traditional barcodes

- More than one QR format is available
- QR codes can be used to transmit malicious codes – known as attagging. Since there are a large number of free apps available to a user for generating QR codes, that means anyone can do this. It is relatively easy to write malicious code and embed this within the QR code. When the code is scanned, it is possible the creator of the malicious code could gain access to everything on the user's phone (for example, photographs, address book, stored passwords, and so on). The user could also be sent to a fake website or it is even possible for a virus to be downloaded.

Figure 3.19 Frame QR code

New developments

Newer QR codes (called **frame QR codes**) are now being used because of the increased ability to add advertising logos (see Figure 3.19). Frame QR codes come with a 'canvas area' where it is possible to include graphics or images inside the code itself. Unlike normal QR codes, software to do this isn't usually free.

Activity 3.3

1 Using the data in Figure 3.14, design the barcodes for:

a 9 0 0 3 4 0 (3 digits on the left; 3 digits on the right)

b 1 2 5 7 6 6 4 8 (4 digits on the left; 4 digits on the right)

c 0 5 8 8 9 0 2 9 1 8 (5 digits on the left; 5 digits on the right)

2 a Describe one advantage of using QR codes rather than traditional bar codes. Explain how barcodes bring the advantage you have described.

b A square QR code contains 40 × 40 tiny squares (pixels) where each tiny square represents a 0 or a 1. Calculate how many bytes of data can be stored on the QR code.

c Describe the purpose of the three large squares at the corners of the QR code.

d Describe one disadvantage of using QR codes.

▲ **Figure 3.20** Digital camera

2

Digital cameras

Digital cameras have essentially replaced the more traditional camera that used film to capture the images. The film required developing and then printing before the photographer could see the result of their work.

This made these cameras expensive to operate since it wasn't possible to delete unwanted photographs.

Modern digital cameras simply link to a computer system via a USB port or by using Bluetooth (which enables wireless transfer of photographic files).

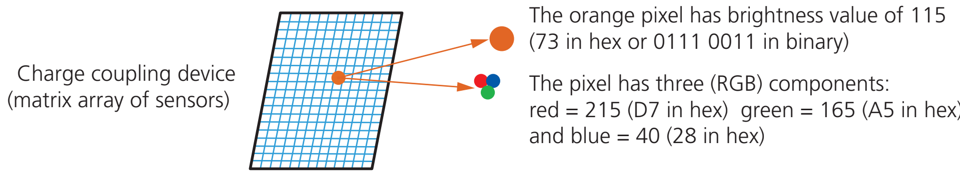
These cameras are controlled by an embedded system which can automatically carry out the following tasks:

- adjust the shutter speed
- focus the image automatically
- operate the flash gun automatically
- adjust the aperture size
- adjust the size of the image
- remove 'red eye' when the flash gun has been used
- and so on.

What happens when a photograph is taken

- the image is captured when light passes through the lens onto a light-sensitive cell; this cell is made up of millions of tiny sensors which are acting as photodiodes (i.e. **charge couple devices (CCD)** which convert light into electricity)
- each of the sensors are often referred to as pixels (picture elements) since they are tiny components that make up the image
- the image is converted into tiny electric charges which are then passed through an **analogue to digital converter (ADC)** to form a digital image array
- the ADC converts the electric charges from each pixel into levels of brightness (now in a digital format); for example, an 8-bit ADC gives 2^8 (256) possible brightness levels per pixel (for example, brightness level 01110011)

- apart from brightness, the sensors also measure colour which produces another binary pattern; most cameras use a 24-bit RGB system (each pixel has 8 bits representing each of the 3 primary colours), which means each pixel has a red value (0 to 255 in denary), a green value (0 to 255) and a blue value (0 to 255); for example, a shade of orange could be 215 (red), 165 (green) and 40 (blue) giving a binary pattern of 1101 0111 1010 0101 0010 1000 (or D7A528 written in hex)



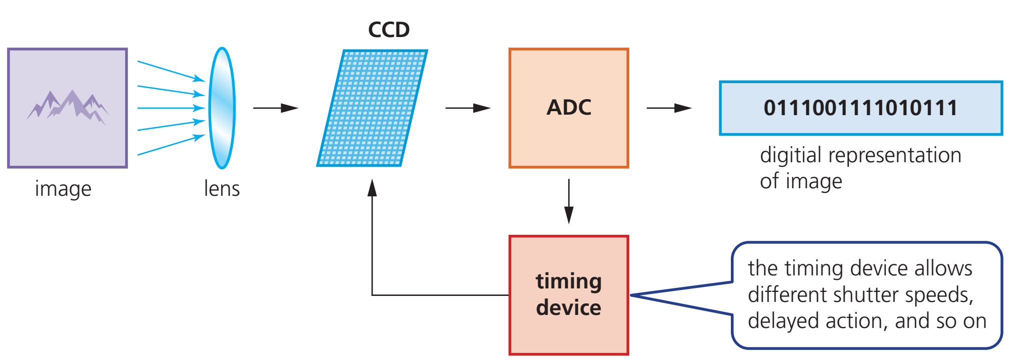
▲ **Figure 3.21** Typical pixel brightness and colour values

- the number of pixels determines the size of the file used to store the photograph
- the quality of the image depends on the recording device (how good the camera lens is and how good the sensor array is), the number of pixels used (the more pixels used, the better the image), the levels of light and how the image is stored (JPEG, raw file, and so on).

Link

For an explanation of how pixels affect file size see Chapter 1.

Mobile phones have caught up with digital cameras as regards number of pixels. But the drawback is often inferior lens quality and limited memory for the storage of photos. But this is fast changing and, at the time of writing, many smartphones now have very sophisticated optics and photography software as standard.



▲ **Figure 3.22** Diagram of how a digital camera works

4

Keyboards

Keyboards are by far the most common method used for data entry. They are used as the input devices on computers, tablets, mobile phones and many other electronic items.

The keyboard is connected to the computer either by using a USB connection or by wireless connection. In the case of tablets and mobile phones, the keyboard is often **virtual** or a type of **touch screen** technology.

▲ **Figure 3.23** Keyboard

▲ **Figure 3.24** Ergonomic keyboard

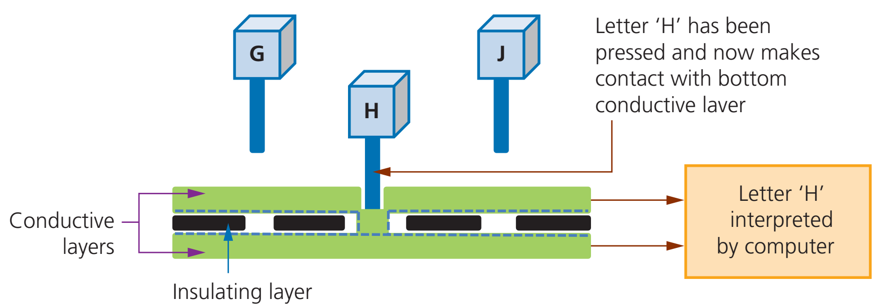
As shown in Chapter 1, each character on a keyboard has an ASCII value. Each character pressed is converted into a digital signal, which the computer interprets.

They are a relatively slow method of data entry and are also prone to errors, however keyboards are probably still the easiest way to enter text into a computer. Unfortunately, frequent use of these devices can lead to injuries, such as **repetitive strain injury (RSI)** in the hands and wrists.

Ergonomic keyboards can help to overcome this problem – these have the keys arranged differently as shown in Figure 3.24. They are also designed to give more support to the wrists and hands when doing a lot of typing.

The following diagram (Figure 3.25) and description summarises how the computer recognises a letter pressed on the keyboard:

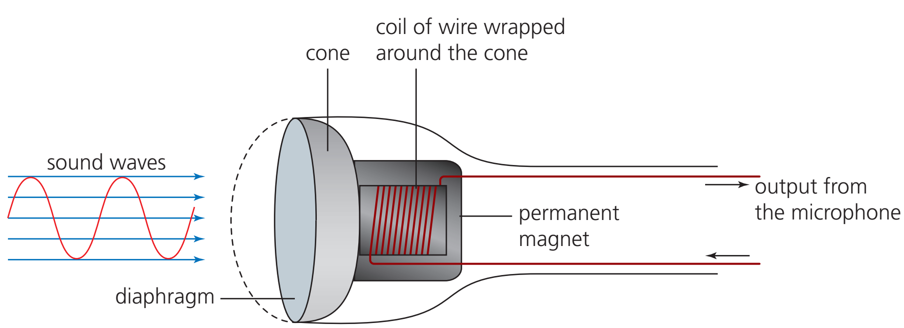
- There is a membrane or circuit board at the base of the keys
- In Figure 3.25, the 'H' key is pressed and this completes a circuit as shown
- The CPU in the computer can then determine which key has been pressed
- The CPU refers to an index file to identify which character the key press represents
- Each character on a keyboard has a corresponding ASCII value (see Chapter 1).



▲ **Figure 3.25** Diagram of a keyboard

Microphones

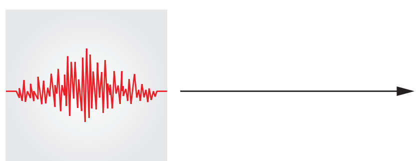
Microphones are either built into the computer or are external devices connected through the USB port or using Bluetooth connectivity. Figure 3.26 shows how a microphone can convert sound waves into an electric current. The current produced is converted to a digital format so that a computer can process it or store it (on, for example, a CD).



▲ **Figure 3.26** Diagram of how a microphone works

- When sound is created, it causes the air to vibrate.
- When a diaphragm in the microphone picks up the air vibrations, the diaphragm also begins to vibrate.
- A copper coil is wrapped around the cone which is connected to the diaphragm. As the diaphragm vibrates, the cone moves in and out causing the copper coil to move backwards and forwards.
- This forwards and backwards motion causes the coil to cut through the magnetic field around the permanent magnet, inducing an electric current.
- The electric current is then either amplified or sent to a recording device. The electric current is analogue in nature.

The electric current output from the microphone can also be sent to a computer where a sound card converts the current into a digital signal which can then be stored in the computer. The following diagram shows what happens when the word 'hut' is picked up by a microphone and is converted into digital values:



1000 0001
0001 1110
1000 1110
0001 1100
1100 1100
1101 1110

Sound wave for 'HUT'

Digital value after conversion

▲ **Figure 3.27** Analogue to digital conversion

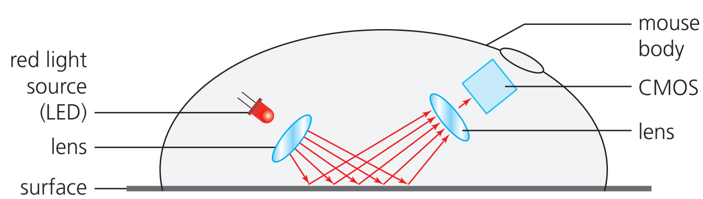
Look at Figure 3.27. The word 'hut' (in the form of a sound wave) has been picked up by the microphone; this is then converted using an analogue to digital converter (ADC) into digital values which can then be stored in a computer or manipulated as required using appropriate software.

6

Optical mouse

An **optical mouse** is an example of a **pointing device**. It uses tiny cameras to take 1500 images per second. Unlike an older mechanical mouse, the optical mouse can work on virtually any surface.

A red LED is used in the base of the mouse and the red light is bounced off the surface and the reflection is picked up by a **complementary metal oxide semiconductor (CMOS)**. The CMOS generates electric pulses to represent the reflected red light and these pulses are sent to a **digital signal processor (DSP)**. The processor can now work out the coordinates of the mouse based on the changing image patterns as it is moved about on the surface. The computer can then move the on-screen cursor to the coordinates sent by the mouse.



▲ **Figure 3.28** Diagram of an optical mouse

Benefits of an optical mouse over a mechanical mouse

- There are no moving parts, therefore it is more reliable.
- Dirt can't get trapped in any of the mechanical components.
- There is no need to have any special surfaces.

Most optical mice use Bluetooth connectivity rather than using a USB wired connection. While this makes the mouse more versatile, a wired mouse has the following advantages:

- no signal loss since there is a constant signal pathway (wire)
- cheaper to operate (no need to buy new batteries or charge batteries)
- fewer environmental issues (no need to dispose of old batteries).

2D

7

3D

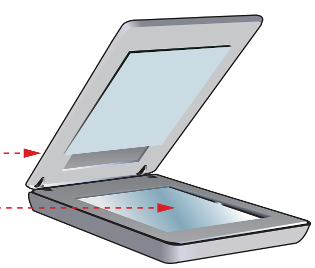
2D and 3D scanners

Scanners are either two dimensional (2D) or three dimensional (3D).

2D scanners

These types of scanner are the most common form and are generally used to input hard copy (paper) documents. The image is converted into an electronic form that can be stored in a computer.

A number of stages occur when scanning a document:



The cover is first raised

… then the document is placed on a glass panel …

… and then the cover is closed.

↓

A bright light then illuminates the document – modern scanners use a type of xenon lamp or LED that produces a very bright white light.

↓

A scan head moves across the document until the whole page has been scanned. An image of the document is produced, which is then sent to a lens using a series of mirrors.

The lens focuses the document image.

↓

The focused image now falls onto a charge couple device (CCD), which converts light into an electric current.

Essentially the CCD is made up of thousands of light-sensitive elements (or pixels). Each element creates an electric charge when light falls on it. This means that the scanned image is now turned into an electronic form.

Software produces a digital image from the electronic form.

▲ **Figure 3.29** How a 2D scanner works

Computers equipped with **optical character recognition (OCR)** software allow the scanned text from the document to be converted into a **text file format**. This means the scanned image can now be edited and manipulated by importing it into a word processor.

If the original document was a photograph or image, then the scanned image forms an image file such as JPEG.

3D scanners

3D scanners scan solid objects and produce a three-dimensional image. Since solid objects have x, y and z coordinates, these scanners take images at several points along these three coordinates. A digital image which represents the solid object is formed.

The scanned images can be used in **computer aided design (CAD)** or, more recently, sent to a 3D printer (see Section 3.2.2) to produce a working model of the scanned image.

There are numerous technologies used in 3D scanners – lasers, magnetic resonance, white light, and so on. It is beyond the scope of this book to look at these in any great depth; however, the second application that follows describes the technology behind one form of 3D scanning.

Application of 2D scanners at an airport

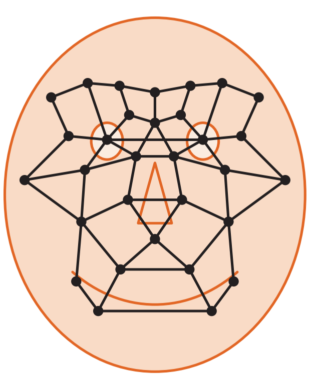
2D scanners are used at airports to read passports. They make use of OCR technology to produce digital images which represent the passport pages. Because of the OCR technology, these digital images can be manipulated in a number of ways.

Link

For more on ASCII, please see Chapter 1.

For example, the OCR software is able to review these images, select the text part, and then automatically put the text into the correct fields of an existing database. It is possible for the text to be stored in an ASCII format – it all depends on how the data is to be used.

At many airports the two-dimensional photograph in the passport is scanned and stored as a JPEG image. The passenger's face is also photographed using a digital camera (a 2D image is taken so it can be matched to the image taken from the passport). The two digital images are compared using face recognition/detection software. Key parts of the face are compared.



▲ **Figure 3.30** Face recognition

The face in Figure 3.30 shows several of the positions used by the face recognition software. Each position is checked when the software tries to compare two facial images. Data, such as:

- distance between the eyes
- width of the nose
- shape of the cheek bones
- length of the jaw line
- shape of the eyebrows,

are all used to uniquely identify a given face.

When the image from the passport and the image taken by the camera are compared, these key positions on the face determine whether or not the two images represent the same face.

Application of 3D scanning – computed tomographic (CT) scanners

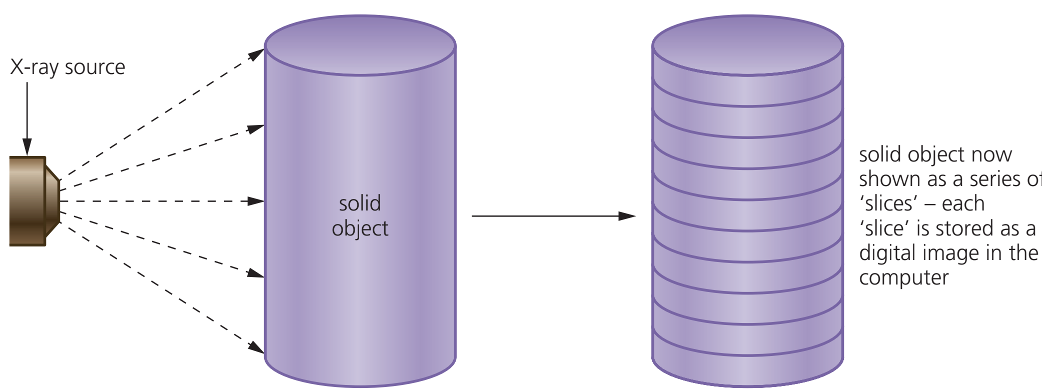
Computed tomographic (CT) scanners are used to create a 3D image of a solid object. This is based on tomography technology, which basically builds up an image of the solid object through a series of very thin 'slices'. Each of these 2D 'slices' make up a representation of the 3D solid object.

Each slice is built up by use of X-rays, radio frequencies or gamma imaging; although a number of other methods exist. Each 'slice' is then stored as a digital image in the computer memory. The whole of the solid object is represented digitally in the computer memory.

Depending on how the image is formed, this type of tomographic scanner can have different names. For example:

Name	CT Scanner	MRI	SPECT
Stands for	computerised tomography	magnetic resonance images	single photon emission computer tomography
Uses	X-rays	radio frequencies	gamma rays

Here is a simple example of how tomography works:



▲ **Figure 3.31** Tomography

Resistive

Infrared

Capacitive

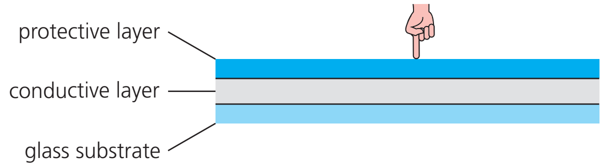
8 Touch screens

Touch screens are now a very common form of input device. They allow simple touch selection from a menu to launch an application (app). Touch screens allow the user to carry out the same functions as they would with a pointing device, such as a mouse. There are three common types of touch screen technologies currently being used by mobile phone and tablet manufacturers. Similar technologies are used in other touch screen applications (for example, food selection at a fast food restaurant):

- capacitive
- infrared
- resistive (most common method at the moment).

Capacitive touch screens

Capacitive touch screens are composed of a layer of glass (protective layer), a transparent electrode (conductive) layer and a glass substrate (see Figure 3.32). Since human skin is a conductor of electricity, when bare fingers (or a special stylus) touch the screen, the electrostatic field of the conductive layer is changed. The installed microcontroller is able to calculate where this change took place and hence determine the coordinates of the point of touching.



▲ **Figure 3.32** Capacitive touch screen

There are presently two main types of capacitive touch screens:

- surface
- projective.

The two methods work in a slightly different way but they both have the same general structure as shown in Figure 3.32.

With **surface capacitive screens**, sensors are placed at the corners of a screen. Small voltages are also applied at the corners of the screen creating an electric field. A finger touching the screen surface will draw current from each corner reducing the capacitance. A microcontroller measures the decrease in capacitance and hence determines the point where the finger touched the screen. This system only works with a bare finger or stylus.

Projective capacitive screens work slightly differently to surface capacitive screens. The transparent conductive layer is now in the form of an X-Y matrix pattern. This creates a three dimensional (3D) electrostatic field. When a finger touches the screen, it disturbs the 3D electrostatic field allowing a microcontroller to determine the coordinates of the point of contact. This system works with bare fingers, stylus and thin surgical or cotton gloves. It also allows multi-touch facility (for example, pinching or sliding).

Advantages compared to the other two technologies

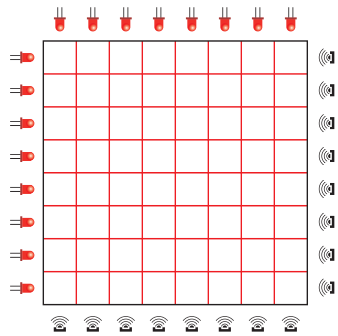
- Better image clarity than resistive screens, especially in strong sunlight
- Very durable screens that have high scratch resistance
- Projective capacitive screens allow multi-touch.

Disadvantages compared to the other two technologies

- Surface capacitive screens only work with bare fingers or a special stylus
- They are sensitive to electromagnetic radiation (such as magnetic fields or microwaves).

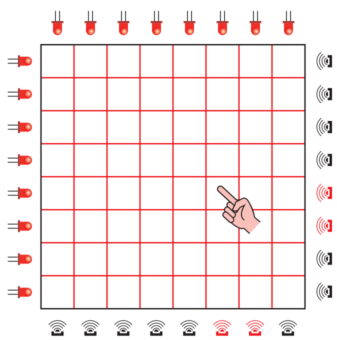
Infrared touch screens

Infrared touch screens use a glass screen with an array of sensors and infrared transmitters.



▲ **Figure 3.33** Array of infrared transmitters and sensors surrounding the screen

The sensors detect the infrared radiation. If any of the infrared beams are broken (for example, with a finger touching the screen), the infrared radiation reaching the sensors is reduced. The sensor readings are sent to a microcontroller that calculates where the screen was touched:



◀ **Figure 3.34** Infrared screen touched causing sensors (shown in red) to show a reduction in infrared radiation – thus the exact position where the screen was touched can be calculated

Advantages compared to the other two technologies

- Allows multi-touch facilities
- Has good screen durability
- The operability isn't affected by a scratched or cracked screen.

Disadvantages compared to the other two technologies

- The screen can be sensitive to water or moisture
- It is possible for accidental activation to take place if the infrared beams are disturbed in some way
- Sometimes sensitive to light interference.

Resistive touch screens

Resistive touch screens are made up of two layers of electrically resistive material with a voltage applied across them. The upper layer is made of flexible polyethylene (a type of polymer) with a resistive coating on one side (see Figure 3.35). The bottom layer is made of glass also with a resistive coating (usually indium tin oxide) on one side. These two layers are separated by air or an inert gas (such as argon). When the top polyethylene surface is touched, the two layers make contact. Since both layers are coated in a resistive material a circuit is now completed which results in a flow of electricity. The point of contact is detected where there was a change in voltage.

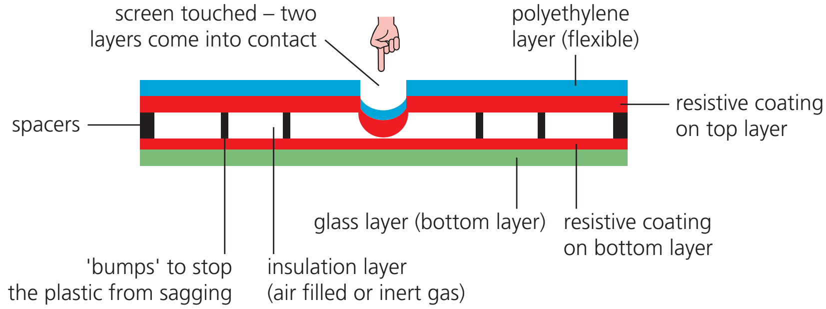


Figure 3.35 Resistive touch screen

A microcontroller converts the voltage (created when the two resistive layers touch) to digital data, which it then sends to the microprocessor.

Advantages compared to the other two technologies

- Good resistance to dust and water
- Can be used with bare fingers, stylus and gloved hand.

Disadvantages compared to the other two technologies

- Low touch sensitivity (sometimes have to press down harder)
- Doesn't support multi-touch facility
- Poor visibility in strong sunlight
- Vulnerable to scratches on the screen (made of polymer).

3.2.2 Output devices

Actuators

When a computer is used to control devices, such as a conveyer belt or a valve, it is usually necessary to use an **actuator** to, for example, start/stop the conveyer belt or open/close the valve. An actuator is a mechanical or electromechanical device such as a relay, solenoid or motor. We will consider a solenoid as the example; this converts an electrical signal into a magnetic field producing linear motion:

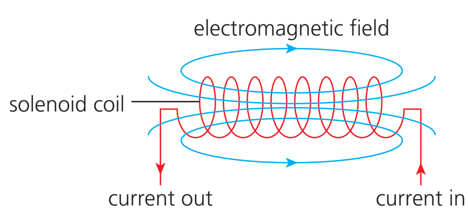


Figure 3.36 A solenoid

If a plunger (for example, a magnetised metal bar) is placed inside the coil, it will move when a current is applied to the coil (see Figure 3.36). This would allow the solenoid to operate a valve or a switch, for example. There are also examples of rotary solenoids where a cylindrical coil is used. In this case, when a current is supplied to the coil, it would cause a rotational movement of the plunger.

Light projectors

There are two common types of light projector:

- digital light projector (DLP)
- liquid crystal display (LCD) projector.

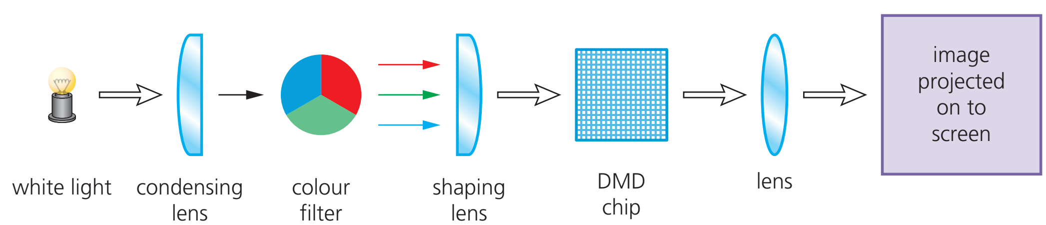
Projectors are used to project computer output onto larger screens or even onto interactive whiteboards. They are often used in presentations and in multimedia applications. The next section compares the basic operation of the two projector technologies.

Digital light projectors (DLP)

The use of millions of micro mirrors on a small **digital micromirror device** (**DMD** chip) is the key to how these devices work.

The number of micro mirrors and the way they are arranged on the DMD chip determines the resolution of the digital image. When the micro mirrors tilt towards the light source, they are ON. When the micro mirrors tilt away from the light source, they are OFF. This creates a light or dark pixel on the projection screen. The micro mirrors can switch on or off several thousand times a second creating various grey shades – typically 1024 grey shades can be produced (for example, if the mirror switches on more often than it switches off, it will produce a lighter shade of grey). This is known as a greyscale image.

A bright white light source (for example, from a xenon bulb) passes through a colour filter on its way to the DMD chip. The white light is split into the primary colours: red, green and blue – the DLP projector can create over 16 million different colours. The ON and OFF states of each micro mirror are linked with colours from the filter to produce the coloured image.



▲ **Figure 3.37** A digital light projector (DLP)

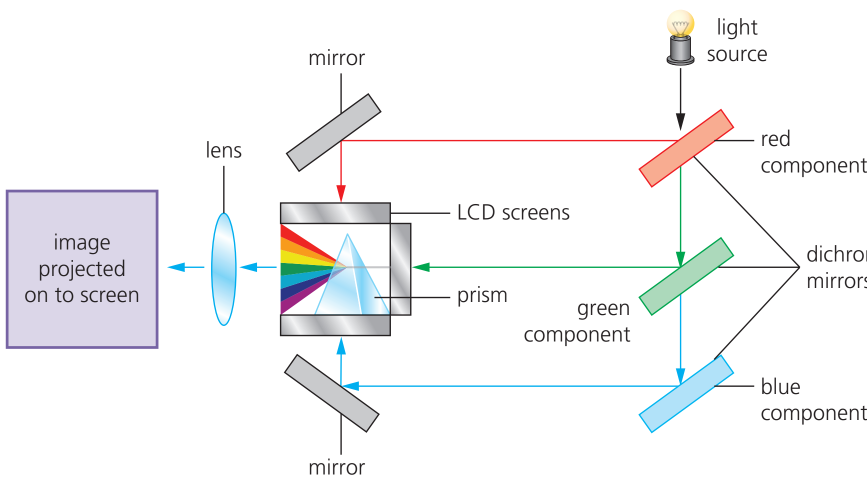
Note: The DMD chip is a microoptoelectromechanical system (MOEMS) that contains several thousand microscopic mirrors (made out of polished aluminium metal) arranged on the chip surface. They are each about 16 μm (16×10^{-6} metres) in size and each corresponds to a pixel in the displayed screen image.

Liquid crystal display (LCD) projector

These are older technology than DLP. Essentially a high-intensity beam of light passes through an LCD display and then onto a screen. How this works in principle is described below:

- a powerful beam of white light is generated from a bulb or LED inside the projector body
- this beam of light is then sent to a group of chromatic-coated mirrors (known as dichromic mirrors); these reflect the light back at different wavelengths

- when the white light hits these mirrors, the reflected light has wavelengths corresponding to red, green and blue light components
- these three different coloured light components pass through three LCD screens (each screen is composed of thousands of tiny pixels which can either block light or let it through; this produces a ***monochromatic*** image)...
- ... consequently, three different versions of the same image are now produced – one is the whole image in different shades of red, one is the whole image in different shades of green and one is the whole image in different shades of blue
- these images are then re-combined using a special prism to produce a full colour image
- finally, the image passes through the projector lens onto a screen.



▲ **Figure 3.38** LCD projector

Advantages and disadvantages of the two types of projector

▼ **Table 3.5** Advantages and disadvantages of DLP and LCD projectors

	Advantages	Disadvantages
Digital light projector (DLP)	higher contrast ratios	image tends to suffer from 'shadows' when showing a moving image
	higher reliability/longevity	
	quieter running than LCD projector	DLP do not have grey components in the image
	uses a single DMD chip, which mean no issues lining up the images	the colour definition is frequently not as good as LCD projectors because the colour saturation is not as good (colour saturation is the intensity of a colour)
	smaller and lighter than LCD projector	
	they are better suited to dusty or smoky atmospheres than LCD projectors	
LCD projector	give a sharper image than DLP projectors	although improving, the contrast ratios are not as good as DLPs
	have better colour saturation than DLP projectors	LCD projectors have a limited life (that is, the longevity is not as good as DLPs)
	more efficient in their use of energy than DLP technology – consequently they generate less heat	since LCD panels are organic in nature, they tend to degrade with time (screens turn yellow and the colours are subsequently degraded over time)

▲ **Figure 3.39** Inkjet printer

Inkjet and laser printers

Inkjet printers

Inkjet printers are essentially made up of:

- a print head, which consists of nozzles that spray droplets of ink onto the paper to form characters
- an ink cartridge or cartridges; either one cartridge for each colour (blue, yellow and magenta) and a black cartridge or one single cartridge containing all three colours + black (Note: some systems use six colours)
- a stepper motor and belt, which moves the print head assembly across the page from side to side
- a paper feed, which automatically feeds the printer with pages as they are required.

The ink droplets are produced currently using two different technologies:

Thermal bubble – tiny resistors create localised heat which makes the ink vaporise. This causes the ink to form a tiny bubble; as the bubble expands, some of the ink is ejected from the print head onto the paper. When the bubble collapses, a small vacuum is created which allows fresh ink to be drawn into the print head. This continues until the printing cycle is completed.

Piezoelectric – a crystal is located at the back of the ink reservoir for each nozzle. The crystal is given a tiny electric charge which makes it vibrate. This vibration forces ink to be ejected onto the paper; at the same time more ink is drawn in for further printing.

When a user wishes to print a document using an inkjet printer, the following sequence of events takes place. Whatever technology is used, the basic steps in the printing process are the same.

▼ **Table 3.6** Steps in inkjet printing process

Stage in process	Description of what happens
1	the data from the document is sent to a printer driver
2	the printer driver ensures that the data is in a format that the chosen printer can understand
3	a check is made by the printer driver to ensure that the chosen printer is available to print (e.g. is it busy, is it off-line, is it out of ink, and so on)
4	the data is then sent to the printer and it is stored in a temporary memory known as a printer buffer
5	a sheet of paper is then fed into the main body of the printer; a sensor detects whether paper is available in the paper feed tray – if it is out of paper (or the paper is jammed) then an error message is sent back to the computer
6	as the sheet of paper is fed through the printer, the print head moves from side to side across the paper printing the text or image; the four ink colours are sprayed in their exact amounts to produce the desired final colour
7	at the end of each full pass of the print head, the paper is advanced very slightly to allow the next line to be printed; this continues until the whole page has been printed
8	if there is more data in the printer buffer, then the whole process from stage 5 is repeated until the buffer is finally empty
9	once the printer buffer is empty, the printer sends an interrupt to the CPU in the computer; this is a request for more data to be sent to the printer; the whole process continues until the whole of the document has been printed

▲ **Figure 3.40** Laser printer

Laser printers

Laser printers use dry powder ink rather than liquid ink and make use of the properties of static electricity to produce the text and images. Unlike inkjet printers, laser printers print the whole page in one go. Colour laser printers use 4 toner cartridges – blue, cyan, magenta and black. Although the actual technology is different to monochrome printers, the printing method is similar but coloured dots are used to build up the text and images.

The following table describes briefly the stages that occur when a document is printed using a laser printer:

▼ **Table 3.7** Steps in laser printing process

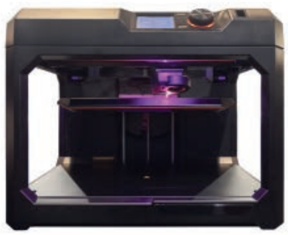
Stage in process	Description of what happens
1	the data from the document is sent to a printer driver
2	the printer driver ensures that the data is in a format that the chosen printer can understand
3	a check is made by the printer driver to ensure that the chosen printer is available to print (e.g. is it busy, is it off-line, is it out of ink, and so on)
4	the data is then sent to the printer and it is stored in a temporary memory known as a printer buffer
5	the start of the printing process involves a printing drum being given a positive charge; as this drum rotates, a laser beam is scanned across it removing the positive charge in certain areas; this leaves negatively charged areas that exactly match the text/images of the page to be printed
6	the drum is then coated with positively charged toner (powdered ink); since the toner is positively charged, it only sticks to the negatively charged parts of the drum
7	a negatively charged sheet of paper is then rolled over the drum
8	the toner on the drum now sticks to the paper to produce an exact copy of the page sent to the printer
9	to prevent the paper sticking to the drum, the electric charge on the paper is removed after one rotation of the drum
10	the paper finally goes through a fuser which is a set of heated rollers; the heat melts the ink so that it fixes permanently to the paper
11	at the very end, a discharge lamp removes all the electric charge from the drum making it ready to print the next page

Applications of inkjet and laser printers

The choice of whether to use an inkjet printer or a laser printer depends on which features make it the most appropriate output device for the given application.

Inkjet printer – inkjet printers are often used for printing one-off photos or where only a few pages of good quality, colour printing is needed; the small ink cartridges or small paper trays would not be an issue with such applications.

Laser printer – these devices produce high quality printouts and are very fast when making multiple copies of a document; any application that needs high volume printing (in colour or monochrome) would choose the laser printer (for example, producing a large number of high-quality flyers or posters for advertising). Laser printers have two advantages: they have large toner cartridges and large paper trays (often holding more than a ream of paper).



▲ **Figure 3.41** Typical 3D printer

▲ **Figure 3.42** An alloy wheel

3D printers

3D printers are used to produce solid objects that actually work. They are primarily based on inkjet and laser printer technology. The solid object is built up layer by layer using materials such as: powdered resin, powdered metal, paper or ceramic.

The alloy wheel in Figure 3.42 was made using an industrial 3D printer.

It was made from many layers (0.1 mm thick) of powdered metal using a technology known as **binder 3D printing**.

Other examples are discussed below.

The following information describes some of the features of 3D printing:

- Various types of 3D printers exist; they range from the size of a microwave oven up to the size of a small car.
- 3D printers use additive manufacturing (i.e. the object is built up layer by layer); this is in sharp contrast to the more traditional method of subtractive manufacturing (i.e. removal of material to make the object). For example, making a statue using a 3D printer would involve building it up layer by layer using powdered stone until the final object was formed. The subtractive method would involve carving the statue out of solid stone (i.e. removing the stone not required) until the final item was produced. Similarly, CNC machining removes metal to form an object; 3D printing would produce the same item by building up the object from layers of powdered metal.
- **Direct 3D printing** uses inkjet technology; a print head can move left to right as in a normal printer. However, the print head can also move up and down to build up the layers of an object.
- **Binder 3D printing** is similar to direct 3D printing. However, this method uses two passes for each of the layers; the first pass sprays dry powder and then on the second pass a binder (a type of glue) is sprayed to form a solid layer.
- Newer technologies are using lasers and UV light to harden liquid polymers; this further increases the diversity of products which can be made.

How to create a solid object using 3D printers

There are a number of steps in the process of producing an object using 3D printers. The steps are summarised below:

A design is made using computer aided design (CAD) software

↓

The finalised drawing is imported into some special software that prepares it in a format that is understood by the 3D printer

↓

The 3D printer is first set up to allow the solid object to be made

↓

The solid object is built up layer by layer (often only 0.1 mm thick); this can take several hours depending on the thickness of the layers, the material used and the size of the final object

↓

The object is removed from the printer and is then prepared; for example, some use a jelly-like support that needs to be washed away by immersion in water, some require the removal of excess plastic powder and others require the cutting away of unused material; in many cases, the object has to be left to 'cure' for a few hours.

◀ **Figure 3.43** How to create an object using a 3D printer

Uses of 3D printing

3D printing is regarded as being possibly the next 'industrial revolution' since it will change the manufacturing methods in many industries. The following list is just a glimpse into what we know can be made using these printers; in the years that follow, this list will probably fill an entire book:

- the covering of prosthetic limbs can be made to exactly fit the limb
- making items to allow precision reconstructive surgery (e.g. facial reconstruction following an accident); the parts made by this technique are more precise in their design since they can be made from exact scanning of the skull
- in aerospace, manufacturers are looking at making wings and other parts using 3D technology; the bonus will be lightweight precision parts
- fashion and art – 3D printing allows new creative ideas to be developed
- making parts for items no longer in production e.g. suspension parts for a vintage car.

These are just a few of the exciting applications which make use of this new technology.

Find out more

The reader is invited to do a search on the internet to find out new and innovative research into 3D printing applications.

LED and LCD screens

LED screens

An LED screen is made up of tiny light emitting diodes (LEDs). Each LED is either red, green or blue in colour. By varying the electric current sent to each LED, its brightness can be controlled, producing a vast range of colours.

This type of screen tends to be used for large outdoor displays due to the brilliance of the colours produced. Recent advancements in LED technology have led to the introduction of OLED (organic LED) screens (see later).

The reader needs to be very careful here. Many television screens are advertised as LED when in fact they are LCD screens which are *backlit* using LEDs.

LCD screens

LCD screens are made up of tiny liquid crystals. These tiny crystals make up an array of pixels that are affected by changes in applied electric fields. How this works is outside the scope of this book. But the important thing to realise is that for LCD screens to work, they require some form of backlighting.

Because LCD's don't produce any light, LCD screens are back-lit using light emitting diode (LED) technology and must not be confused with pure LED screens. Use of LED backlighting gives a very good contrast and brightness range. Before the use of LEDs, LCD screens used cold cathode fluorescent lamp (CCFL) as the back-lit method.

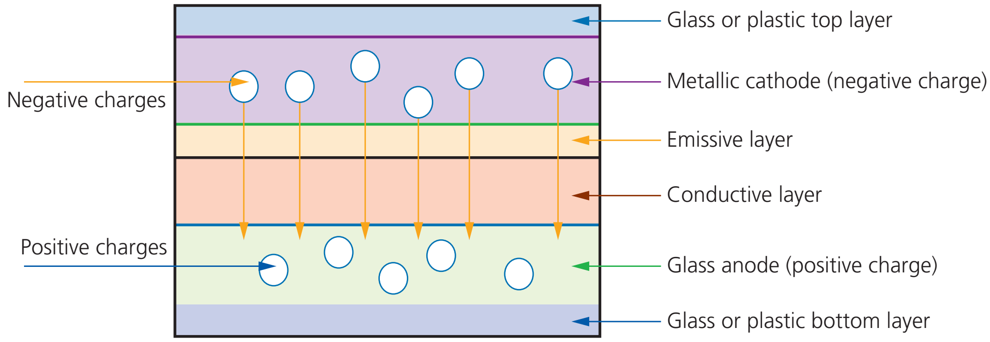
Essentially, CCFL uses two fluorescent tubes behind the LCD screen which supply the light source. When LEDs are used, a matrix of tiny blue-white LEDs is used behind the LCD screen.

LEDs have become increasingly more popular, as the method of back lighting, due to a number of advantages over older CCFL technology:

- LEDs reach their maximum brightness almost immediately (there is no need to 'warm up' before reaching full efficiency)
- LEDs give a whiter light that sharpens the image and makes the colours appear more vivid; CCFL had a slightly yellowish tint
- LEDs produce a brighter light that improves the colour definition
- monitors using LED technology are much thinner than monitors using CCFL technology
- LEDs last indefinitely; this makes the technology more reliable and makes for a more consistent product
- LEDs consume very little power which means they produce less heat as well as using less energy.

Organic light emitting diodes (OLED)

Newer LED technology is making use of **organic light emitting diodes (OLEDs)**. These use organic materials (made up of carbon compounds) to create semi-conductors that are very flexible. Organic films are sandwiched between two charged electrodes (one is a metallic **cathode** and the other a glass **anode**). When an electric field is applied to the electrodes, they give off light. This means that no form of backlighting is required. This allows for very thin screens. It also means that there is no longer a need to use LCD technology, since OLED is a self-contained system.



▲ **Figure 3.44** How an OLED screen works

But the important aspect of OLED technology is how thin this makes the screen. It is possible, using OLED technology, to bend screens to any shape (see Figure 3.45). When this is adopted by mobile phone manufacturers, it makes it possible to develop phones that can wrap around your wrist – much like a watch strap. Imagine screens so thin that they can be folded up and placed in your pocket until they are needed. Or how about using folding OLED displays attached to fabrics creating 'smart' clothing (this could be used on outdoor survival clothing where an integrated circuit, mobile phone, GPS receiver and OLED display could all be sewn into the clothing)?

▲ **Figure 3.45** OLED television (curved screen)

Advantages of using OLED compared to existing LEDs and LCDs:

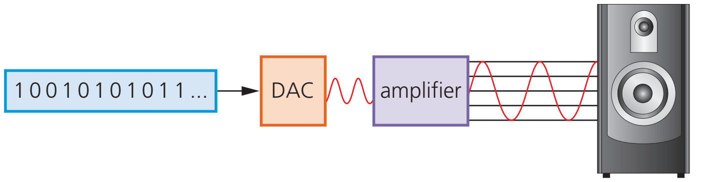
- The plastic, organic layers of an OLED are thinner, lighter and more flexible than the crystal structures used in LEDs or LCDs.
- The light-emitting layers of an OLED are lighter; OLED layers can be made from plastic rather than the glass as used in LED and LCD screens.
- OLEDs give a brighter light than LEDs.
- OLEDs do not require backlighting like LCD screens – OLEDs generate their own light.
- Since OLEDs require no backlighting, they use much less power than LCD screens (most of the LCD power is used to do the backlighting); this is very important in battery-operated devices such as mobile phones.
- Since OLEDs are essentially plastics, they can be made into large, thin sheets (this means they could be used on large advertising boards in airports, subways, and so on).
- OLEDs have a very large field of view, about 170 degrees, which makes them ideal for use in television sets and for advertising screens.

(Loud) speakers

Loudspeakers are output devices that produce sound. When connected to a computer system, digitised sound stored on a file needs to be converted into sound as follows:

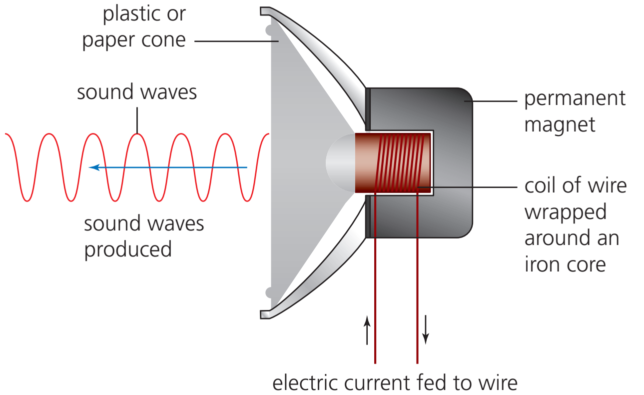
- The digital data is first passed through a digital to analogue converter (DAC) where it is changed into an electric current.
- This is then passed through an amplifier (since the current generated by the DAC will be very small); this creates a current large enough to drive a loudspeaker.
- This electric current is then fed to a loudspeaker where it is converted into sound.

The following schematic shows how this is done:



▲ **Figure 3.46** Digital to analogue conversion

As Figure 3.46 shows, if the sound is stored in a computer file, it must pass through a **digital to analogue converter (DAC)** to convert binary (digital) data into an analogue form (electric current) that can then drive the loudspeaker. Figure 3.47 shows how the loudspeaker converts the electric current into sound:



▲ **Figure 3.47** Diagram showing how a loudspeaker works

- When an electric current flows through the coil of wire that is wrapped around an iron core, the core becomes a temporary electromagnet; a permanent magnet is also positioned very close to this electromagnet.
- As the electric current through the coil of wire varies, the induced magnetic field in the iron core also varies. This causes the iron core to be attracted towards the permanent magnet and as the current varies this will cause the iron core to vibrate.
- Since the iron core is attached to a cone (made of paper or thin synthetic material), this causes the cone to vibrate, producing sound waves.

Activity 3.4

1 **a** Explain the main differences in operation of a laser printer compared to an inkjet printer.

b **i** Name one application of a laser printer and one application of an inkjet printer.

ii For each of your named applications in **b i**, give a reason why the chosen printer is the most suitable.

2 The nine stages in printing a page using an inkjet printer are shown below. The nine stages are NOT in the correct order.

By writing the letters ***A*** to ***I***, put each of the stages into the correct order.

A – the data is then sent to the printer and it is stored in a temporary memory known as a printer buffer

B – as the sheet of paper is fed through the printer, the print head moves from side to side across the paper printing the text or image; the four ink colours are sprayed in their exact amounts to produce the desired final colour

C – the data from the document is sent to a printer driver

D – once the printer buffer is empty, the printer sends an interrupt to the CPU in the computer; this is a request for more data to be sent to the printer; the whole process continues until the whole of the document has been printed

E – the printer driver ensures that the data is in a format that the chosen printer can understand

F – at the end of each full pass of the print head, the paper is advanced very slightly to allow the next line to be printed; this continues until the whole page has been printed

G – a check is made by the printer driver to ensure that the chosen printer is available to print (e.g. is it busy, is it off-line, is it out of ink, and so on)

H – if there is more data in the printer buffer, then the whole process from stage 5 is repeated until the buffer is finally empty

I – a sheet of paper is then fed into the main body of the printer; a sensor detects whether paper is available in the paper feed tray – if it is out of paper (or the paper is jammed) then an error message is sent back to the computer

3 **a** Explain the difference between LED screens and LCD-LED backlit screens.

b Modern LCD screens use blue-white LEDs as backlighting. Cold cathode ray (fluorescent) tubes were used. Give three advantages of using LEDs.

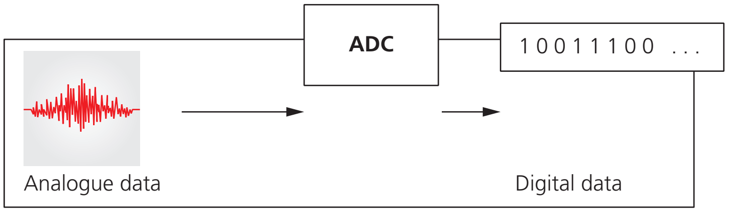
4 Filipe has music stored on his computer's backing store. He wishes to listen to his music through a pair of loudspeakers. Describe how the music, which is digitally stored can be played through his two analogue loudspeakers.

▲ **Figure 3.48** Mercury thermometer

3.2.3 Sensors

Sensors are input devices which read or measure physical properties from their surroundings. Examples include temperature, pressure, acidity level and length (there are many others). Real data is analogue in nature; this means it is constantly changing and doesn't have a single discrete value. Therefore, analogue data needs some form of interpretation by the user, for example, the temperature measurement on a mercury thermometer requires the user to look at the height of the mercury column and use their best judgement (by looking at the scale) to find the temperature. There are an infinite number of values depending on how precisely the height of the mercury column is measured.

However, computers cannot make any sense of these physical quantities so the data needs to be converted into a digital format. This is usually achieved by an **analogue to digital converter (ADC)**. This device converts physical values into discrete digital values.



▲ **Figure 3.49** ADC

Link

For more on actuators see Section 3.2.2.

When the computer is used to control devices, such as a motor or a valve, it is necessary to use a digital to analogue converter (DAC) since these devices need analogue data to operate in many cases. Actuators are used in such control applications.

Sensor readings may cause the microprocessor to, for example, alter a valve or a motor that will then change the next reading taken by the sensor. So the output from the microprocessor will impact on the next input received as it attempts to bring the system within the desired parameters. This is known as feedback.

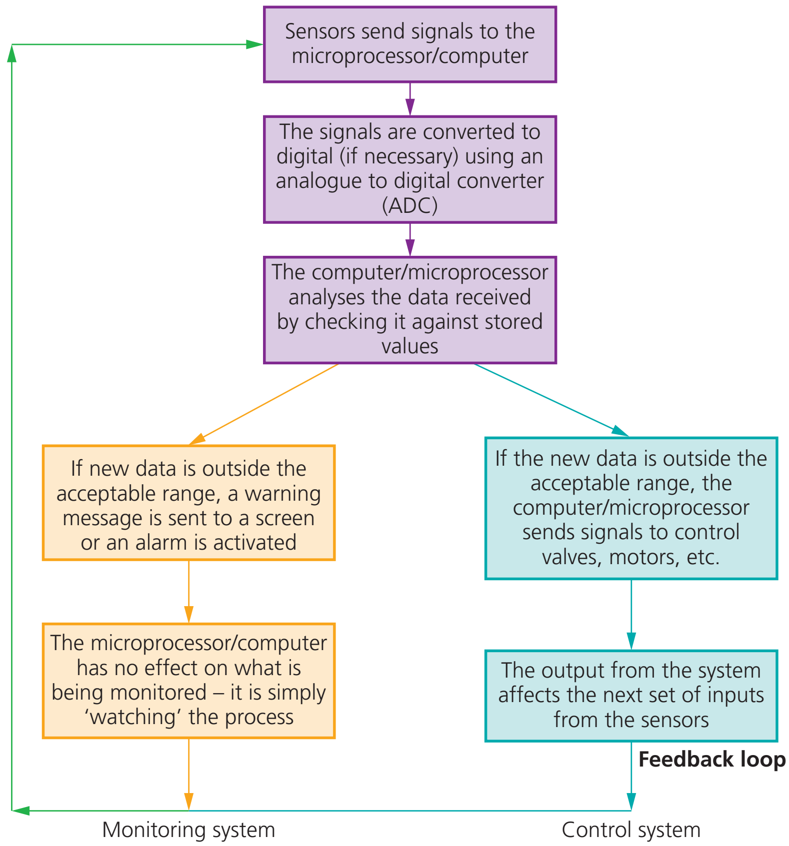
It is important to realise that sensors send out constant values; they don't suddenly send a reading when the parameter they are measuring changes. It is the microprocessor they are giving the input to that will analyse the incoming data and take the necessary action.

Table 3.8 shows a number of common sensors and examples of applications where the sensors might be used.

▼ **Table 3.8** Sensors

Sensor	Description of sensor	Example applications
Temperature	measures temperature of the surroundings by sending signals; these signals will change as the temperature changes	• control of a central heating system • control/monitor a chemical process • control/monitor temperature in a greenhouse
Moisture	measures water levels in, for example, soil (it is based on the electrical resistance of the sample being monitored)	• control/monitor moisture levels in soil in a greenhouse • monitor the moisture levels in a food processing factory
Humidity	this is slightly different to moisture; this measures the amount of water vapour in, for example, a sample of air (based on the fact that the conductivity of air will change depending on the amount of water present)	• monitor humidity levels in a building • monitor humidity levels in a factory manufacturing microchips • monitor/control humidity levels in the air in a greenhouse
Light	these use photoelectric cells that produce an output (in the form of an electric current) depending on the brightness of the light	• switching street lights on or off depending on light levels • switch on car headlights automatically when it gets dark
Infrared (active)	these use an invisible beam of infrared radiation picked up by a detector; if the beam is broken, then there will be a change in the amount of infrared radiation reaching the detector (sensor)	• turn on car windscreen wipers automatically when it detects rain on the windscreen • security alarm system (intruder breaks the infra-red beam)
Infrared (passive)	these sensors measure the heat radiation given off by an object, for example, the temperature of an intruder or the temperature in a fridge	• security alarm system (detects body heat) • monitor the temperature inside an industrial freezer or chiller unit
Pressure	a pressure sensor is a transducer and generates different electric currents depending on the pressure applied	• weighing of lorries at a weighing station • measure the gas pressure in a nuclear reactor
Acoustic/sound	these are basically microphones that convert detected sound into electric signals/pulses	• pick up the noise of footsteps in a security system • detect the sound of liquids dripping at a faulty pipe joint
Gas	most common ones are oxygen or carbon dioxide sensors; they use various methods to detect the gas being monitored and produce outputs that vary with the oxygen or carbon dioxide levels present	• monitor pollution levels in the air at an airport • monitor oxygen and carbon dioxide levels in a greenhouse • monitor oxygen levels in a car exhaust
pH	these measure acidity through changes in voltages in, for example, soil	• monitor/control acidity levels in the soil in a greenhouse • control acidity levels in a chemical process
Magnetic field	these sensors measure changes in magnetic fields – the signal output will depend on how the magnetic field changes	• detect magnetic field changes (for example, in mobile phones and CD players) • used in anti-lock braking systems in cars
Accelerometer	these are sensors that measure acceleration and motion of an application, i.e. the change in velocity (a piezoelectric cell is used whose output varies according to the change in velocity)	• used in cars to measure rapid deceleration and apply air bags in a crash • used by mobile phones to change between portrait and landscape mode
Proximity	these sensors detect the presence of a nearby object	• detect when a face is close to a mobile phone screen and switches off screen when held to the ear
Flow (rate)	these sensors measure the flow rate of a moving liquid or gas and produce an output based on the amount of liquid or gas passing over the sensor	• used in respiratory devices and inhalers in hospitals • measure gas flows in pipes (for example, natural gas)
Level	these sensors use ultrasonics (to detect changing liquid levels in, for example, a tank) or capacitance/conductivity (to measure static levels (for example, height of water in a river) – note, level sensors can also be optical or mechanical in nature	• monitor levels in a petrol tank in a car • in a pharmaceutical process where powder levels in tablet production need to be monitored • leak detection in refrigerant (air conditioning)

Sensors are used in both monitoring and control applications. There is a subtle difference between how these two methods work (the flowchart is a simplification of the process):



▲ **Figure 3.50** Monitoring and control systems using sensors

Examples of monitoring

- Monitoring of a patient in a hospital for vital signs such as heart rate, temperature, etc.
- Monitoring of intruders in a burglar alarm system
- Checking the temperature levels in a car engine
- Monitoring pollution levels in a river.

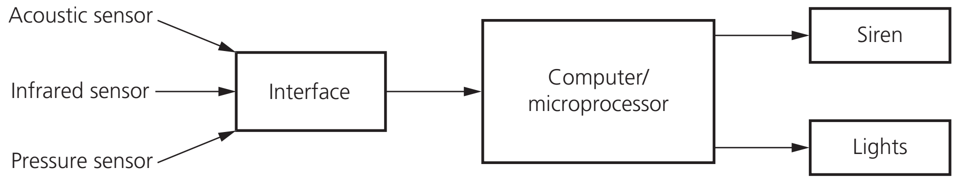
Examples of control

- Turning street lights on at night and turning them off again during daylight
- Controlling the temperature in a central heating/air conditioning system
- Chemical process control (for example, maintaining temperature and pH of process)

- Operating anti-lock brakes on a car when necessary
- Controlling the environment in a green house.

Monitoring applications

Security systems



▲ **Figure 3.51** Security system

Note: compare this to Figure 3.9 (embedded systems) which shows the security system in more detail. Figure 3.51 concentrates on the sensor input.

The security monitoring system will carry out the following actions:

- the system is activated by keying in a password on a keypad
- the **infrared sensor** will pick up the movement of an intruder in the building
- the **acoustic sensor** will pick up sounds such as footsteps or breaking glass
- the **pressure sensor** will pick up the weight of an intruder coming through a door or through a window
- the sensor data is passed through an ADC if it is in an analogue form ...
- ... to produce digital data
- the computer/microprocessor will sample the digital data coming from these sensors at a given frequency (e.g. every 5 seconds) ...
- ... the data is compared with the stored values by the computer/microprocessor
- if any of the incoming data values are outside the acceptable range, then the computer sends a signal ...
- ... to a siren to sound the alarm, or
- ... to a light to start flashing
- a DAC is used if the devices need analogue values to operate them
- the alarm continues to sound/lights continue to flash until the system is re-set with a password.

Monitoring of patients in a hospital

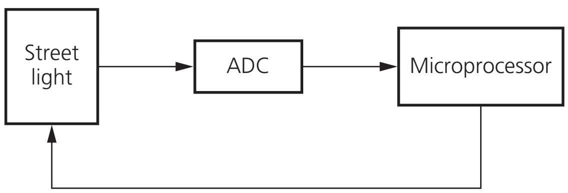
- A number of sensors are attached to the patient ...
- ... these measure vital signs such as: temperature, heart rate, breathing rate, etc.
- these sensors are all attached to a computer system
- the sensors constantly send data back to the computer system
- the computer samples the data at frequent intervals
- the range of acceptable values for each parameter is keyed into the computer
- the computer compares the values from the sensors with those values keyed in
- if anything is out of the acceptable range, a signal is sent by the computer ...
- ... to sound an alarm
- if data from the sensors is within range, the values are shown in either graphical form on a screen and/or a digital read out
- monitoring continues until the sensors are disconnected from the patient.

Control applications

Control of street lighting

This next sequence shows how a microprocessor is used to control the operation of a street lamp. The lamp is fitted with a light sensor which constantly sends data to the microprocessor. The data value from the sensor changes according to whether it is sunny, cloudy, raining or it is night time (etc.):

- the light sensor sends data to the ADC interface
- this changes the data into digital form and sends it to the microprocessor
- the microprocessor samples the data every minute (or at some other frequency rate)
- if the data from the sensor < value stored in memory …
- … a signal is sent from the microprocessor to the street lamp …
- … and the lamp is switched on
- the lamp stays switched on for 30 minutes before the sensor readings are sampled again (this prevents the lamp flickering off and on during brief heavy cloud cover, for example)
- if the data from the sensor >= value stored in memory …
- … a signal is sent from the microprocessor to the street lamp …
- … and the lamp is switched off
- the lamp stays switched off for 30 minutes before sensor readings are sampled again (this prevents the lamp flickering off and on during heavy cloud cover for example).



▲ **Figure 3.52** Street lighting

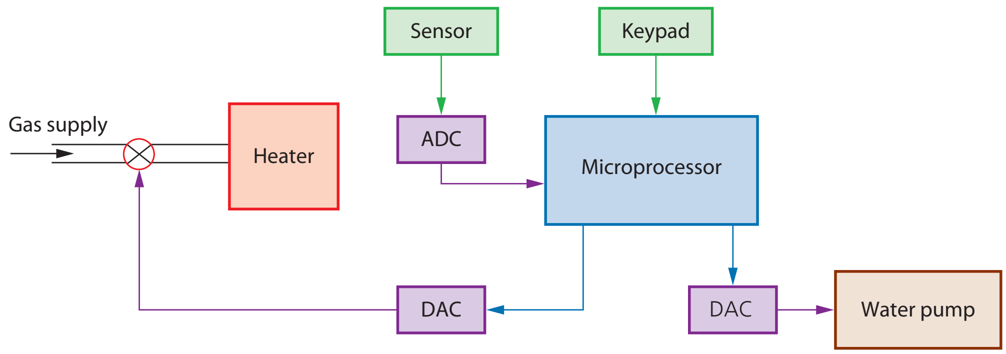
Anti-lock braking systems (on cars)

Anti-lock braking systems (ABS) on cars use **magnetic field sensors** to stop the wheels locking up on the car if the brakes have been applied too sharply:

- when one of the car wheels rotates too slowly (i.e. it is locking up), a magnetic field sensor sends data to a microprocessor
- the microprocessor checks the rotation speed of the other three wheels
- if they are different (i.e. rotating faster), the microprocessor sends a signal to the braking system …
- … and the braking pressure to the affected wheel is reduced …
- … the wheel's rotational speed is then increased to match the other wheels
- the checking of the rotational speed using these magnetic field sensors is done several times a second …
- … and the braking pressure to all the wheels can be constantly changing to prevent any of the wheels locking up under heavy braking …
- … this is felt as a 'judder' on the brake pedal as the braking system is constantly switched off and on to equalise the rotational speed of all four wheels
- if one of the wheels is rotating too quickly, braking pressure is increased to that wheel until it matches the other three.

Central heating systems

In this example, a gas supply is used to heat water using a heater. A valve on the gas supply is controlled by a microprocessor and is opened if the heating levels need to be increased. A water pump is used to pump hot water around the central heating system whenever the temperature drops below a pre-set value:



▲ **Figure 3.53** Controlling a central heating system

So how does this work?

- the required temperature is keyed in and this is stored in the microprocessor memory (this is called the pre-set value)
- the temperature sensor is constantly sending data readings to the microprocessor
- the sensor data is first sent to an ADC to convert the analogue data into digital data
- the digital data is sent to the microprocessor
- the microprocessor compares this data with the pre-set value
- if the temperature reading >= pre-set value then no action is taken
- if the temperature reading < pre-set value, then a signal is sent …
- … to an actuator (via a DAC) to open the gas valve to the heater
- … to an actuator (via a DAC) to turn on the water pump
- the process continues until the central heating is switched off.

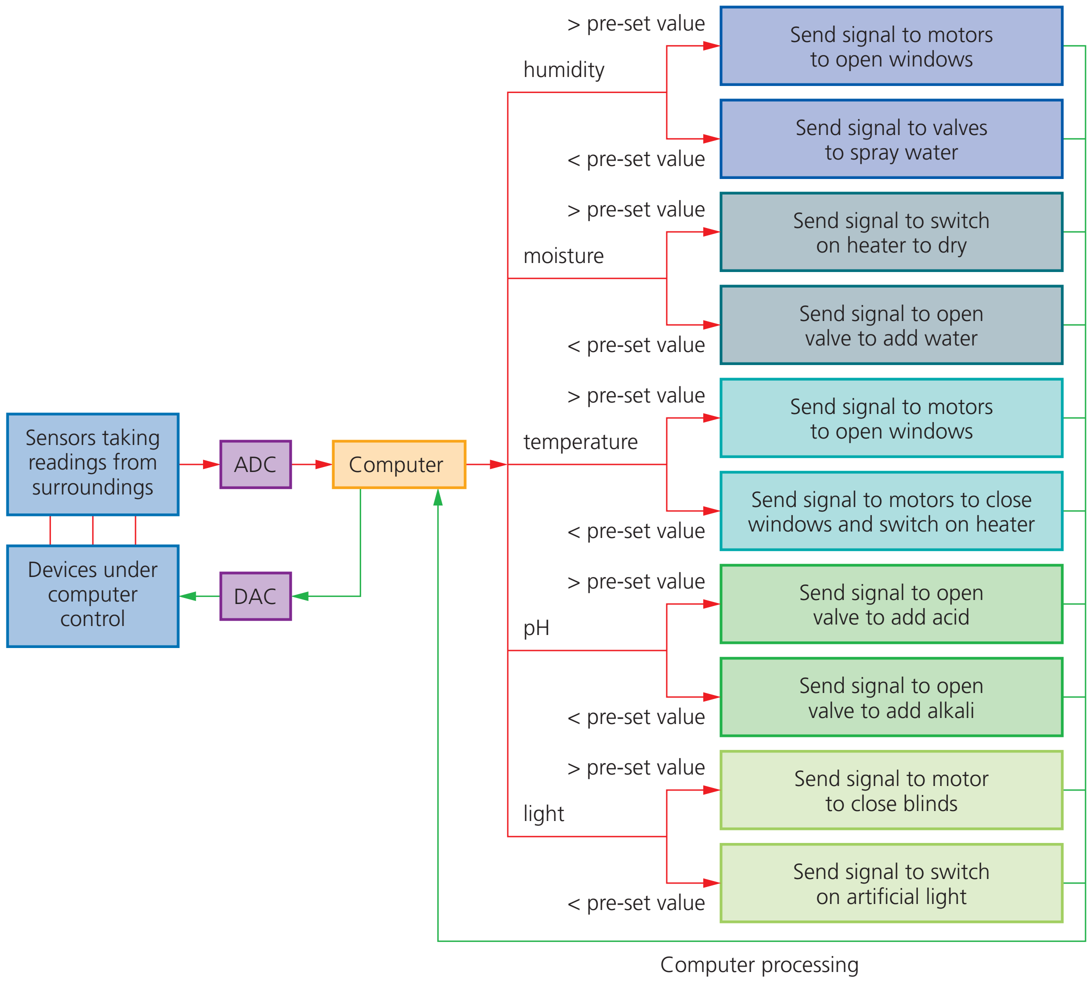
Chemical process control

A certain chemical process only works if the temperature is above 70°C and the pH (acidity) level is less than 3.5. Sensors are used as part of the control system. A heater is used to heat the reactor and valves are used to add acid when necessary to maintain the acidity. The following description shows how the sensors and computer are used to control this process:

- **temperature** and **pH sensors** read data from the chemical process
- this data is converted to digital using an ADC and is then sent to the computer
- the computer compares the incoming data with pre-set values stored in memory
- … if the temperature < 70°C, a signal is sent to switch on the heater
- … if the temperature >= 70°C, a signal is sent to switch off the heaters
- … if the pH > 3.5, then a signal is sent to open a valve and acid is added
- … if the pH <= 3.5, then a signal is sent to close this valve
- the computer signals will be changed into analogue signals using a DAC so that it can control the heaters and valves
- this continues as long as the computer system is activated.

Greenhouse environment control

Five different sensors could be used here to control the greenhouse environment, namely: **humidity**, **moisture**, **temperature**, **pH** and **light**. To simplify this problem the control mechanisms are shown in Figure 3.54.



▲ **Figure 3.54** Control of greenhouse environment

Because of the number of sensors, this is clearly quite a complex problem. Let us consider the humidity sensor only. This sends a signal to an ADC, which then sends a digital signal to the computer. This compares the input with stored (pre-set) values and decides what action needs to be taken (follow the orange lines in Figure 3.54). If humidity is > pre-set value, the computer sends a signal to a DAC (follow the green lines in the figure) to operate the motors to open windows thus reducing the humidity. If it is < pre-set value, the computer sends a signal to open valves to spray water into the air (follow the green lines). If the reading = pre-set value, then no action is taken (this isn't shown in the diagram since it could follow either direction). The control process continues as long as the system is switched on. Similar arguments can be used for all five sensors.

Activity 3.5

1 An air conditioning unit in a car is being controlled by a microprocessor and a number of sensors.

a Describe the main differences between ***control*** and ***monitoring*** of a process.

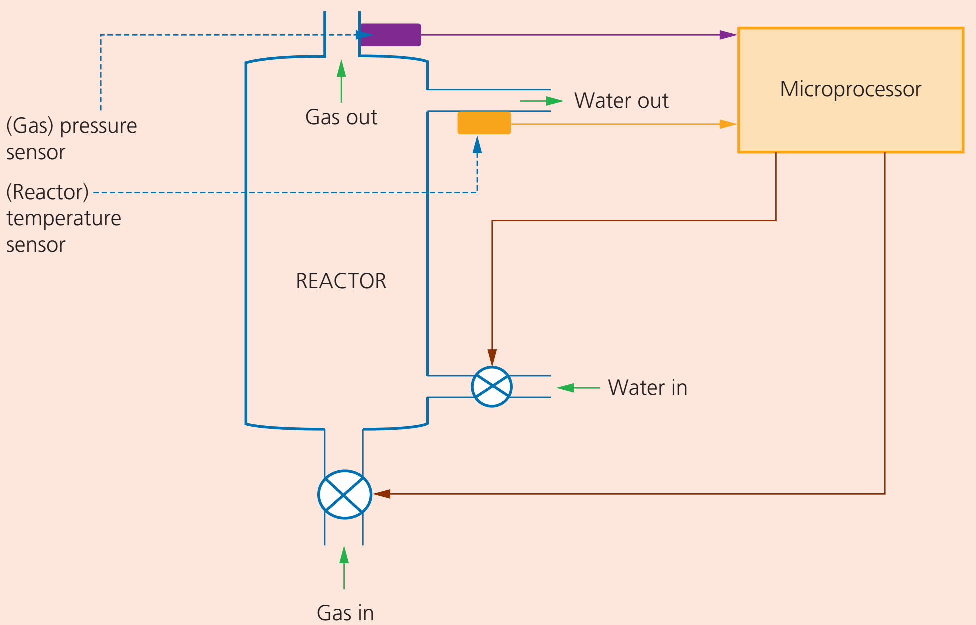
b Describe how the sensors and microprocessor would be used to control the air conditioning unit in the car. Name at least two different sensors that might be used and explain the role of positive feedback in your description.

You might find drawing a diagram of your intended process to be helpful.

2 Look at Figure 3.54 and describe how the pH sensor would be used to control the acidity levels in the soil to optimise growing conditions in the greenhouse.

3 The diagram (Figure 3.55) below shows a nuclear reactor. Two of the sensors used in the control and monitoring of the reactor are:

- a temperature sensor to monitor the reactor temperature (if this exceeds 300°C then the water flow into the reactor is increased)
- a pressure sensor to monitor the gas pressure of carbon dioxide circulating in the reactor (if this is less 10 bar then the gas pump is opened)
- note that: ⊗ represents a gas or liquid pump

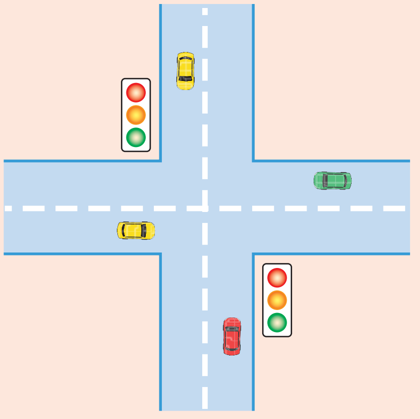


▲ **Figure 3.55**

Describe how the sensors and microprocessor are used to maintain the correct water (reactor) temperature and gas pressure in the reactor. Name any other hardware devices you think may be needed in your description.

4 The junction (Figure 3.56) is controlled by traffic lights.

Describe how sensors in the road and a microprocessor are used to control the traffic at the junction. The microprocessor is able to change the colour sequence of the lights.



▲ **Figure 3.56**