

# ROBOTICS: DESIGNING AND MAKING A WALKING ROBOT

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Robots often appear in films, usually at the command of an evil master or mistress intent upon serious wrongdoing! The history of real robots began about forty years ago with a patent for 'programmed article transfer' machine from an American engineer called George Devol. The word 'robot' is from the Czech *robota* - meaning forced labour or drudgery.

Robots take on many different forms. Some medical schools use computer-controlled human replicas which breathe, blink, have a heartbeat and will react to certain medication. They are used to teach students how to deal with cardiac arrest, changes in pulse or blood pressure, and other emergencies.

The Sierra Engineering Company of California produces a whole range of accurate human replicas for testing car safety systems, aeroplane ejector seats and space equipment. They have human temperatures and are covered in plastic skin which approximates to the resilience of human skin. They also have simulated bones and internal organs.

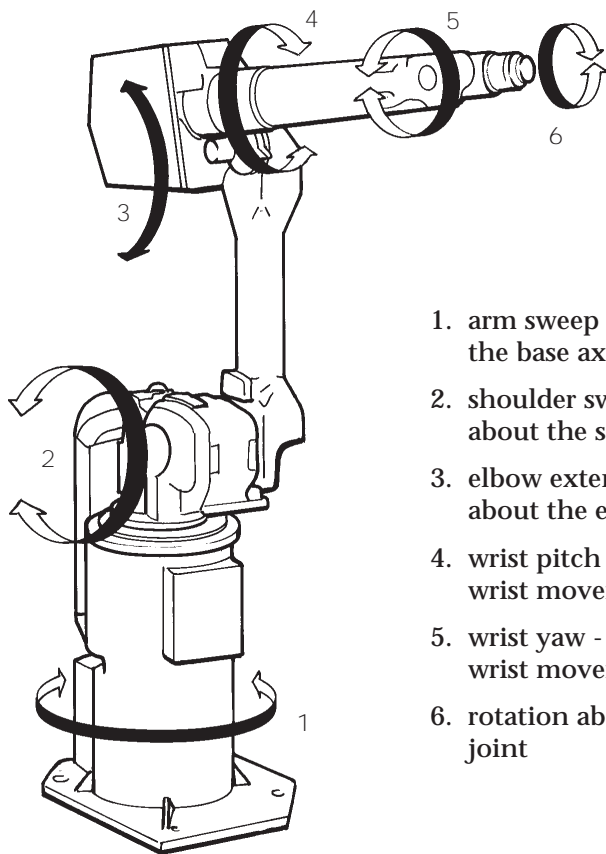
## ROBOTS IN MANUFACTURING INDUSTRY

In the context of manufacturing technology, a formal definition for a robot would include the idea that is a **reprogrammable** piece of machinery that uses a **manipulator**.

There are obviously many other reprogrammable pieces of equipment, such as computer numerically controlled (CNC) lathes and milling machines - even electronic calculators. In industry there are numerous instances in which manipulators are used, for example in moving and controlling paper in the printing industries. **Robots are the only devices that bring these two features together.**

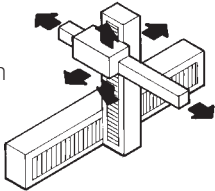
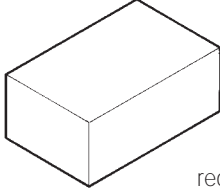
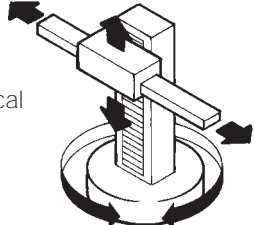
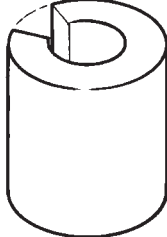
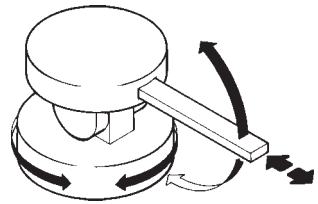
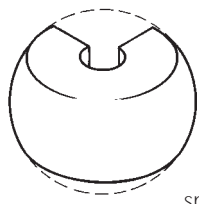
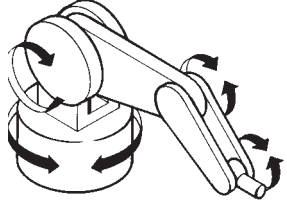
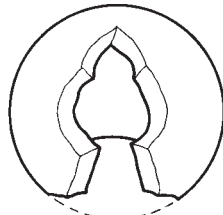
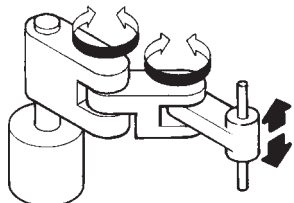
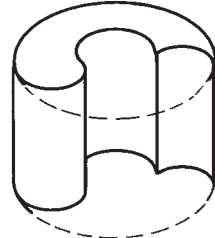
We spend a lot of time in our everyday lives manipulating objects - using a pen or pencil to write or draw would be examples of this. In doing this, we move our bodies through a combination of independent movements.

Many robotic devices are **anthropomorphic** i.e. they look like human arms, which is not surprising as they are often designed to replace human workers. The ways in which robots move are described by **6 degrees of freedom**:



1. arm sweep - rotation about the base axis
2. shoulder swivel - rotation about the shoulder axis
3. elbow extension - rotation about the elbow axis
4. wrist pitch - up and down wrist movement
5. wrist yaw - side-to-side wrist movements
6. rotation about the wrist joint

Degrees of arm freedom is important to robot work envelope. **Work envelope** is the area in which the robot can reach and work. An anthropomorphic robot has a spherical work envelope. Less complex robots with fewer degrees of freedom have work envelopes that are shaped like rectangles, cylinders or other shapes.

CONFIGURATION (Degrees of freedom)	WORK ENVELOPE
<p>cartesian</p> 	 <p>rectangular</p>
<p>cylindrical</p> 	 <p>cylindrical</p>
<p>polar</p> 	 <p>spherical</p>
<p>anthropometric</p> 	 <p>spherical</p>
<p>SCARA</p> 	 <p>cylindrical</p>

WHY ROBOTS?

- they may be stronger - allowing them to lift heavy weights or apply great forces.
- they are able to work for very long periods as they do not request tea breaks or holidays. They are sometimes, but rarely sick!
- they are consistent. Once they are taught how to perform a task they are able to repeat it with great precision. Human workers will tire over a period of time, with a loss of productivity, and the possibility of making mistakes.
- they can work in a number of environments that humans would find either unpleasant, or even dangerous. They are able to handle very hot or cold objects, components that are radioactive. They can work in the dark.

In robotics terms, the arm becomes the **manipulator**; the hand is often called the **end effector** as it may be:

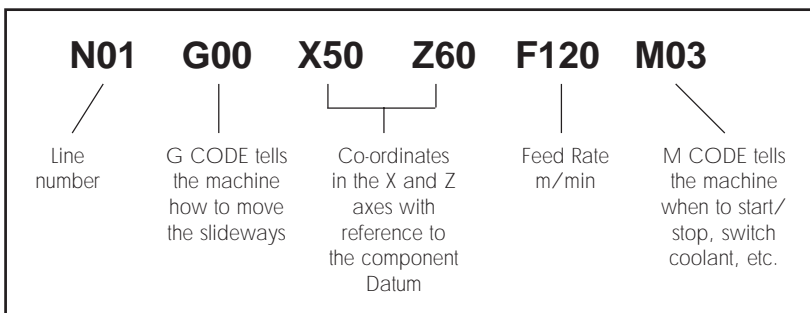
- used to grip tools (such as paint spraying or welding equipment),
- magnetic,
- suction pads (locating the windscreens in motor cars on the assembly line),

as well as anthropomorphic grippers.

In anthropomorphic terms, the robot has the following equivalents:

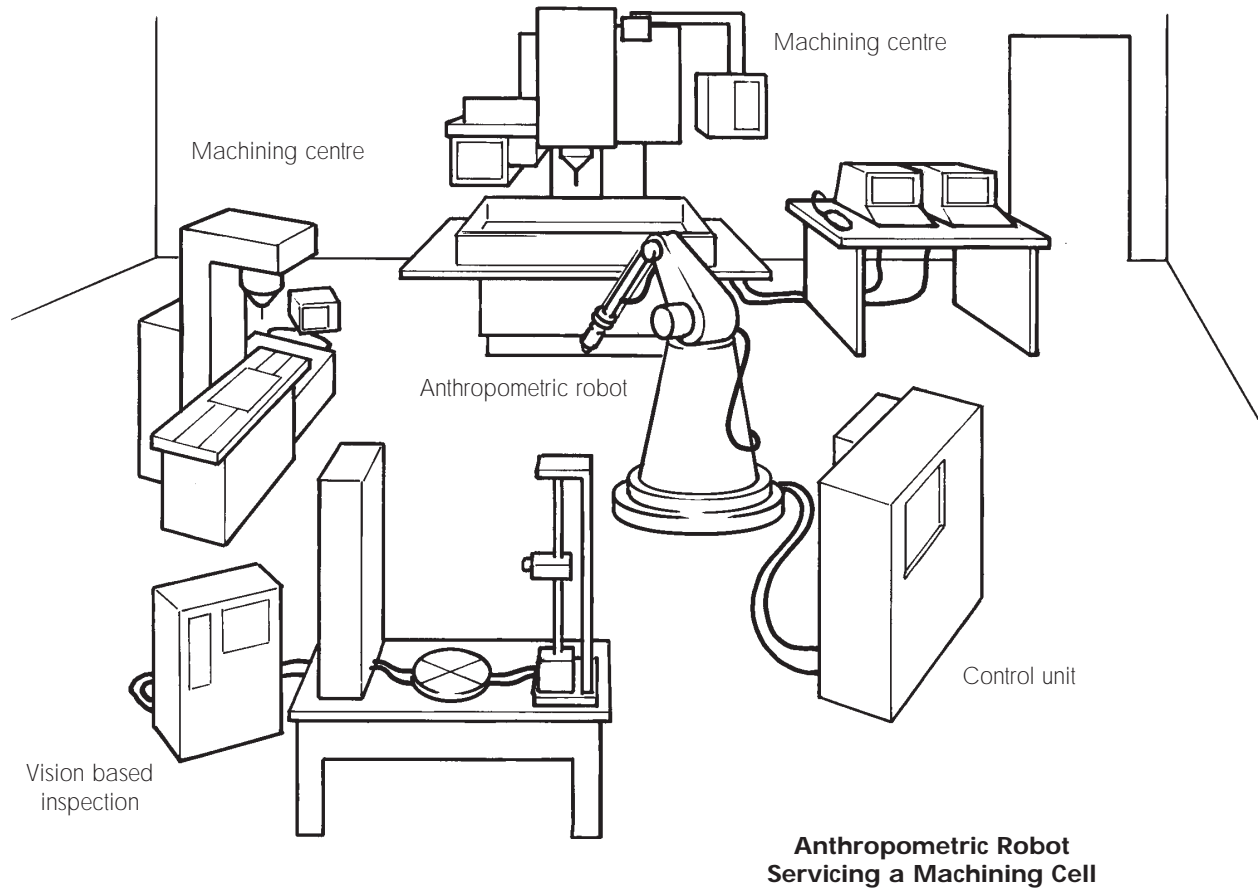
Brain	Computer
Senses (sight, sound, smell, feel)	Measuring devices (cameras, pressure sensors etc.)
Blood supply	Electrical/pneumatic/hydraulic power
Arm/wrist/hand with appropriate muscles	Manipulator and end effector
Possibly legs and feet	Wheels or tracks

The robot's task is determined by a **computer program** which will specify the order of events.



**Applications when the end-effector is usually a gripper**

- loading and removing products from machines - for example during an injection moulding process. In some cases, a robot is used to move parts or components from one machine to the next, or between conveyor belts or processing lines. These parts may be hot, cold, heavy, or dangerous.

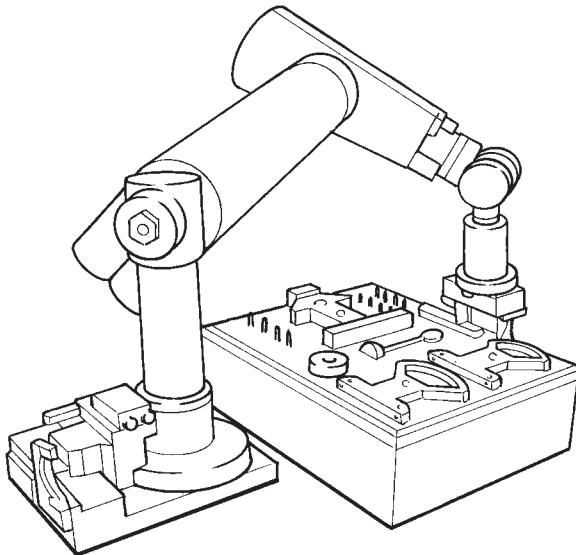


***Applications when the end-effector is usually a tool***

- welding or paint spraying - in motor car industry

***Applications when the end-effector could be both***

- inspection and testing - checking of dimensions, shape or defects. Robots are used for looking for cracks in castings, or leaks around car windscreens.
- assembly - 'pick and place' robots to place electronic components on to printed circuit boards; assembling electric motors etc. In addition to fitting parts together (which may include the use of screw thread fasteners), assembly processes may also include the gluing, sealing or welding of components.



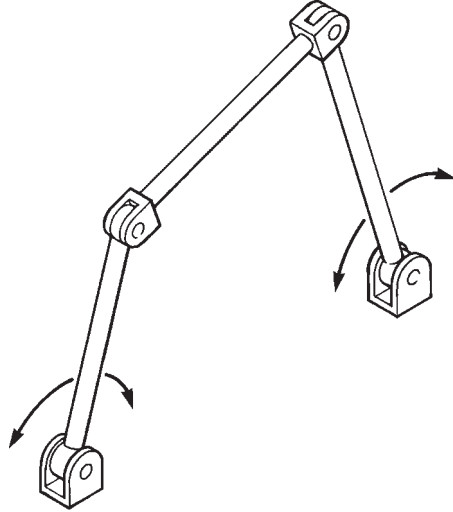
**MECHANISMS AND ROBOTS**

Mechanical systems use moving parts such as levers, gears and linkages. An input movement to a mechanical system causes an output movement that might be very different.

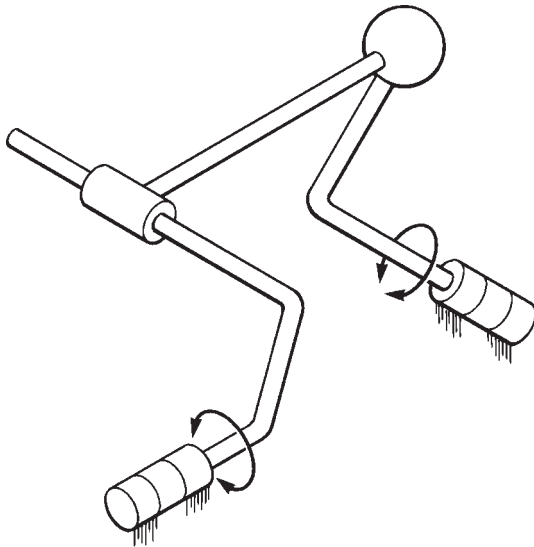
Robots employing mechanical systems are designed so that a particular point or link in the mechanism moves in a known and controlled way in response to an input command from the computer program.

In terms of robot design and configuration, there are two types:

a) **Planar** - restricted to one degree of freedom

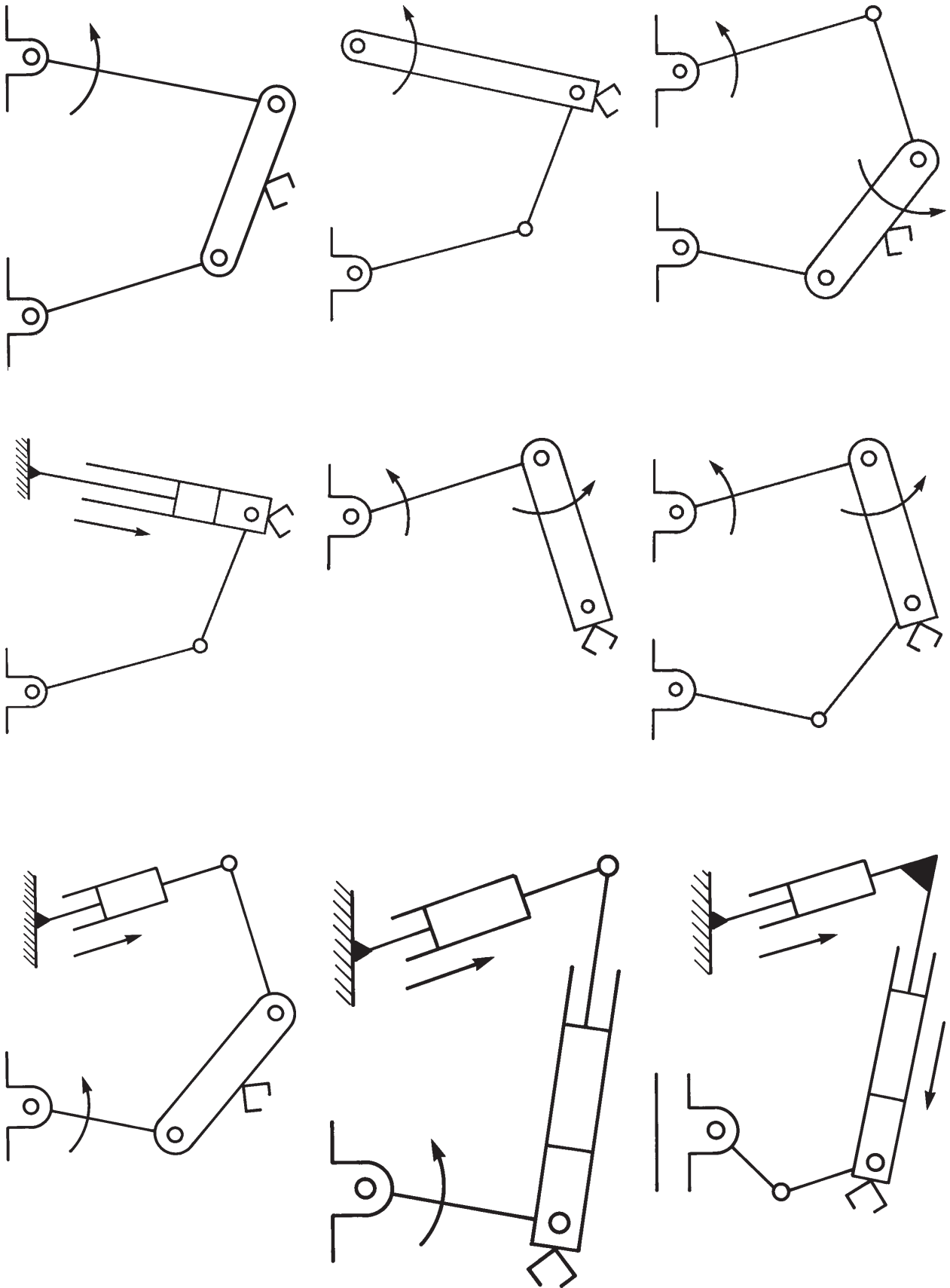


b) **Spatial**

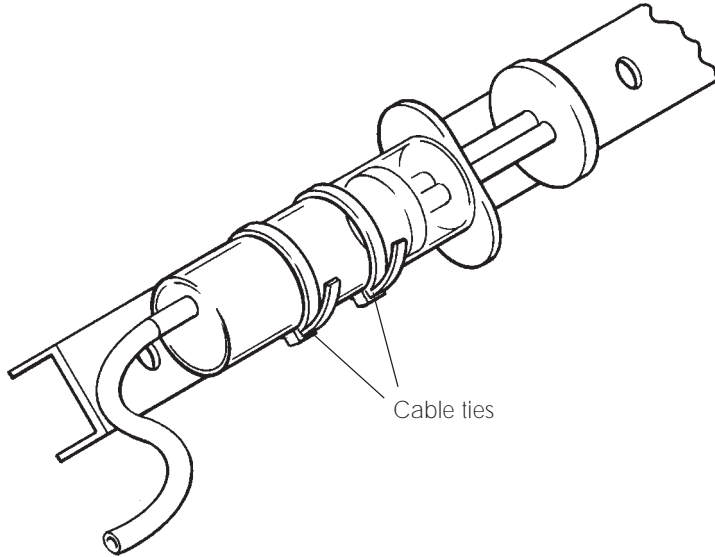


Mechanical systems can be used to control the movements of both robotic manipulators (arms) and end effectors (hands). In order to understand the potential of these systems, you can attempt the following activities - these will give you very useful design experience when you come to make your own robot later on.

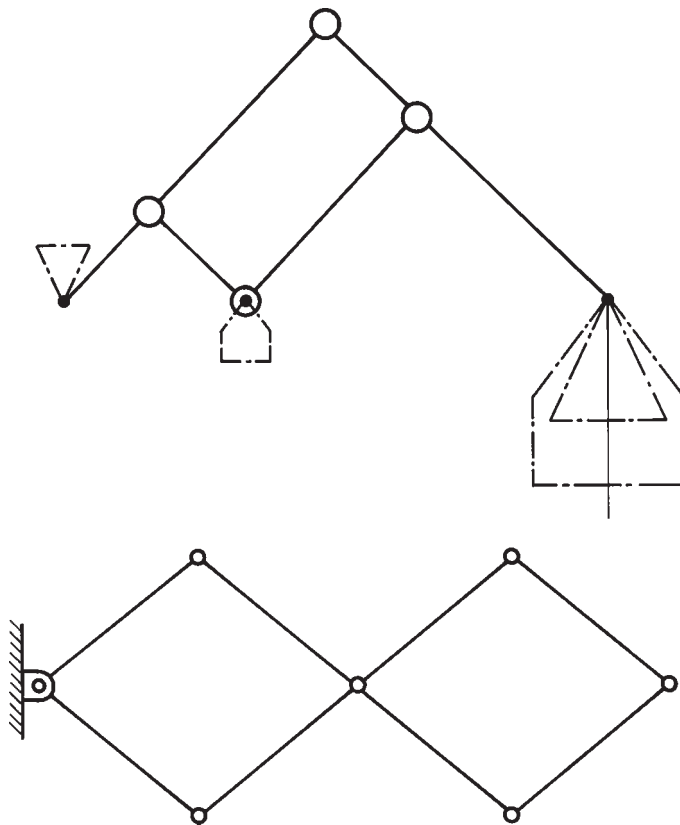
You can construct the linkages by using components from kits such as 'Meccano' 'Legotechnic' or 'Polymech'. Alternatively, you could make your own parts by the using the 'roll tube' technique as described in the TEP 14-16 textbook on 'Structures', or aluminium structural sections produced by the press tool in the 14-16 'Manufacturing' text.



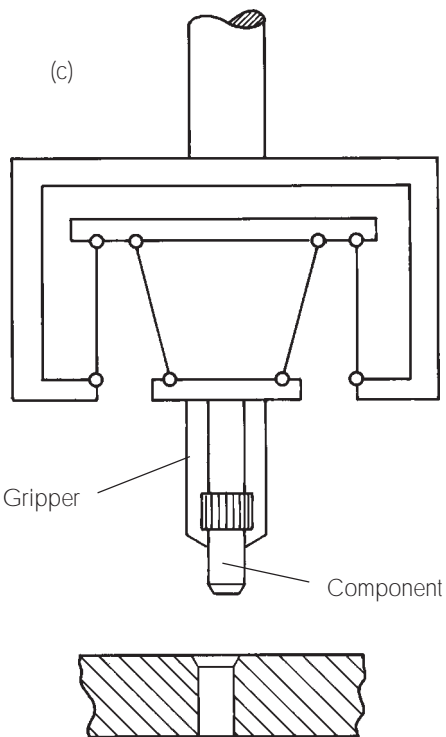
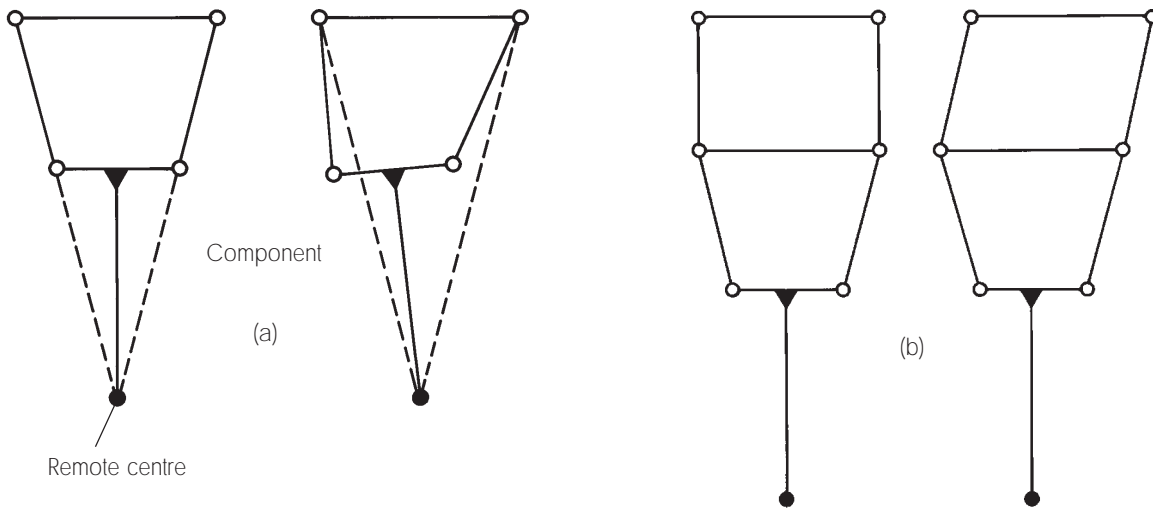
Syringes can be used where they are pistons and cylinders (pneumatic or hydraulic) as part of the systems. These can be attached to the linkage firmly and neatly using cable ties.



It is also possible to use pantograph linkages. These form the basis of the activity in the 14-16 book for Mechanical Systems involving the design and manufacture of an engraver.



You may also wish to consider a particular arrangement called the **remote centre compliance (RCC) linkage**. This parallelogram-based system allows for both lateral (i.e. the gripper may be to either side of where it should be) and angular errors (it should be vertical, but it is not) to be accommodated - a very important feature where a robot is involved for example, in assembly tasks.



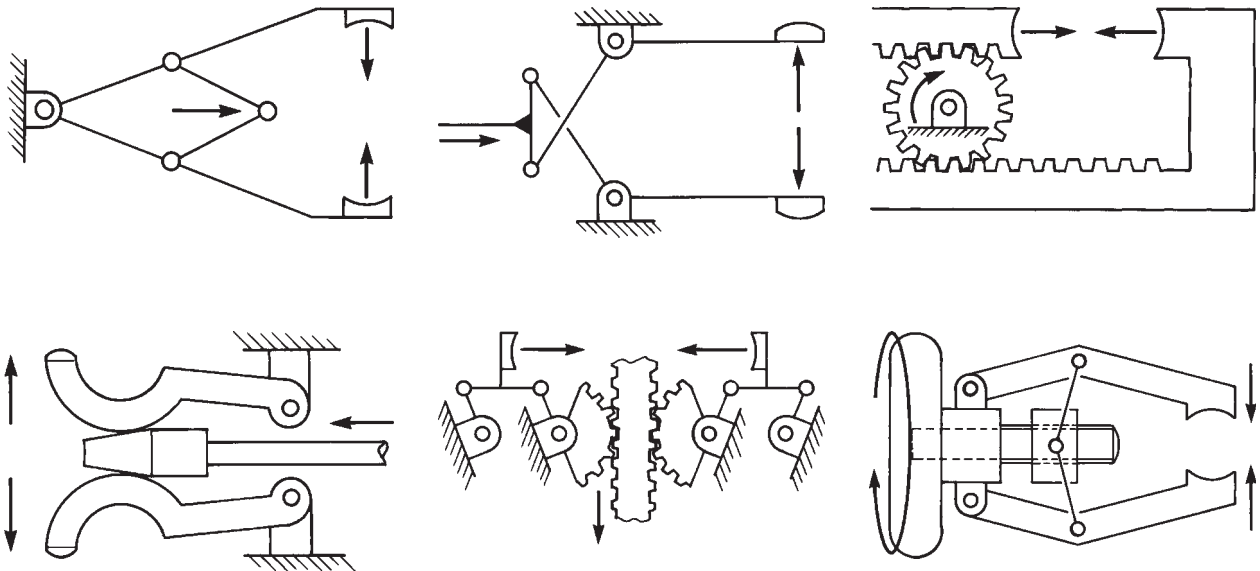
The remote centre compliance (RCC) linkage which allows for errors:

- a) in the angle of component, and
- b) in its position

A practical use of this linkage is given in diagram (c)

There are number of other mechanical ways of operating robotic end effectors that act as grippers. These would include:

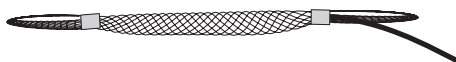
- using rack and pinion systems
- using cams
- using screwthreads



All of the elements for these mechanical systems are readily available, either as part of technology kits such as 'LegoTechnic' or separately through component suppliers.

### OTHER WAYS OF GRIPPING AND RELEASING PRODUCTS

Although only mechanical solutions for end effector design have been considered, robots can also use **magnetic** and **vacuum** systems. It would also be possible to use the Shadow 'Digit' air muscle, and to exploit its gripping potential as it inflates. Using a flexible bag such as the muscle would allow it to grip components that have conveniently located holes or bores. It could be inserted into the hole and inflated.



Shadow Air Muscle

It would also be possible to use an external gripper in the form of a ring that might be placed over the neck of a bottle, and inflated.

These types of flexible grippers are used to move delicate components made, for example, of glass.

**WALKING AND CLIMBING ROBOTS: WHEELS AND TRACKS**

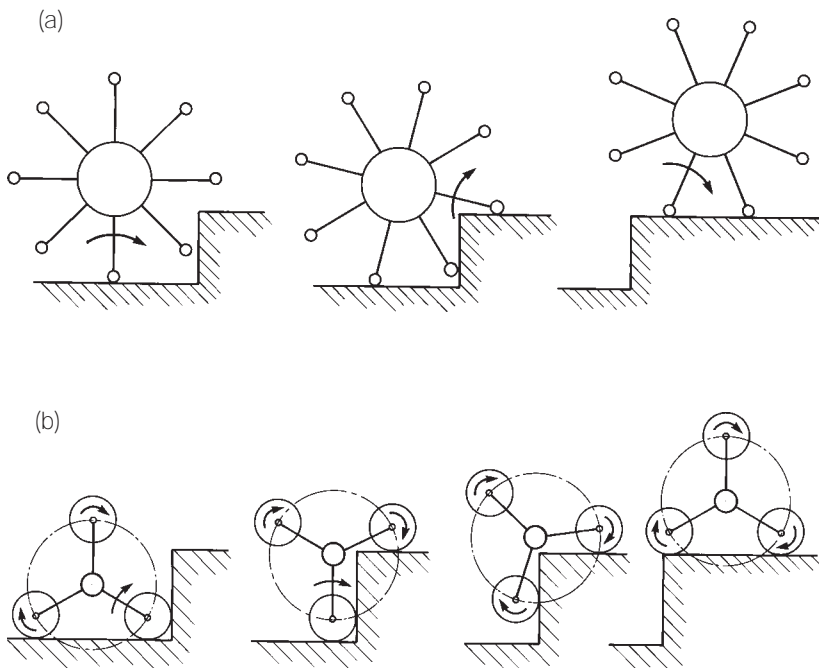
So far only stationary robots have been considered, but there are many robots who spend all of their working lives on the move.

Examples of these would include, the tracked vehicle used by the bomb squad to investigate suspicious packages in cars and buildings and automated guided vehicles (AGVs) that move materials and completed components around automated factories.

**See Yamazaki Case Study, Technology Study File 7: 'Computer Integrated Manufacture'**

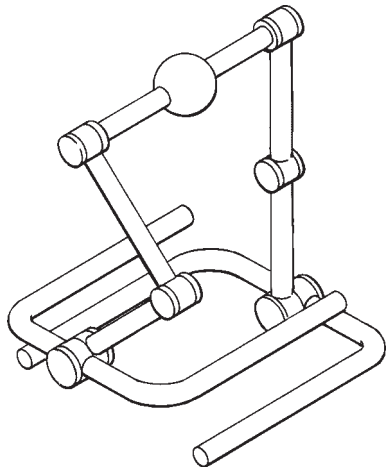
In both these cases, the robots move along fairly flat and even surfaces. There is a lot of interest and value in developing walking robots that can negotiate confined spaces in buildings, climb stairs or carry loads over soft ground. The uses for these machines could be in helping handicapped people, for use in agricultural purposes or for military applications.

Two methods of climbing steps and stairs are shown below:



Climbing a step:  
 (a) the rimless wheel, (b) the 'Venetian' wheel

It is notoriously difficult to reproduce in a robot the human activity of walking - doing this requires very powerful software. It is possible to replicate the walking action through a fairly simple mechanical arrangement as found in children's toys.



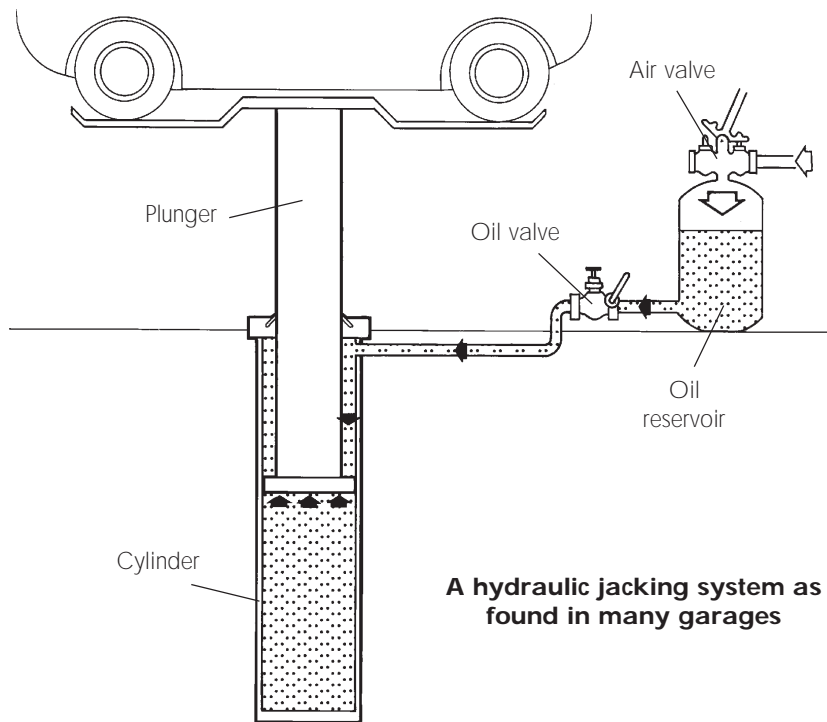
A two legged walking mechanism

**PROVIDING THE INPUT FORCE: ACTUATING SYSTEMS**

The input force to operate manipulators and end effectors could be electric motors, or pneumatic or hydraulic systems . All of these systems can be used or modelled using the resources available at school or college.

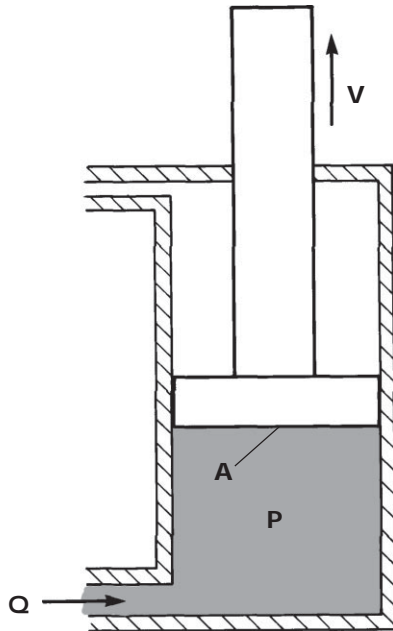
*Hydraulic systems*

In industry, this is a popular way of generating very large forces, made possible by the very high working pressures. Outside the area of robotics, there are many examples of machines that employ hydraulic actuating systems - these include earth moving vehicles, the compacting system for household rubbish at the rear of refuse collection carts, and the car crushing machines to be found in scrap yards. They are also widely used in the aerospace and machine-tool industries.



**A hydraulic jacking system as found in many garages**

In robotics terms, hydraulic actuating systems are very attractive because of their high force: weight ratio. These means a lot of 'muscle', from lightweight and compact hydraulic hardware. It is possible to confirm this mathematically:



The diagram shows an hydraulic cylinder supplied with oil at a rate of  $Q$  m<sup>3</sup>/s, and at a pressure of  $P$  N/m<sup>2</sup>. The piston, of area  $A$  m<sup>2</sup>, moves at a velocity of  $V$  m/s. Power is related to pressure and flow rate as follows:

$$\begin{aligned}
 \text{power} &= \text{force} \times \text{velocity} \\
 &= (PA) \times V \\
 &= P \times AV \\
 &= PQ.
 \end{aligned}$$

Therefore for a given power, an hydraulic actuator working at a high pressure, requires only a small flow rate of oil - it can therefore be quite small.

Hydraulic oil itself is relatively incompressible - making hydraulic drives relatively insensitive to disturbances in load. Its high stiffness also allows for very high degrees of control be achieved.

Although hydraulic systems seem attractive, there are always some disadvantages:

- hydraulic systems are expensive, due to the high precision necessary in the manufacture of the component parts. This high degree of accuracy is necessary due to the high working pressures involved.
- there is a possibility that the system might leak - this is not at all desirable in an environment where hygiene is important, for example in the food manufacturing industries.
- the system requires room to accommodate all the pipework - this may be an important consideration where space is at a premium.

### *Pneumatics*

Pneumatic devices are activated by air. By compressing air, either electrically or manually, stored energy is available to operate pneumatic systems.

Common pneumatic devices are either **reciprocating**, that is moving linearly backwards and forwards, or **rotary**.

Reciprocating pneumatic devices:

- *road drills*
- *paint spraying equipment*
- *brakes on a train or lorry*
- *doors on buses or trains*
- *actuators moving products from conveyor systems*

Rotary pneumatic devices:

- *drills - including those at the dentist!*
- *hoists*
- *mixers*

Pneumatic systems are used widely across many aspects of manufacturing industry. The advantages, (some of which are shared by hydraulic systems) are:

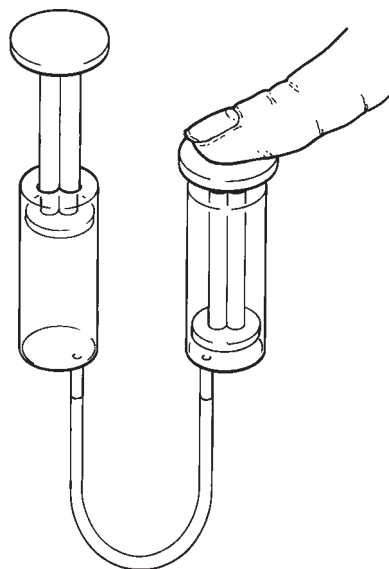
- availability - most factories and manufacturing businesses (and now schools and colleges) have compressed air supplies, or a portable compressor unit. Air is an easily available substance which can be extracted from the atmosphere for compression and restored to the atmosphere after it has been used. (This contrasts with hydraulics which must have a return system, and is very messy if leakage occurs.)
- most pneumatic components are relatively cheap, and are available 'off-the-shelf'. They are normally reliable, and easily and cheaply maintained.
- they can be used in adverse environments - pneumatics components are not significantly affected by dust or corrosive atmospheres. There is no fire hazard when pneumatics is concerned, which means that systems can be used in situations where a risk of explosion would prohibit the use of electricity.

Compressed air is not inflammable and can be used in high-temperature situations where the use of electrics or hydraulics could be dangerous or expensive.

Again there are disadvantages, which include:

- although readily available, the compressing of air, normally through electrical pumps, is expensive
- because of the 'springiness' of air, accuracy of control is far less than using hydraulic or electrical systems

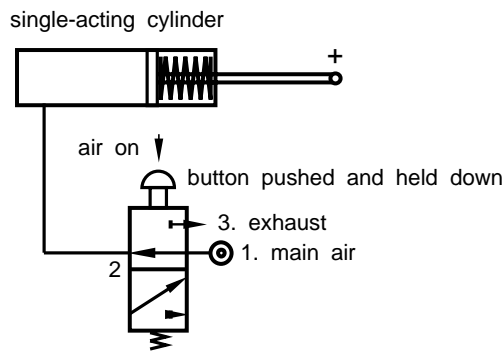
(You can demonstrate this clearly for yourself by using a pair of syringes, connected by tubing. Keep your thumb on the end of one syringe whilst you operate the other. Do this first with only air in the system, i.e. pneumatically, and then add water to produce an hydraulic arrangement. Note how much more 'positive' the transmission of force from syringe to syringe becomes.)



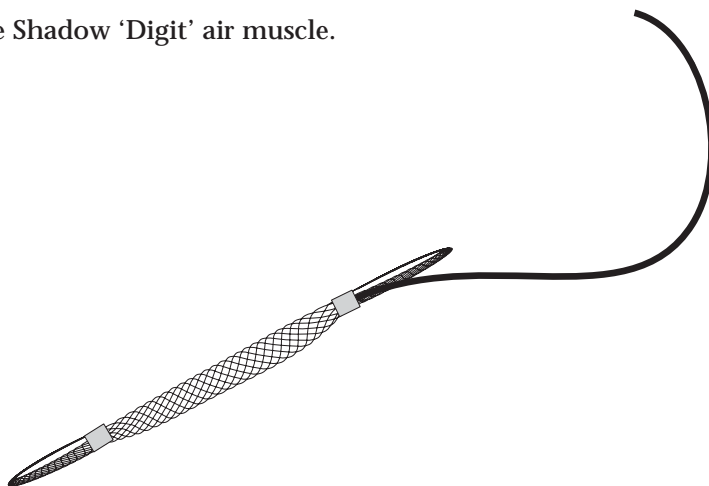
- transmission of air signals in pipes is much slower than electrical signals in wires.
- pneumatic components are very bulky and very expensive if very large forces are required.
- compressed air systems can be noisy.

Many schools and colleges now have rooms that are equipped with compressed air supplies. Pneumatic actuators for robotic systems can be built using:

- standard components, such as 3 and 5-port valves, single and double-acting cylinders. These components are available in a range of sizes, including miniature form.

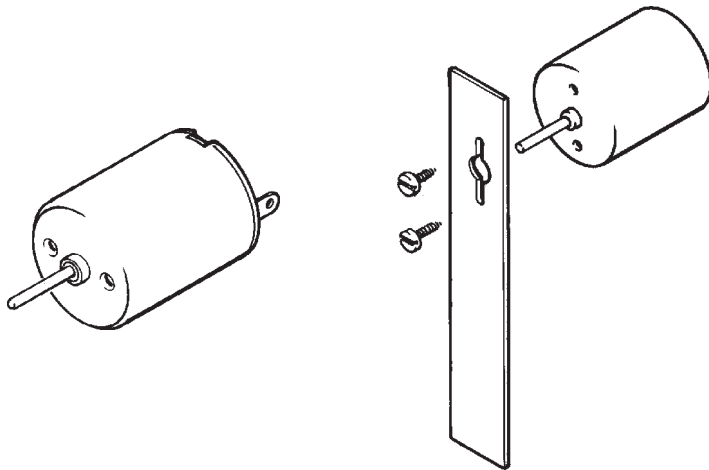


- syringes. Whilst these are cheap, and easy to use, the low efficiency of these devices makes them only really suitable for modelling ideas.
- the Shadow 'Digit' air muscle.



*Electric motors*

These are easily available and widely used in industry, schools and colleges in a range of sizes and power ratings.



They are extensively used in robotic applications as they are easy to control, providing fast and accurate control of speed and position. Two major types of motor are used: stepping motors and DC servomotors.

Stepping motors find wide application in computer-controlled machinery since a computer is ideal for generating the required pulsed control signals. Stepping motors move through a fixed angle for each pulse, and since the step size is fixed, a particular position can be achieved by sending the appropriate number of pulses to the motor. Typical step sizes are 7.5 degrees, 5 degrees and 1.5 degrees.

Where high power is required, and position measurement in order to facilitate feedback control, d.c. motors are used.

Some caution must be exercised where these motors are used, particularly when these are the cheaper examples which are prone to producing electrical 'noise' - which can cause serious interference to other parts of a circuit.

Electrical systems are quiet and clean - the main drawback is their low power to weight and weight to torque ratios.

The use of electric motors on occasions can be potentially hazardous. Because of the risk of arcing they would not be used in inflammable environments, for example, where paint-spraying takes place.

DESIGN CONTEXT

*Interest in human-like robotic devices stretches back into history. A brass robot in Greek mythology called Talus protected the island of Crete by hugging intruders to death. The Victorians drew cartoons of domestic robots which they hoped would do all the housework in the homes of the future.*

*Design and manufacture a robot that:*

*a) forms part of an active museum display to demonstrate the principles of robotics. Your device could be mobile, or could demonstrate simply an aspect of the anthropomorphic basis of robotics design*

*or*

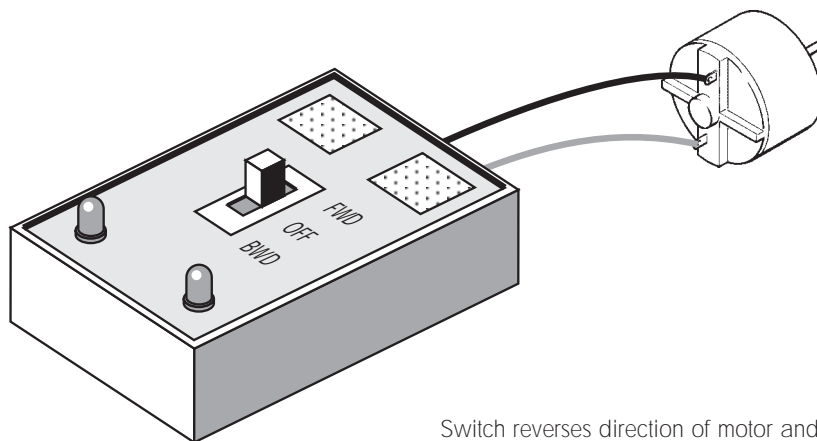
*b) forms an educational toy to demonstrate the principles of robotics movement to children.*

Mobility for the robot will be provided by using electric motors driven through a gearbox arrangement. Manipulators and end effectors can employ electrical, pneumatic or hydraulic systems.

PROVIDING MOBILITY FOR THE ROBOT

Whether you decide it is appropriate to move the robot by using wheels or tracks, or by making it 'walk', the spindle speed of the electric motor will need to be reduced significantly. This will be achieved through using a gearbox.

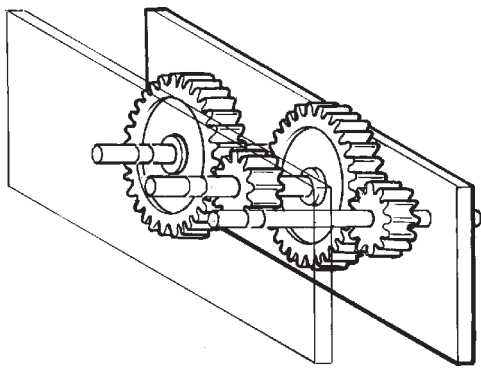
**See Technology Study File 10: 'Controller for Animatronic Toy'**



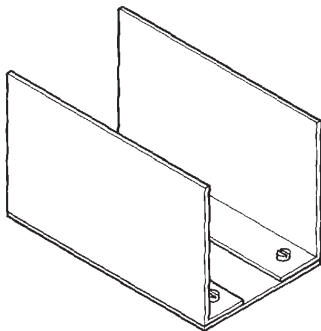
Switch reverses direction of motor and causes LEDs to flash or buzzers to sound according to direction in which motor spindle is turning

**A BASIC CONSTRUCTION  
METHOD FOR MAKING GEARBOXES**

Commercial gearboxes often use a combination of injection moulded plastic parts and metal pressings for frames or cases. The type of gear box you are designing will be made by the two-plate method. In this, two metal or plastic plates have to be held a sufficient distance apart to take the gears. There are several ways of joining the two plates:

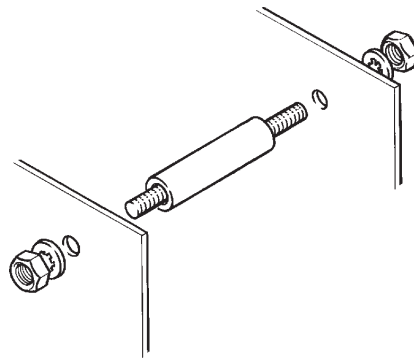


- Two pre-formed (metal) plates are fastened to a base plate using nuts and bolts

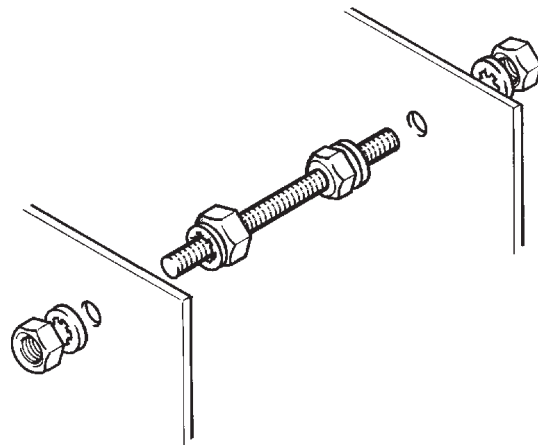


- Two plates are held together with spacers. The spacers can be made in many different ways. Examples are described below:

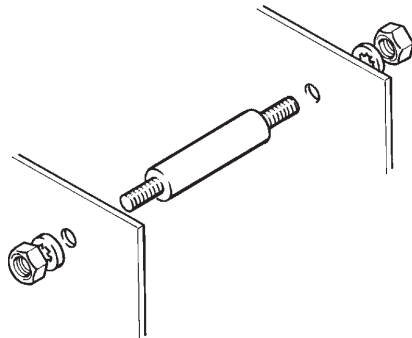
1. Metal or plastic tubing with a length of threaded studding along the centre. Ideally, the ends of the tubing should be faced off in a lathe.



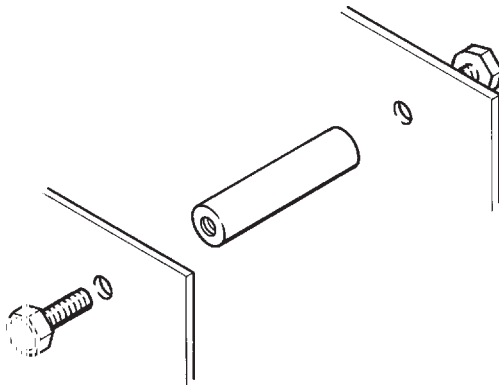
2. Threaded studding without a tube covering.



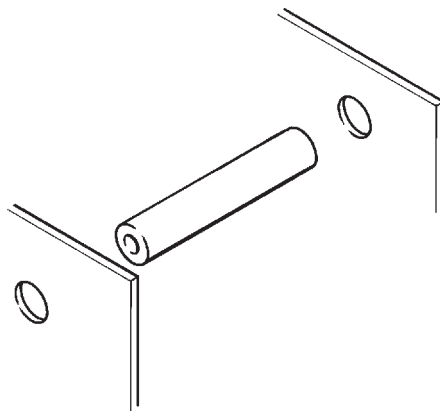
3. Metal rod with spigots turned down on both ends and threaded.



4. Metal rod with a drilled threaded hole at both ends. The ends need facing off in a lathe.



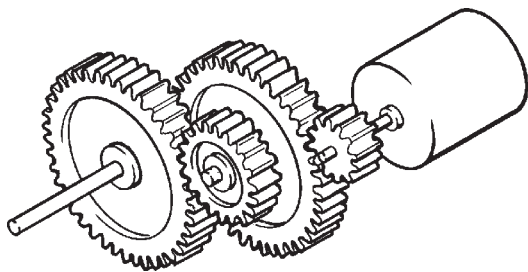
5. Metal/plastic rod or tubing which is force-fitted into holes in the side plates; i.e. the hole is slightly smaller than the diameter of the tube or rod. NOTE: This method will not allow you to take the gearbox apart very easily.



**SETTING OUT THE GEARS - USING A MOTOR**

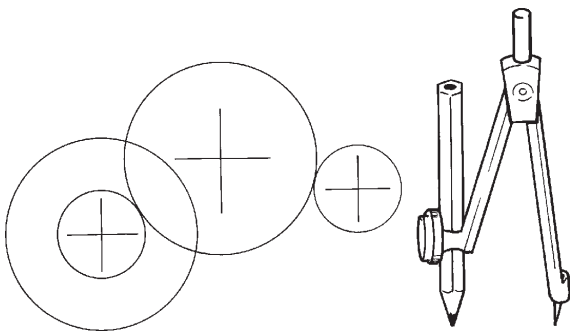
The way you arrange the gears depends on the ratio you require between the and output speeds. The free running of a small motor is about 3000 rev/min. When the motor is doing work driving the gearbox, and moving the robot, the speed will be around 50% less at 1500 rev/min.

In the example shown below, a 10 tooth gear on the motor spindle meshes with a 40 tooth gear. The ratio between driver gear and driven gear is 4:1.

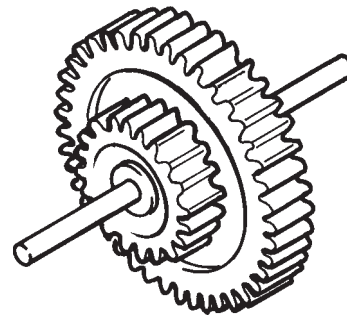


The driven 40 tooth gear is force-fitted onto the same shaft as a 20 tooth gear which meshes with a second 40 tooth gear on the output shaft. The ratio between the 20 tooth driver gear and the driven gear is 2:1. The total ratio of the gear train is now the two ratios multiplied together - i.e.,  $2:1 \times 4:1 = 8:1$ .

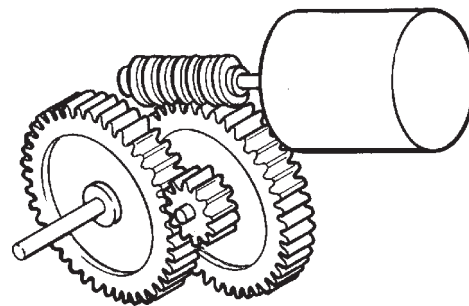
You can reduce the speed even more by adding pairs of gears to the gear train. To work out your gear train on paper, draw the gears as a series of circles using compasses. As the examples show, the gear train does not have to be in a straight line.



Most of the larger plastic gears available to you are designed to force fit onto a 3 mm diameter steel shaft. Pairs of gears can be placed on the same shaft so that they both turn together. (Gears are sometimes available moulded as complete pairs.)

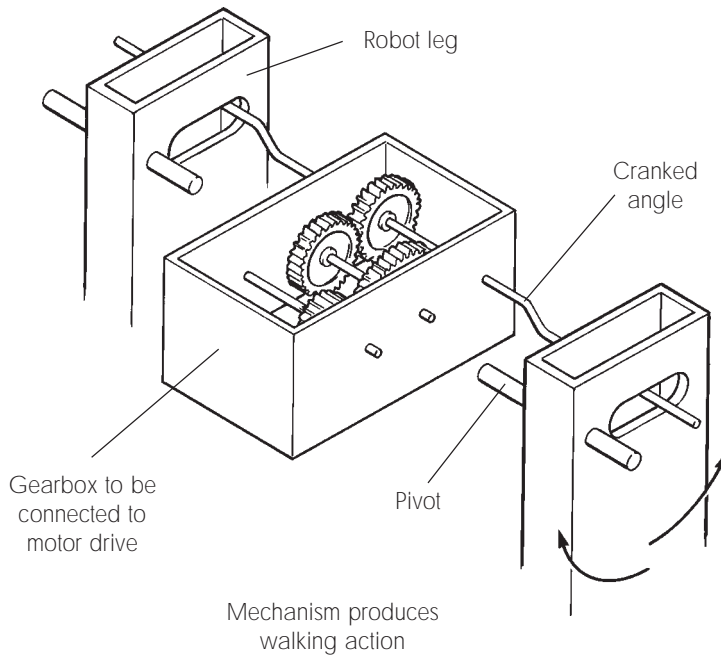


The first gear in a gear train can be driven by a worm gear fixed to the motor spindle. This gives a very large reduction in speed. For every turn of the worm gear, the driven gear moves through the width of one tooth.

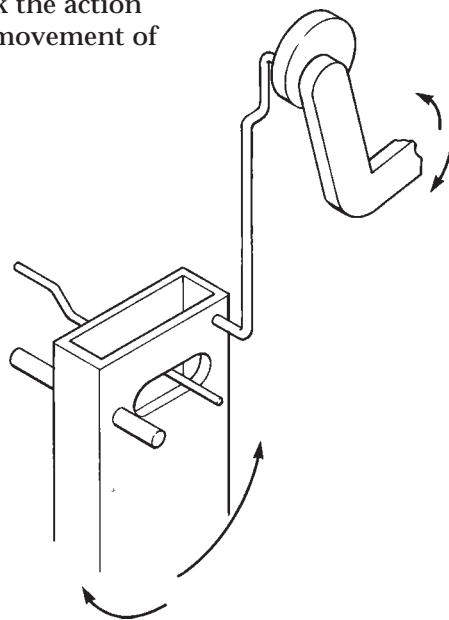


A worm gear driving a 40 tooth gear needs to turn 40 times to make the driven gear turn once. (Note: Gears designed to mesh with worms are slightly concave across the teeth. Worms will, however, mesh with ordinary gears but not quite so well.)

One method of achieving a walking action is to use a mechanical system based upon the following arrangement:



If you think this is desirable to do, you could link the action of the legs to the movement of the arms



## EVALUATING YOUR ROBOT

To evaluate the effectiveness of your robotic device, you should consider whether it meets your specification. Your evaluation should be in at least 4 strands:

1. evaluating the performance of the gearbox
2. evaluating the effectiveness of the manipulator
3. evaluating the effectiveness of the end effector
4. overall suitability of the robotic device

### 1. Gearbox performance

Conduct tests to find out:

- If all the gears turn smoothly before the motor is swung down to mesh with the first gear.
- If the motor drives the gear train smoothly when it is swung into position. Check to see if the motor is meshing too tightly with the first gear.
- If the whole gear train slows down when a load is applied to the output shaft.

### 2. Manipulator effectiveness

The tests you may need to perform will vary with the design of manipulator you have chosen to construct. In general terms, you should check for:

- the positional accuracy with which the manipulator operates - with out any slipping of the component parts
- a general rigidity and stability of the component parts, as the manipulator moves to various positions.
- the ease with which the manipulator is moved into its required position, and stays there

### 3. Effectiveness of end effector

Again the evaluation of this aspect of your robotic device will vary dependent upon its configuration and its required performance. You could consider:

- the ease with which the components are held within the end effector
- the lifting and gripping power of the effector - across a range of different loads
- the ease with which components are released by the end effector

### 4. Suitability of the overall product

In terms of meeting the defined needs through the product specification. Is it possible to gather some 'expert evaluation' through users of the product - other than yourself, or other members of the group?