TECHNOLOGY SUBJECTS SUPPORT SERVICE

Leaving Certificate

Technology

Applied Control Technology

Introduction to Robotics

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Introduction to Robotics

In today's world robots are all around us, they come in a variety of different shapes and sizes, designed to do an extraordinary range of tasks. Typically when we think of robots we picture these big humanoid robots from sci-fi films like "Transformers" or the big robotic arms seen manufacturing cars on automated assembly lines.

What is a robot? A robot is "intelligent", a man made device that can move by itself, whose motion can be modelled, planned, sensed and controlled and who's motion and behaviour can be influenced by programming. A robot is a general purpose, programmable manipulator. In practice it is usually an electro- mechanical system which by its movements and appearance conveys that it has intent of its own.

Today, commercial and industrial robots are in widespread use, performing jobs more cheaply or with greater accuracy and reliability than humans. They are also employed for jobs that are too dirty, dangerous or boring to be suitable for humans. Robots are widely used in manufacturing, assembly and packing, earth and space exploration, surgery, weaponry, laboratory research and mass production of consumer and industrial goods. As robotic technology develops and becomes cheaper domestic robots for cleaning or mowing the lawn are available, along with robotic toys for children of all ages.

When we talk about robots, what we are really talking about is machines that will do what human beings would normally be expected to do. These machines mimic the operation of the human being or at least certain parts of it. Most shop floor robots are the emulation of one arm of a human.

- Their motors are the muscles
- The general purpose computer the human brain
- Robotic vision, the eye

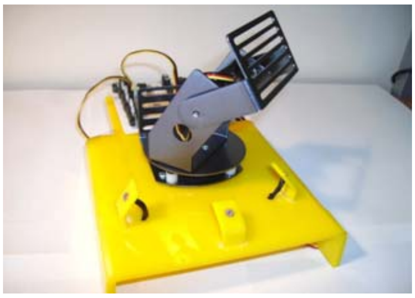
We combine these various elements in different ways to create the robot that we require.

The most common robot used in industry today is the robot arm. These arms are used to weld, package, paint, position and assemble a host of products that we use daily. Basically a robot arm is a series of linkages that are connected in such a way that a servo motor can be used to control each joint. The controlling computer, the brain of the robot, is programmed to control the various motors on the robot in a way that allows it to perform specific tasks.

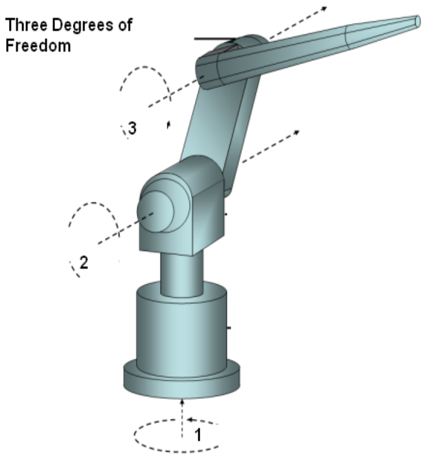
The robot arm can be designed in a number of different ways, the size and shape of this arm is critical to the robotic architecture of the robot. The arm is the part of the robot that positions the final grabber arm or spray head to do their pre-programmed business. If the design of the arm is too large or small this positioning may not be possible. Many arms resemble the human arm, containing shoulders, elbows wrists

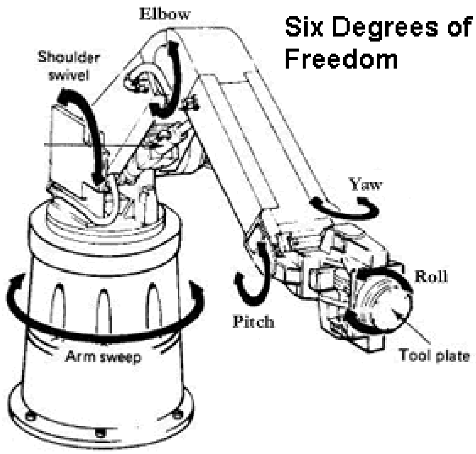
and hands. The design of the human arm is exceptional and allows for precise and complicated movement.

As a rule you need one motor for each degree of freedom that you want to achieve.



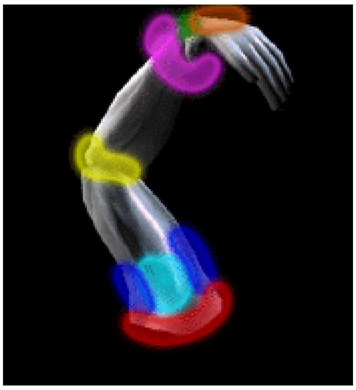
A degree of freedom is typically one joint movement. So a simple robot with 3 degrees of freedom can move three ways: up and down, left and right, forward and back. This simple pan and tilt robot has 2 degrees of freedom, powered by two servo motors. It can rotate left to right and lift up and down.





Many robots today can be designed to move with 7 degrees of freedom.

Degrees of Freedom:



The following will demonstrate the degrees of freedom using the human arm.

First Degree: Shoulder Pitch

Point your entire arm straight out in front of you. Move your shoulder up and down. The up and down movement of the shoulder is called the shoulder pitch.

Second Degree: Arm Yaw

Point your entire arm straight out in front of you. Move your entire arm from side to side. This side to side movement is called the arm yaw.

Third Degree: Shoulder roll

Point your entire arm straight out in front of you. Now, roll your entire arm from the shoulder, as if you were screwing in a light bulb. This rotating movement is called a shoulder roll.

Fourth Degree: Elbow Pitch

Point your entire arm straight out in front of you. Hold your arm still, then bend only your elbow. Your elbow can move up and down. This up and down movement of the shoulder is called the shoulder pitch.

Fifth Degree: Wrist Pitch

Point your entire arm straight out in front of you. Without moving your shoulder or elbow, flex your wrist up and down. This up and down movement of the wrist is called the wrist pitch.

Sixth Degree: Wrist Yaw

Point your entire arm straight out in front of you. Without moving your shoulder or elbow, flex your wrist from side to side. The side to side movement is called the wrist yaw.

Seventh Degree: Wrist Roll

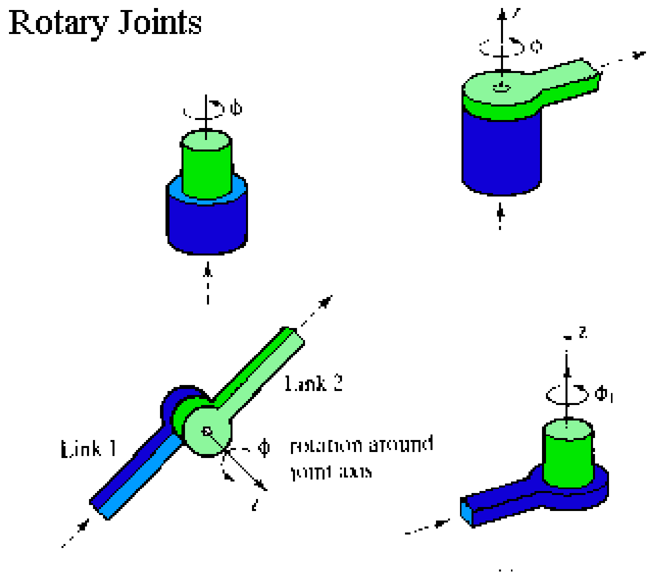
Point your entire arm straight out in front of you. Without moving your shoulder or elbow, rotate your wrist, as if you were turning a doorknob. The rotation of the wrist is called the wrist roll.

The Crust Crawler Robot has 5 degrees of freedom and is a Revolute Robot.

Robotic joints

It is obvious that in order to achieve different degrees of freedom, different robotic joints are needed. Unlike human joints where we saw 3 degrees of freedom in the shoulder, the joints in a robot are normally restricted to 1 degree of freedom, to simplify the mechanics and control of the manipulator. There are two types of joints commonly found in robots: rotary joints and prismatic joints.

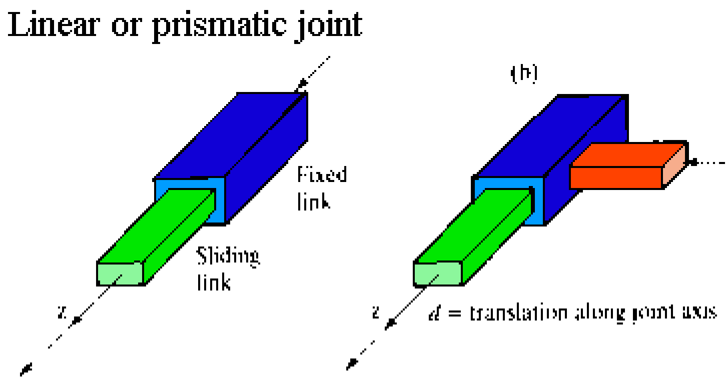
Rotary or revolute joints



The top two linkages in the diagram above are generally used as a waist joint. An example of a waist joint can be seen in the Crust Crawler robot, it is the joint that pivots the entire robot. The Blue section is fixed and the green rotates about it.

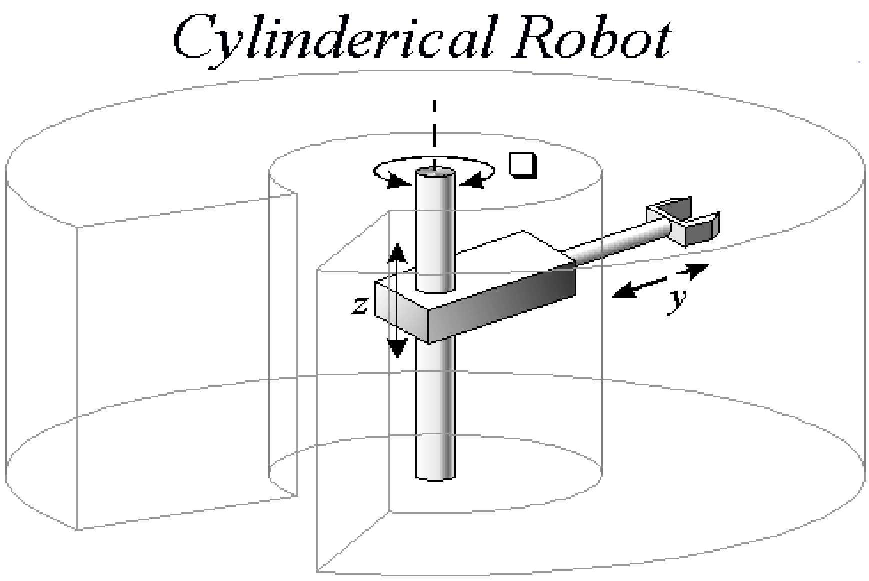
The bottom linkages are examples of elbow joints. In the case of the four joints they are only capable of one degree of rotation, the joint variable is the angle that the joint move to. Most rotary joints cannot rotate through 360° degrees as they are mechanically restrained by the arm construction and the servo motor.

Linear Joints



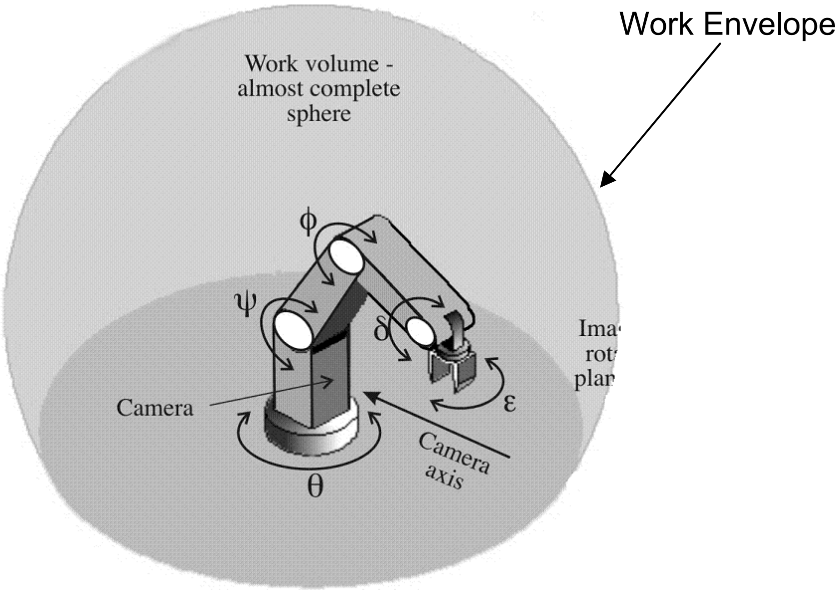
A prismatic joint is a sliding joint. It can be used for merely a simple axial direction. These linear joints are not as common as the rotary joints but are very useful.

The cylindrical robot below has both types of joints evident. The rotary joint allows the grabber to rotate about the axis; while the linear joints Y&Z determine height and reach.



Work Envelope

The volume of space that a robot operates within, is called the **Work Envelope**



The work envelope defines the space around a robot that is accessible for the end effector or gripper.

As a robot moves around the limits of its reaches it traces out a specific shape. The Cylindrical robot in the last image has a visible work area of a cylinder. A Cartesian robot sweeps out a rectangular volume, a polar a partial sphere.

Classification of Robots

There are a number of factors that help decide the type of robot required for a specific task. The main factor is the type of movement needed to achieve the desired robotic motion. Some applications only require a robot to move a product along a desired axis, while other robotic arms need to manoeuvre about an object through a number of different axes at once. The arrangement of joints in different ways fulfils different coordinate systems.

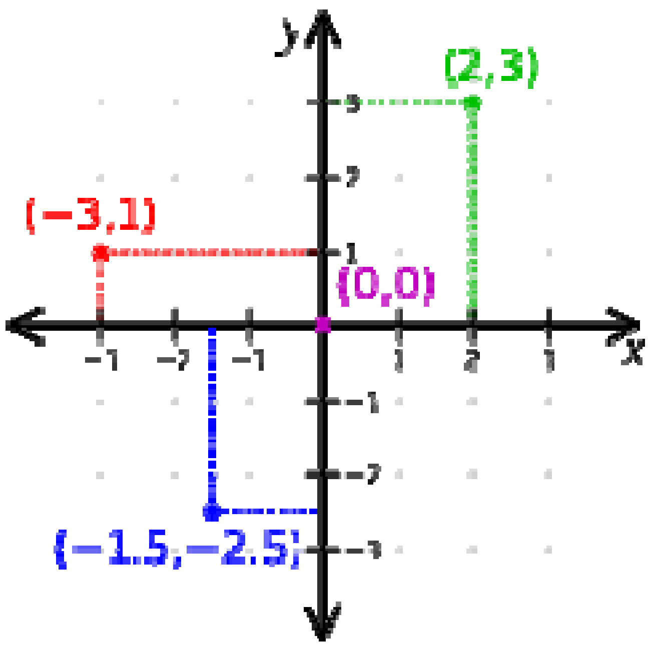
Coordinate Systems/Frames

Coordinate system types determine position of a point with measurements of distance or angle or combination of them. A point in space requires three measurements in each of these coordinate types. It must be noted that the same point can be found in any system. Different coordinate systems are merely to cater for a different situation. Three major coordinate systems used in the study of robotics are:

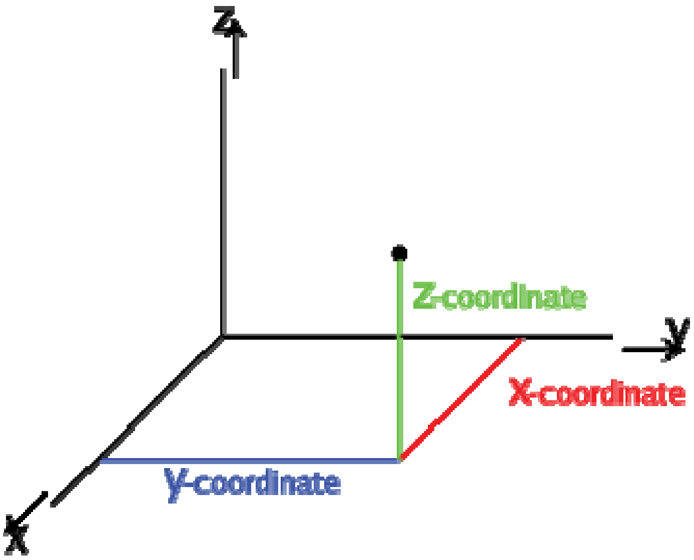
- Cartesian
- Cylindrical
- Spherical

Cartesian coordinate frame:

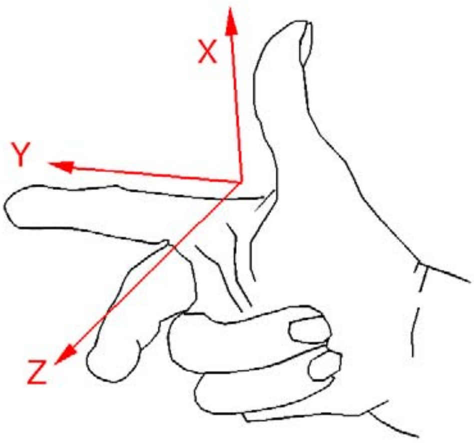
The most used and familiar coordinate system is the Cartesian coordinate system. Most will be familiar with this as the X, Y; axis is at 90° to each other. A point can be located on a plane by locating the distance of a point from its origin (0, 0) along each axis. This is a 2 dimensional representation, hence the two axis X & Y.



To find a point in space it is necessary to add a third axis (Z).This third axis will form a 3 dimensional grid that matches a set of coordinates to a single point in space.

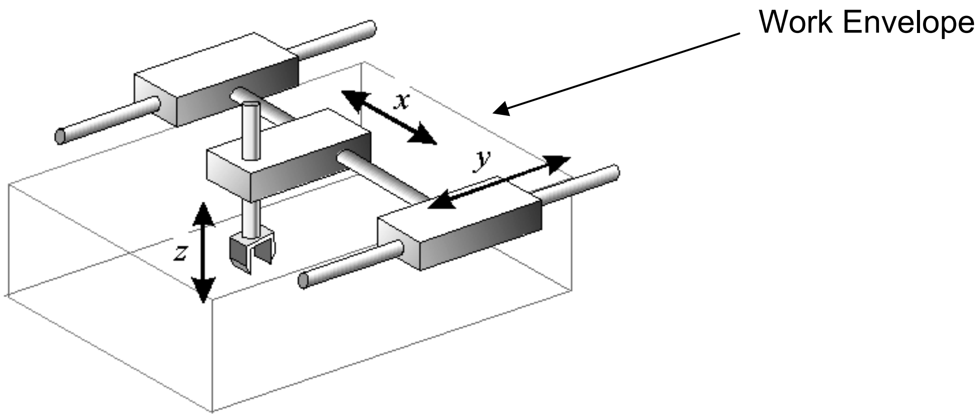


The axes of machines are always defined by what is known as the right-hand rule. If we take the thumb as pointing in the direction of the positive X-Axis then the second finger is pointing towards the positive Y-Axis and the middle finger towards the positive Z-Axis. The Z axis is always in the direction of the spindle or grab arm as shown in the 'Cartesian Robot' below.

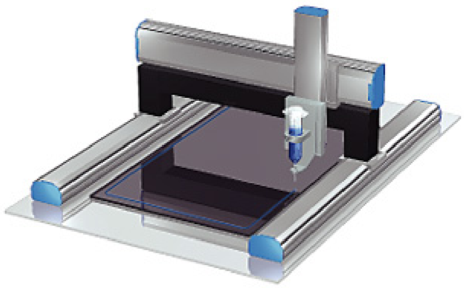


Right-hand rule

Cartesian Robots:



Cartesian robots are used for pick and place work, application of sealant, assembly operations, handling machine tools and arc welding. It's a robot whose arm has three prismatic joints, whose axes are coincidental with the Cartesian coordinators.

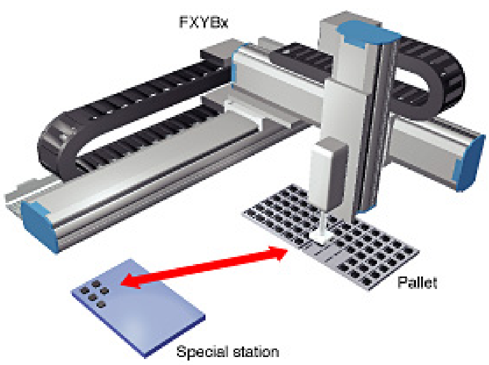


Application of Cartesian Robot

Applying Adhesive

This robot is being used to apply adhesive to a pane of glass. This robot is capable of handling large sized work pieces.

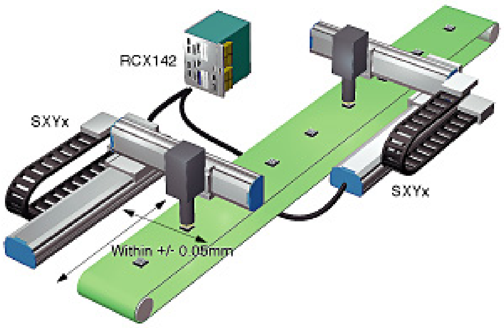
Most laser cutters and CNC machines work on the principle similar to this robot



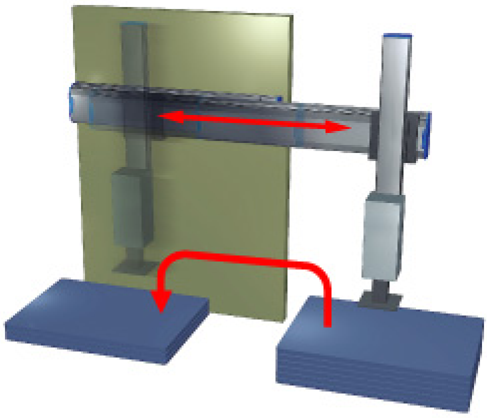
Pallet transfer

This orientation of a Cartesian robot transfers Integrated Circuits (ICs) from a pallet and transfers the part to a specific place.

Product inspection



Companies need to monitor their products to ensure that they are of a high quality. Cameras mounted on the Cartesian robot above monitor the passing components for inaccuracy. Due to its construction the robot can move along with the moving conveyor and focus on a product at once.

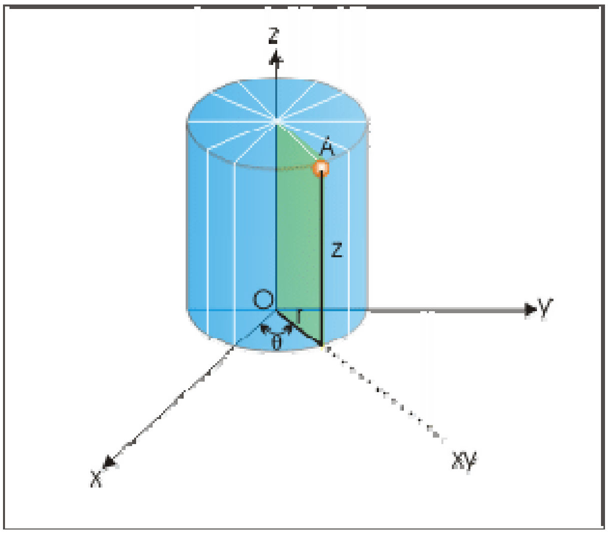


Transfer and stacking

Owing to its linear movement the Cartesian robot is ideal for the transfer and stacking of sheet metal or timber sheets. It can feed sheets into processing machines or draw them away as finished products.

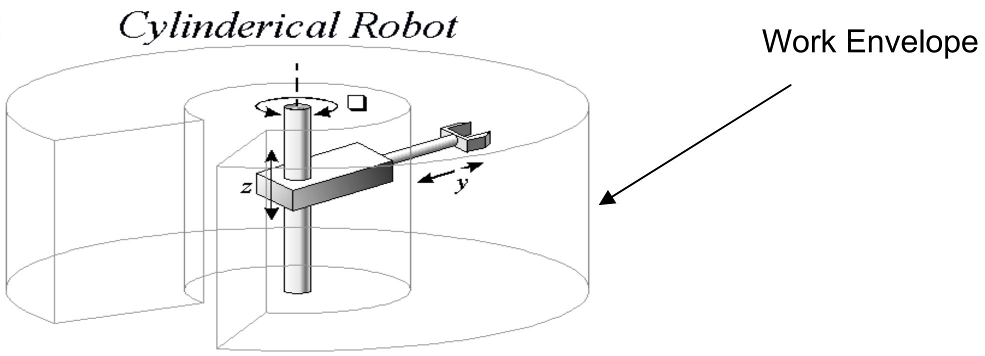
Cylindrical coordinate frame:

A three dimensional point "A" in a cylindrical co-ordinate frame is considered to be located on a cylinder of a radius "R" with a height "Z". The third piece of information required to define the point comes from an angle θ on the XY plane.



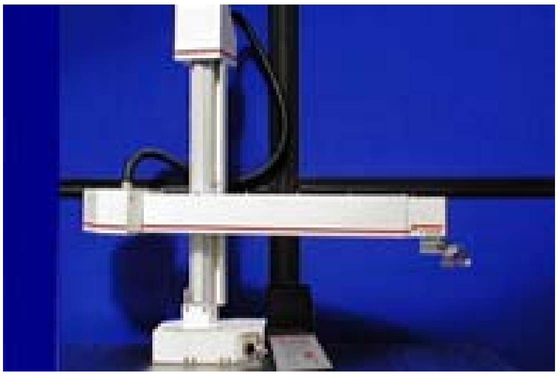
Cylindrical robots:

Cylinder robots are used in assembly operations, handling of machine tools, spot welding and handling at die cast machines. They also have many uses in medical testing. The example below has two prismatic joints and one rotary joint. A Cylindrical robot is able to rotate along its main axes forming a cylindrical shape.



Application of the Cylindrical Robot:

Basic Cylindrical Robots



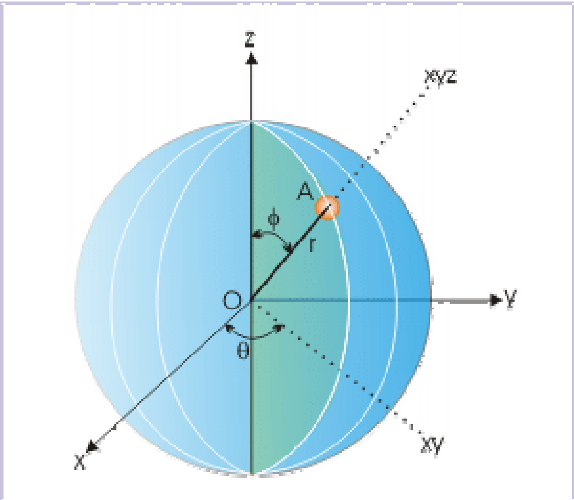
Medical Robot

The medical robot is used in numerous medical applications, for DNA screening, forensic science, drug development and toxicology. These robots are suitable in medical research where hundreds of samples must be tested and the same repetitive tasks performed many times. The robot eliminates human error providing more repeatable yields and consistent results

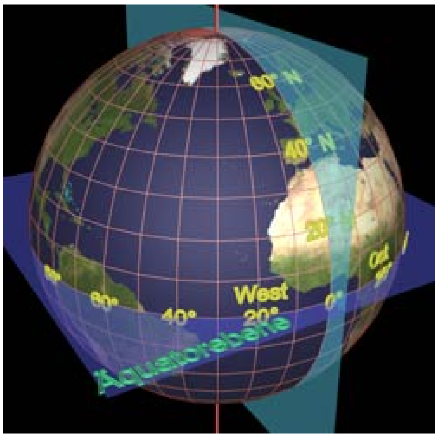
A typical example of its duties would be to pull out a drawer to access a test plates, lift out a sample plate, close the drawer and finally take the sample to another instrument to be tested.

Spherical / Polar coordinate frame:

A three dimensional point A in a spherical coordinate system can be found on a sphere of radius “R”. The point lies on a particular cross section of the sphere; like in the cylindrical frame the cross section makes an angle “θ” from the ZX plane. Once the plane is found the last point can be found by joining the point A to the origin, the angle (φ) this creates with the Z axis defines the point.

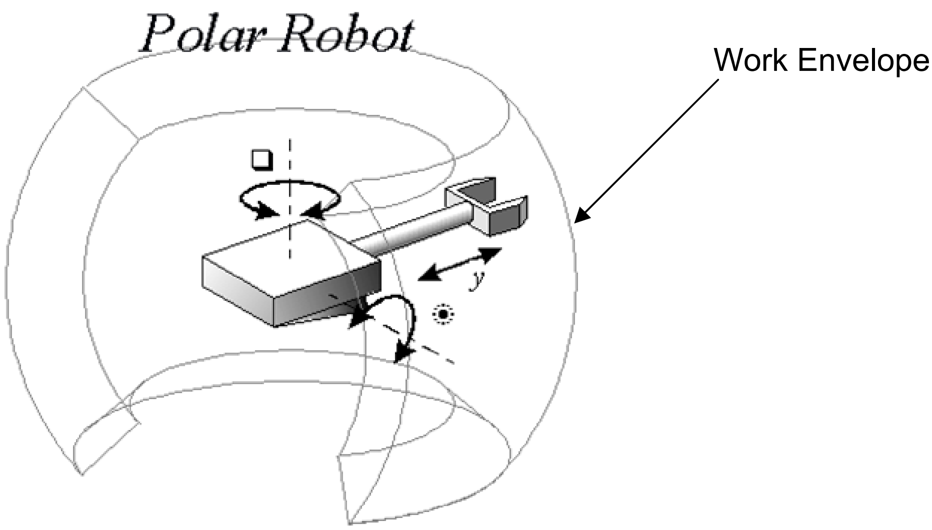


To simplify let’s look at how a position on the earth’s surface is located. As with the spherical coordinate system the surface of the earth becomes “R”. Maps use lines of longitude (θ) and latitude (φ) to define a particular position on earth’s surface. We now have three pieces of information that allow us to know our position.



Spherical or Polar Robots:

Spherical or Polar Robots combine rotational movements with single linear movements of the arm. The polar robot is sometimes referred to as the gun turret configuration. They are generally used in many welding applications mainly spot, gas and arc. Polar robots are extremely suitable for reaching into horizontal or inclined tunnels



Applications of a Polar/ Spherical Robot:

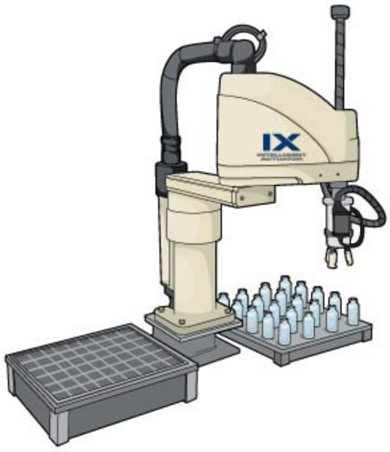

Polar robot welding

The main application for these types of robots is welding. They can be quite large and weigh over a 1000kg. Polar Robots are used widely in the car manufacturing industry.


Numerous Polar robots at work

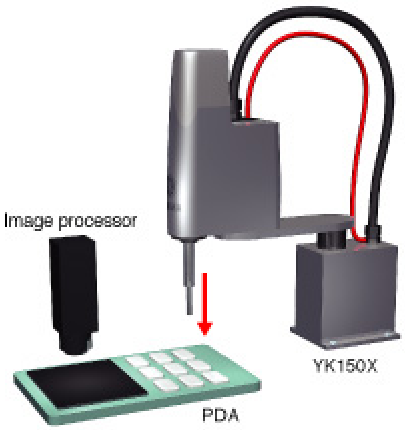
The Scara Robot:

This configuration was developed to meet the needs of modern assembly work where fast movement with light payloads is required. The rapid placement of electronic components on PCB's is an obvious application. The Scara robot is a combination of two horizontal rotational axes and one linear that moves vertically.



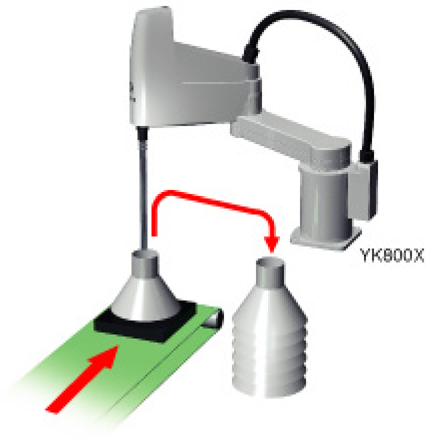
Scara Robot

Applications of a Scara Robot:



The Scara robot is testing a newly made calculator to ensure it is operational prior to packaging. The camera observes the screen to see if the operation performed by the robot is achieving the desired result.

Testing a finished product

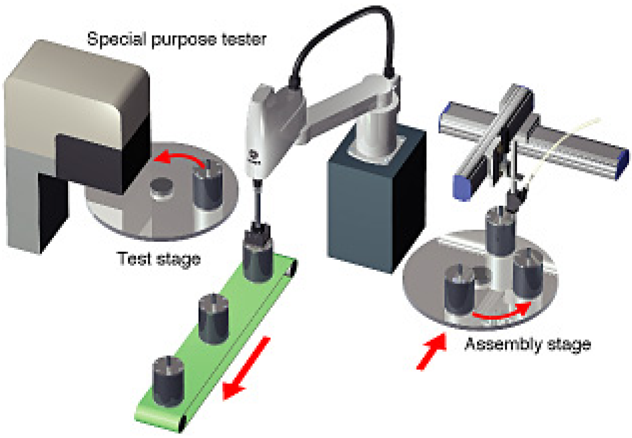


Stacking lightweight components

The Scara design can quickly remove components from an assembly line and accurately stack them.

Part assembly

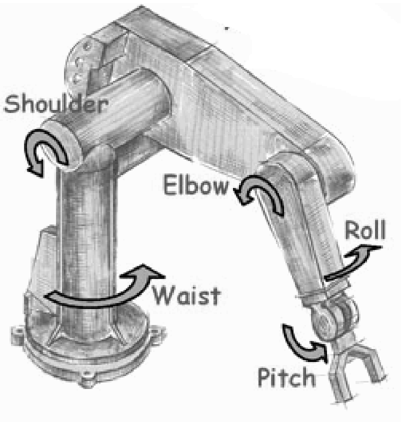
The Scara robot is excellent for precision positioning and makes it very suitable for the assembly of components. The picture above shows the robot taking parts from the supply unit and assembling them. The robot can pivot around to the left and change its gripping hand to a screw or drilling head. These different heads for the robot are known as end effectors.



Multi function

Here the Scara can be seen transferring the component from the assembly stage to the testing stage. Once the component has passed the quality check the robot arm will place it on the conveyor belt to be transferred to the next stage.

Revolute Robot:



The Revolute Robot

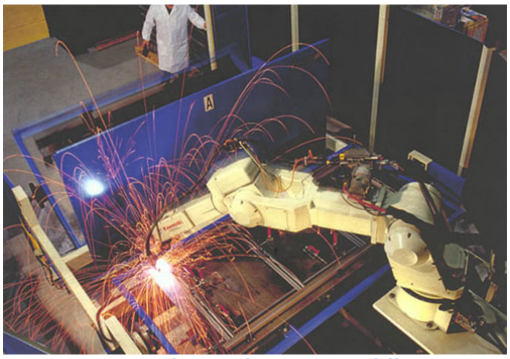
The revolute robot or Puma as it is also known most resembles the human arm with three main rotational degrees of freedom. The manipulator rotates on the base much like the human waist. The other two rotational axes resemble the shoulder and the elbow. The additional wrist action adds two more degrees of freedom, movement up and down (pitch) and rotation (roll). A final movement is Yaw which is the movement of the wrist from side to side; this is not in the example above.

Applications of a Revolute robot:

This kind of robot is ideal for spray painting where it can be taught the human movements required to paint an object.

Revolute Spraying Robot

Due to their manufacture based on the human hand the Revolute robot is suitable for numerous application. These include welding, pick and place operations, component assembly and electrical soldering.



Revolute robot MIG welding

Humanoid Robot:

The development of robots resembling the human body over the last number of years has been for more entertainment value than that of practicality. However this trend is changing with much research being carried out on how these robots could blend into our lives and perform human chores. The film industry has released films like ET, Transformers, AI and I robot that have all toyed with the idea of robots as humans with feelings and emotions.

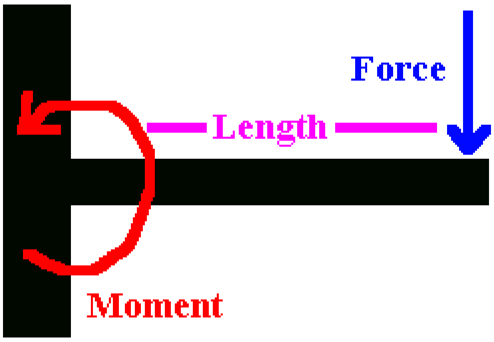
Honda Humanoid Robot

At a New York stock exchange ceremony the four foot ASIMO robot ascended a set of stairs, shook hands with the chair person, rang the opening bell and waved and clapped along with hundreds of traders on the floor of the Exchange

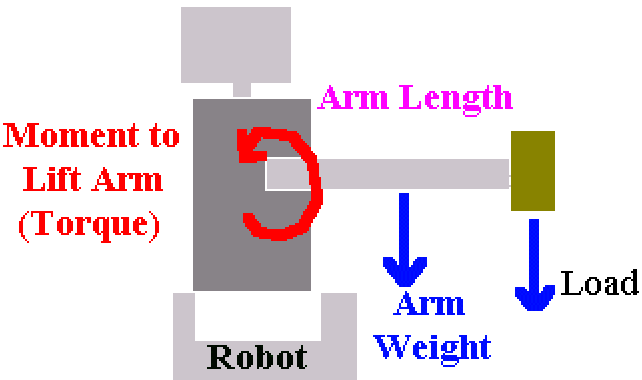
HONDA has begun to consider potential ways its humanoid robots can benefit the world. Perhaps in the future ASIMO will assist the elderly and help with household chores

Forces and Moments

For an efficient and successful robot it is necessary to look at the various forces that both inhibit and help the operations of a robot. It is important to select the right servo motor for a specific joint as over loading can cause the life of the servo to be cut short. Firstly the torque required of the servo will be defined by the force (moment) acting about it. *Moment = Force (Newton's) x Distance (Meters).*



The force the arm will exert on the servo will be determined by a number of factors. The main consideration is the weight that the arm is required to lift. Secondly the weight and length of the arm are two important factors. The weight of the arm and the weight of the load must be added together. The length of the arm is also important as it determines the distance of the load from the fulcrum (pivot point). As Moment = Force x Distance, the moment acting around the servo will be greater the longer the arm.



To calculate the total moments about the servo you would add the moments of the arm and the load together.

*Moment = (Load weight x arm length) + (arm weight * ½ arm length)*

Notice that for the arm length we only use half the value. This is because the weight of the arm is acting over the entire arm and not at the very end of it. The centre of gravity of the arm is where the arm would balance perfectly if suspended from a string. In this example we can estimate the centre of gravity of the arm is the centre of the arm.

Once this calculation has been complete the answer is the actual torque being applied. This is the minimum torque required from a motor. To allow for simple overloading and smooth operation a motor of a higher torque value should be used; this is known as a factor of safety. It is recommended that if a motor of 100Nm is needed then look for a motor with 20% higher torque.

Actuators:

Motors are the most common way to control the movements of robots and are known as actuators. They can be connected to gears and wheels and are a perfect way of adding mobility. There are a number of different types of motors that can be used, dc, stepper and servo motors.

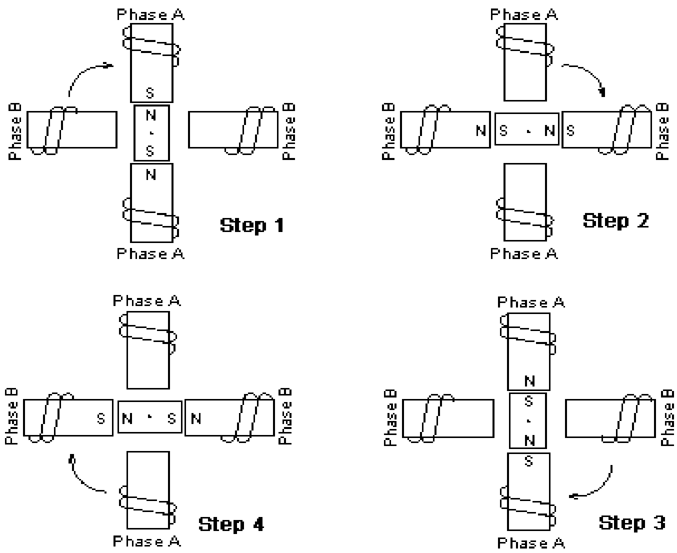
DC Motors

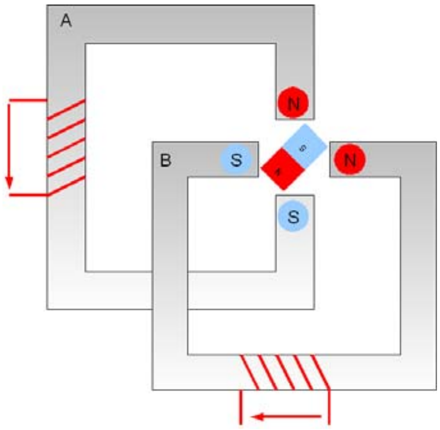
These are the most common motors available, connected to a power supply by two wires. The direction of a DC motor can be changed by reversing the polarity of the motor supply voltage. DC motors draw a large amount of current and as a result cannot be wired straight from a control system such as PIC. DC motors do not offer accurate, controlled rotation.

Stepper Motors

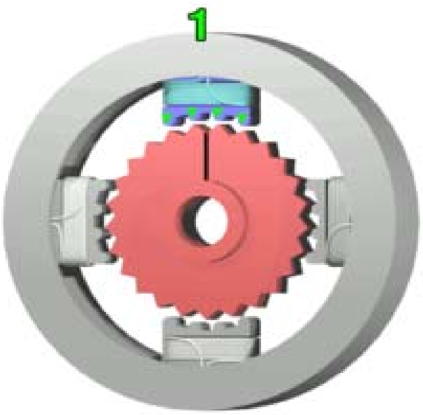
Stepper motors work in a similar way to dc motors, however where a dc motor has just one electromagnet, the stepper has many. The stepper is controlled by the sequential turning on and off of these coils. Each time a new coil is energized the motor rotates another couple of degrees. The number of degrees that a motor turns with each pulse is called the step angle. Repeating the sequence causes it to move a few more degrees, this continues until a full rotation is achieved.

The diagram below shows how a basic motor works. The magnet in the middle is joined to the motor shaft. The four magnets on the outside represent each coil of the stepper motor. As the coils are energized the centre magnet is attracted in different directions, therefore the correct sequence of pulses will achieve motor rotation.

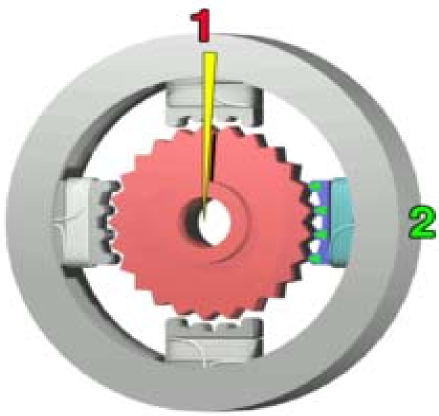




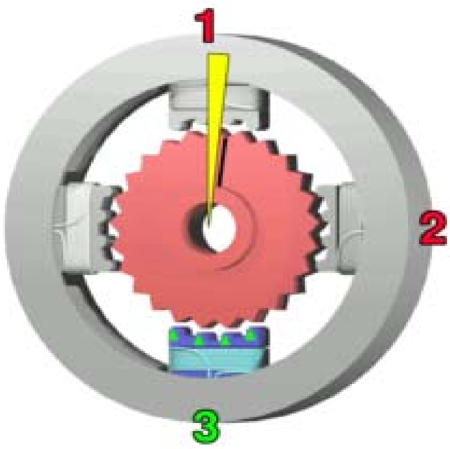
The common stepper motors that are used in projects operate on the same principle as the simple examples above. The main benefit of the stepper motor is controlled movement. The above motors have step angles of 90°. This large angle will not make for smooth movements. This is over come using of a gear shaped toothed steel disc that replaces the rotating magnet in the centre.



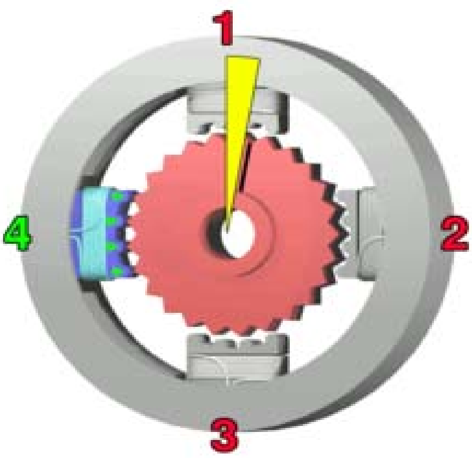
The top electromagnet (1) is turned on, attracting the nearest teeth of the disc. When the teeth are aligned to the top electromagnet they are slightly out of line with electromagnet (2).



The top electromagnet(1) is turned off and the right electromagnet (2) is energized, pulling the teeth slightly right. The amount of movement is 3.6° for this motor.



Continuing the sequence the electromagnet(3) is powered and another step occurs



The last electromagnet (4) is activated pulling the rotor another 3.6°. When the first electromagnet is energized again the teeth in the sprocket will have rotated by one tooth. As there are 25 teeth on the disc it will take 100 steps to complete one rotation. 25teeth x 4steps per tooth = 100 steps.

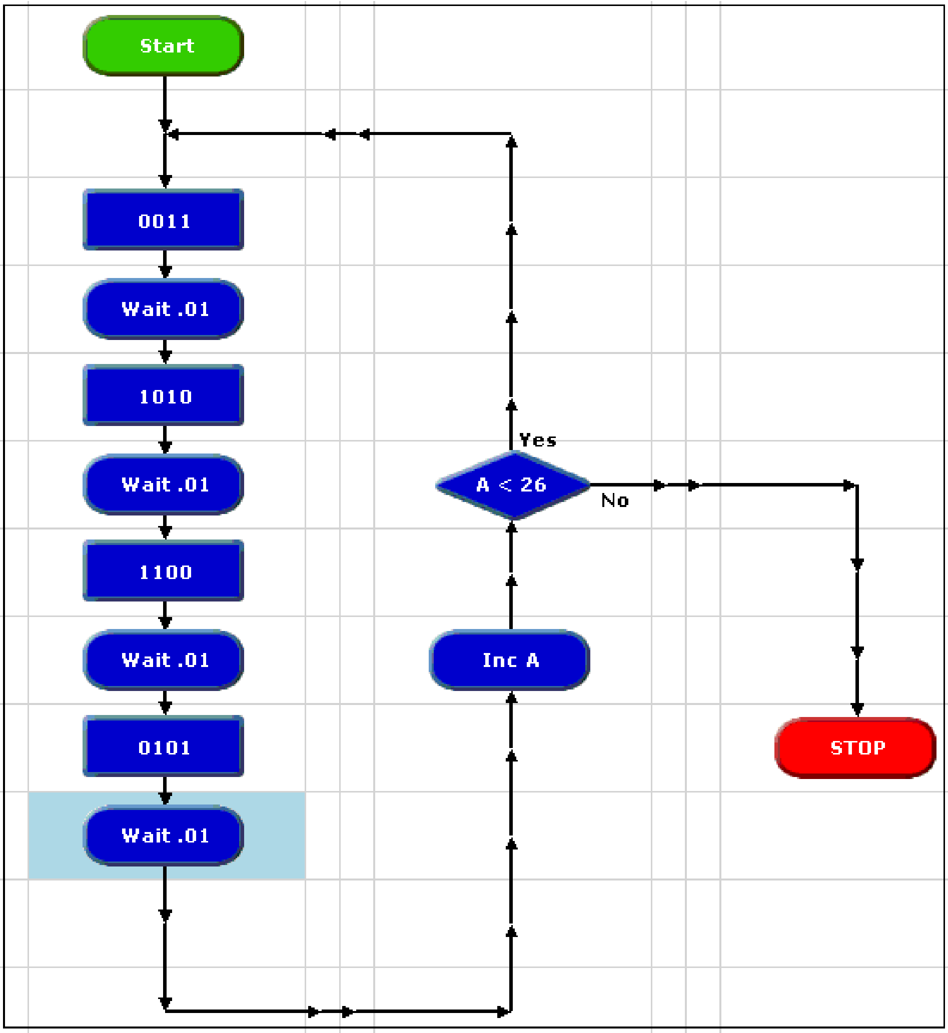
Stepper motors convert electrical pulses into discrete mechanical rotational movements. They offer very good holding torque, speed regulation and accurate movement. The wearing parts in a stepper motor are limited, unlike the DC motor they do not contain brushed which can wear and lead to malfunction. Steppers are used in printer control, conveyor belt drives, photo or film processing machine and also in scanners.

Standard stepper motor

Stepper motors require a controller to operate them. Logicator caters for stepper control once the correct sequencing table for the specific motor is available. The motor has six wires that will connect to the PIC board. Two are used for constant 0v & 5v, the four others are direct outputs from the PIC. A typical table is as follows

	Output0	Output1	Output2	Output3
Step 1	0	0	1	1
Step 2	1	0	1	0
Step 3	1	1	0	0
Step 4	0	1	0	1

This table is entered as outputs blocks in Logicator. The speed of the motor is determined by the length of a wait block that is placed between each output block. The number of steps can be controlled by the number of times the sequence is looped



In this program the Inc command is used to record the number of times the sequence has run. Once it reaches 26 loops the program will terminate.

The motor can be made rotate in the opposite direction by reversing the sequence of the table

Steppers are suitable for use in open looped systems as they do not provide feedback to the controller. Once the pulse step has been sent to the stepper the control does not know if it reached this point.

Servo Motors

Of the three motors, the servo motor offers the smoothest and greatest control. They can be told to rotate to a specific point, making them ideal for applications that require precise movement. The rotation of a servo is limited; most rotate from 90° to 180° though some can complete a full rotation. They cannot rotate continually due to their structure so are unsuitable for driving wheels, but their torque and control make them suitable for powering robotic arms and such.

Servo motor

Servo motors are made up of a number of components that are housed neatly in a self contained unit. They contain a motor, gearbox and driver controller, allowing them to be controlled directly from a microcontroller.

Servos have three wires connected to them. As with the stepper motor two of the wires are for the power supply- 0v & 5v. The third cable feeds straight from the PIC output pin and cannot be received via a transistor chip, this is to ensure that it is a frequency that the servo receives, not a straight current.

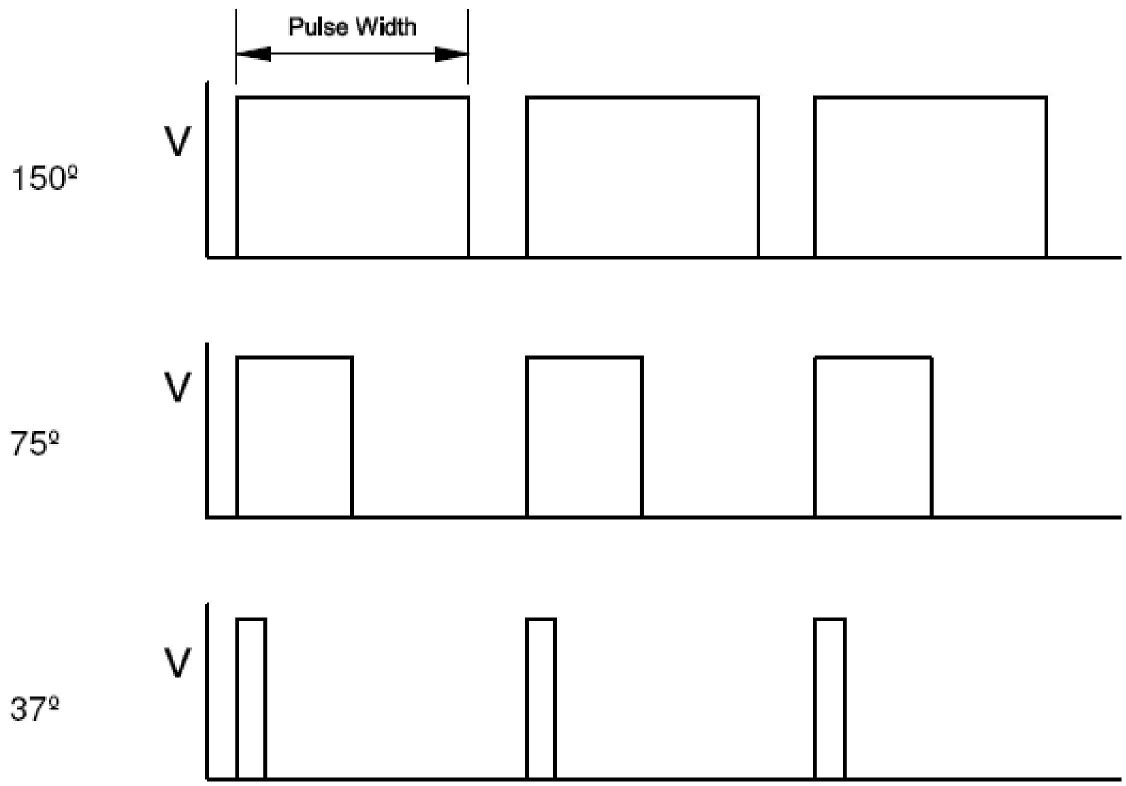
The potentiometer is connected to the motor through a gear train. A signal is given to the motor to rotate to a given position, as the motor turns it also moves the potentiometer causing its resistance to change. This resistance is monitored by the control circuit ensuring

that the servo is in the correct position. If the servo is accidentally knocked out of place the control circuit will know and correct it positioning. This is an example of closed loop control which will be covered later.

Servos are positioned using a technique called Pulse Width Modulation. Servos generally require a pulse width of 0.75ms to 2.25ms every 20ms. This pulse width must be constantly repeated every 20ms, if the pulse is lost the servo will loose its position. Pulse widths of 0.75ms to 2.25ms take the servo from 0° to 150°, any pulse widths between these can be selected to achieve the required position. It is the pulse width that controls the position of the servo, not the number of times it is repeated each second.

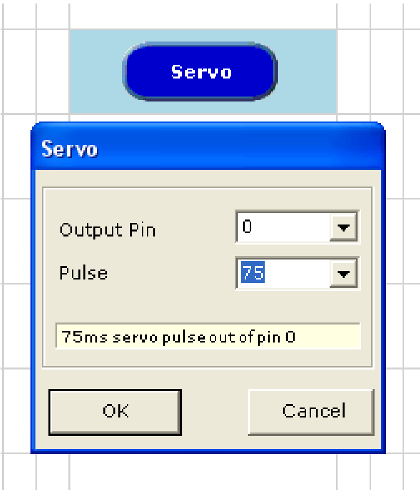
Logicator represents a range of pulse widths between 0.75ms and 2.25ms as 75 and 225 respectively.

3 Typical Pulse Widths

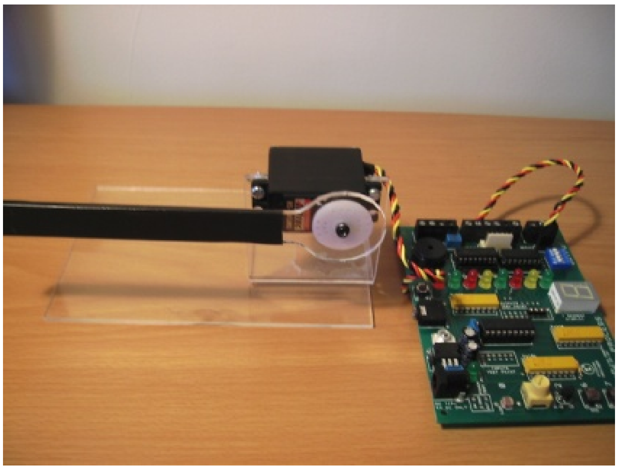


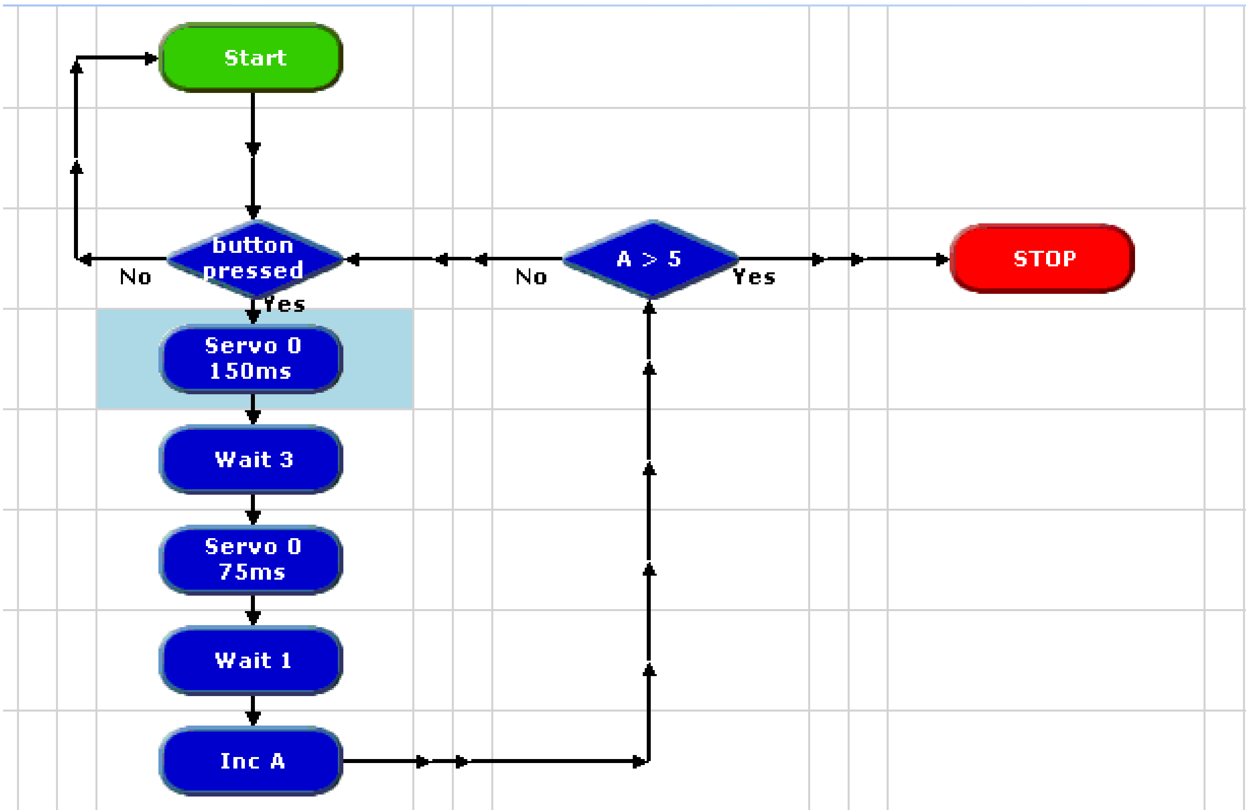
Programming of a servo motor in Logicator is done using the Servo Block that can be found towards the bottom of the right-hand side menu.

When this block is opened there are two parameters that must be set. Firstly the output pin of the PIC chip that the servo is connected to must be selected. On the T4 training boards this is Pin0. Secondly the pulse width desired for the servo must be set between 75 and 225. For more detailed programs this frequency can be expressed as a variable.



It is important that a wait block is added after each servo block to give the servo time to move into the desired position. An example of a circuit that would open and close a car barrier a set number of times (6) and terminates follows.





In the above Logicator file the program waits for the barrier up button to be pressed. Once it is the barrier opens up, waits for 3secs and then closes the barrier. It then waits a second before counting the car entered. A test is then performed to see if here are more than 5 cars in the car park, if not the loops starts again. Once [A] reaches 6 then the test will recognizes this and terminates the program.

End Effectors

In the robotic world it is generally understood that the end of the wrist is the end of the robot. The robot has the capability of moving to various positions within the limits of its work envelope. The robot is not yet prepared for the operation that it has to carry out; it does not have the correct "Hand". The end effector is the correct name for the attachment that can be mounted to a bolting plate fitted to the wrist. These attachments can be for grasping, lifting, welding, painting and many more. This means that the standard robot can be carry out a vast range of different applications depending on the end effector that is fitted to it.

Mechanical Gripper

There are two types of end effectors- **grippers** and **tools.** Tools are used where an operations such as welding, painting or drilling need to be performed. Their shapes and types are numerous and varied.

Drilling end effector with brush attached

There are three basic categories of grippers- mechanical, magnetic and pneumatic.

Mechanical Gripper

Multiple fingered gripper

The most common type of gripper is the two finger type as seen in the picture previously. There are multiple finger types capable of more complex tasks available also.

The mechanics of a gripper is that the gripper fingers close against the object with sufficient mechanical force to hold the object firmly against gravity and movement forces. The force should not however be too severe and cause damage to the component. The grippers may be powered by servos, pneumatic or hydraulic power.

Mechanical grippers may not always be suitable for handling some components due to their size or delicacy. Magnetic or pneumatic grippers offer alternative solutions to managing components.

Magnetic Gripper

These grippers are use to handle ferrous material. The grippers will be electromagnetic or permanent magnets. The electromagnetic can pick and release it component by switching on and off the magnet. Using a permanent means that the component cannot be simply dropped from the magnet, it must be slid off using a pneumatic piston. This may seem pointless when an electromagnet can be used. There is reduced risk of sparking because no electrical power is used, makes these types more suited in certain hazardous environments.

Pneumatic or Vacuum Grippers

Circular vacuum or suction cups made from plastic or rubber form pneumatic grippers. The cups press against the material to be lifted and the air drawn out by means of a pump, creating a plunger effect. This suction force allows the component to be lifted. The weight and centre of gravity of the components determines the number of suction cups used.

Vacuum Gripper

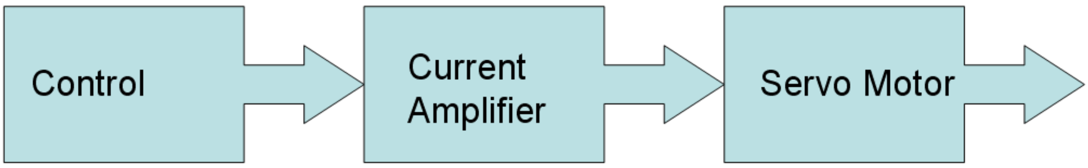
To allow for an effective suction the object to be lifted must have a relatively smooth flat and clean surface. Releasing of the part once it reaches its destination simply means neutralising the vacuum and allowing air into the suction pads.

Open and Closed Loop Control

Principles of a Practical Control system

All control systems contain three elements:

- The control
- Current Amplifiers
- Servo Motors



The control is the 'brain' of the system. The control reads the instructions from the program and performs all of the calculations and measurements that determine where the robot tool should be for any given instant in time during the run of the program. This can be a complex process using advanced mathematical principles. The result is that the control can send signals to the servo motors to control the axis positions up to several hundred times per second. The type of signal sent depends on whether Open loop or Closed loop control is used – see below.

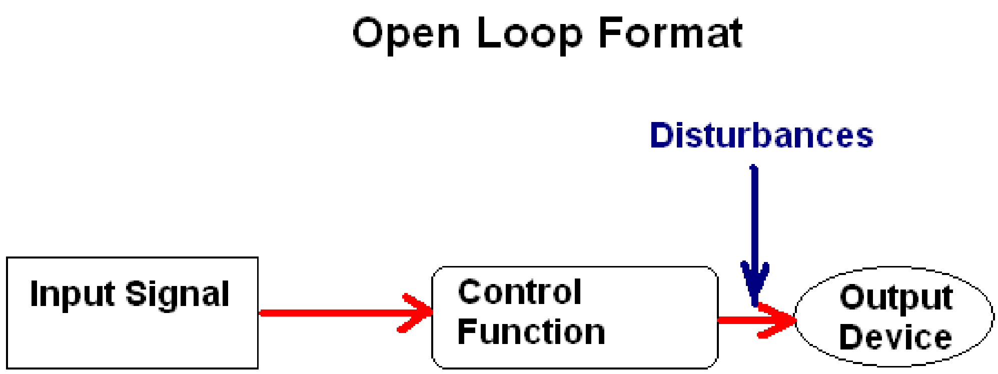
The output from the control is usually a small voltage (typically plus or minus five volts). In order to drive the stepper motors a current amplifier is needed. This uses

the voltage signal from the control (called the demand voltage) to control the current that powers the stepper motors.

The second types of motors are AC or DC servo motors. These behave in a similar manner to a conventional AC or DC motor but are designed to provide more constant running characteristics. These motors will exert a torque in proportion to the current running through them. They are used with Closed Loop control only.

Open Loop.

This is the simplest type of control and contains the three basic elements described above.

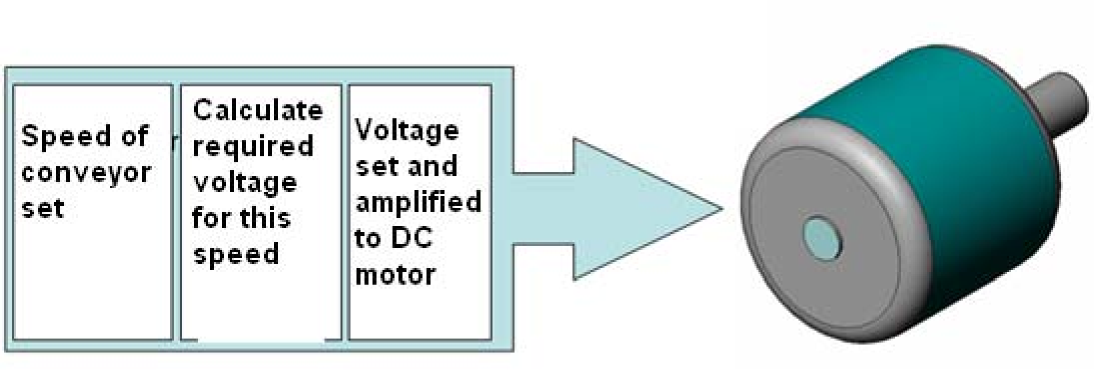


Elements of an open loop control

The open loop system works as follows:

A new conveyor is installed in a factory to transfer goods from one area to another. The conveyor will run at a constant speed for a given product; however there are three different products that may be on the conveyor at three different speeds. The speed of the conveyor can be set by the operator.

A DC motor is installed to drive the conveyor belt, a controller will be used which will be able to provide a variable voltage output. A control dial is provided to vary the input to the controller and set the speed. When setting the speed of the conveyor the operators will need to use a measuring device to record the speed of the belt and manually set it to the desired speed for a given operation. Each speed setting can be marked on the dial and allow the operator to choose the desired setting whenever necessary



Open loop control system

However certain factors are liable to occur which may prevent the conveyor from running at the set speed. If the weight of the good being transported varies the load on the motor will increase and decrease, causing the conveyor to speed up or slow down. Similarly if the conveyor is not maintained increased forces due to friction in bearings etc will cause greater load and slow the motor.

The Open Loop system is not self monitoring. Once the controller sends out the voltage to the motor it does not know if the motor is going at that desired speed as there is no sensor on the motor.

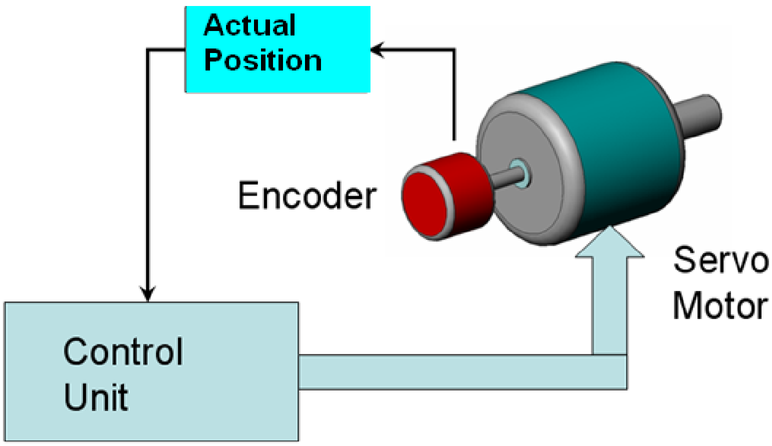
Advantages of Open Loop

Open Loop is relatively cheap to install and in many situations it may not be necessary to have high accuracy that requires constant monitoring. In the conveyor system it may be acceptable to have a system that has only a speed accuracy of 10%. Open Loop Control provides the capability of running the conveyor at different speeds at a moderate cost.

Closed loop control.

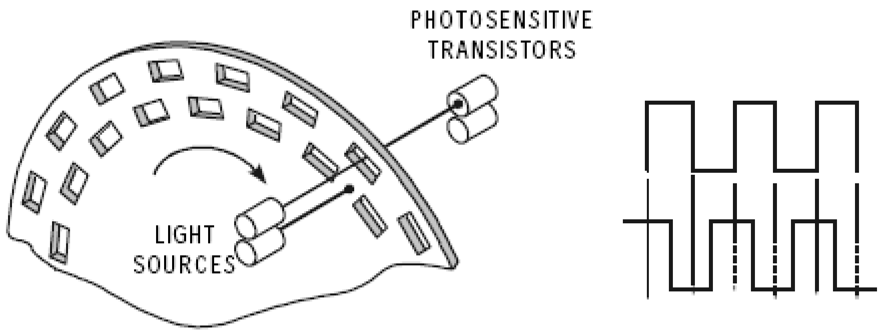
This method of control has one additional element- feedback. A closed loop control is a more accurate system of control. It constantly monitors its movements and actions using sensors. The process under control can be temperature, speed, pressure etc.

Elements of a closed loop control system



Encoders

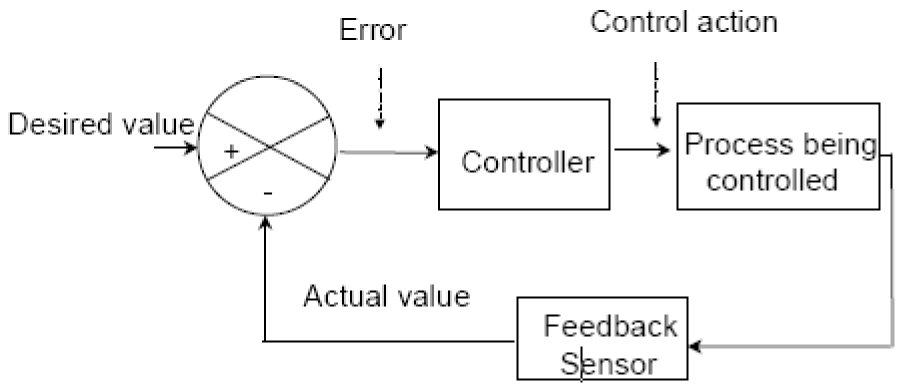
Disc Encoder



For closed loop control it is necessary for the control system to be able to monitor the movements of the motor it is controlling. We saw previously how some servos use a potentiometer to monitor its position. Most systems use encoders to provide the feedback to the controller as to the actual position of the motor.

The picture above shows the basic structure of an incremental optical encoder. This encoder is connected to the shaft of the motor. A circular disc spins between a beam of light. A light sensor called a photosensitive transistor monitors the light and receives a series of light pulses as the disc rotates. The number of slots on the disc will determine the resolution and accuracy of the encoder. This disc has two sets of slots allowing for greater accuracy than a disc with just one. The light sensor feeds the information about the light pulses back to the controller allowing it to calculate the speed, position and direction of the motor.

Closed Loop Control



The value we are trying to achieve is the input value set by the users and is often called the 'desired value' or 'set point'. The sensor gives the actual value of the condition we are controlling and is often titled 'measured value' or 'actual value'.
Closed loop control uses a comparator. It compares two values by subtracting the actual value from the desired value. Any difference between the two produces an error
which is fed to the controller. The controller generates a control action on the process
to try and eliminate this error.

On / Off Control

This is the simplest form of closed loop control. When the system notes an error present between the desired and the actual value it goes into full corrective. Let's take a simple example of controlling the water heating temperature in a domestic home. When the temperature of the water is low the thermostat closes and full power is given to the element which starts to heat the water quickly. When the temperature reaches the desired heat it turns it off again, but the elements are still warm so the temperature goes slightly above the desired. The water cools again and the cycle

starts all over again. This is not much of a problem with water but the stop start effect on motors and servos can cause problems in inaccuracy.

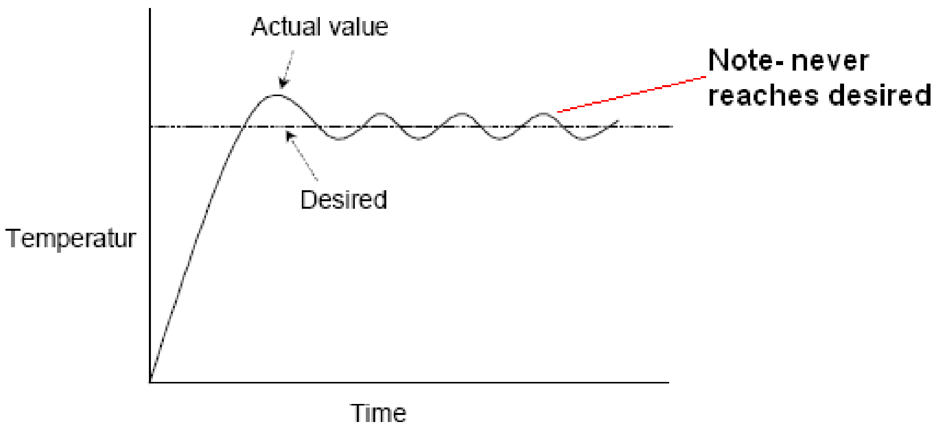
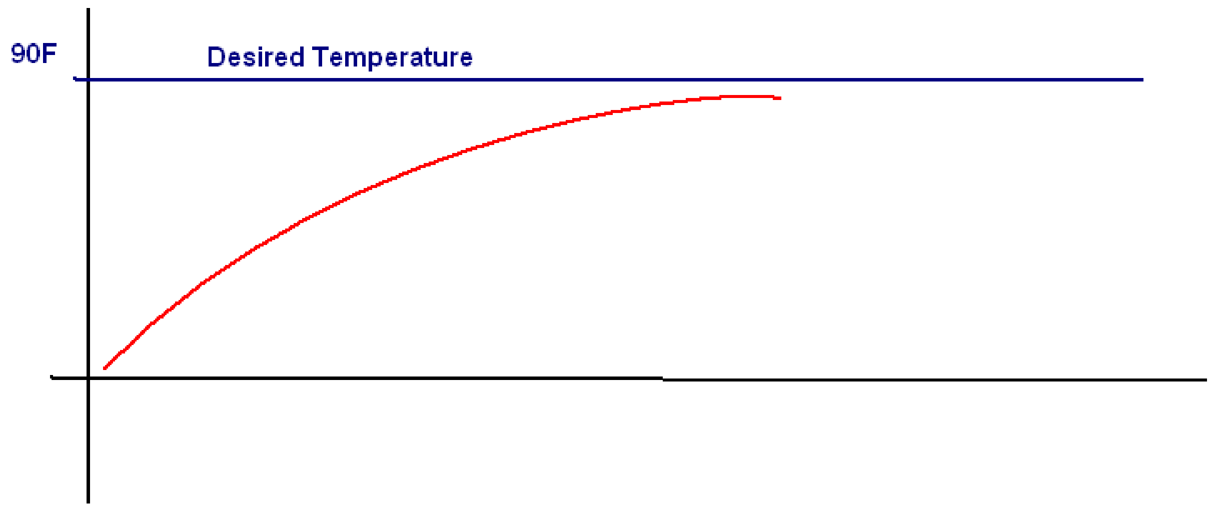


Figure 1 On- Off Control

The unsteady graph shows the effect of **On – Off control**, and the result of the output being either on or off.

Proportional Control

Proportional control improves on the On-Off control with an action that is proportional to the error. Using the domestic water heating example; say the heater has just been turned on, then the control will give full power to the element to heat the water fast. However as the controller notes the water coming closer to the temperature it will start to limit the current flow to the element, the closer the water comes to the desired temperature the smaller the current flow to the element and the less chance there is of the water temperature shooting above the desired value.



Proportional Control

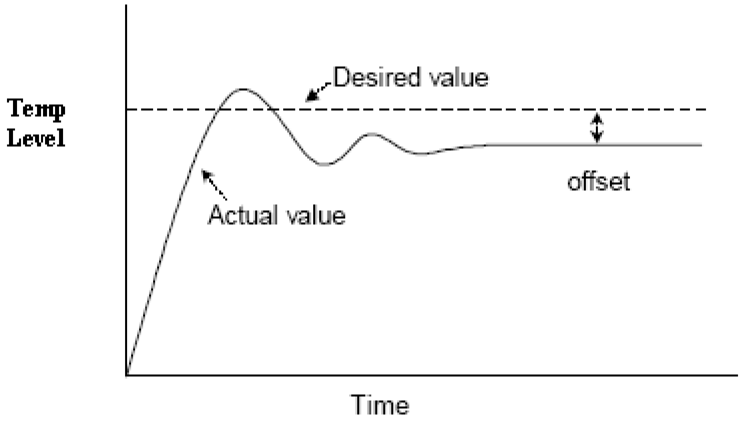
Proportional control eliminates the oscillating values that could be seen with the On-Off system. It causes a smooth rise towards and reduces the over shoot from the desired position.

The limitation of proportional control is that the response to change is very slow, the closer it gets to the desired the slower the movement becomes. Noting the graph above it appears that the actual level has nearly levelled off and it is still not at the desired value. The gap between the desired and the actual valuations is commonly known as the **offset.**

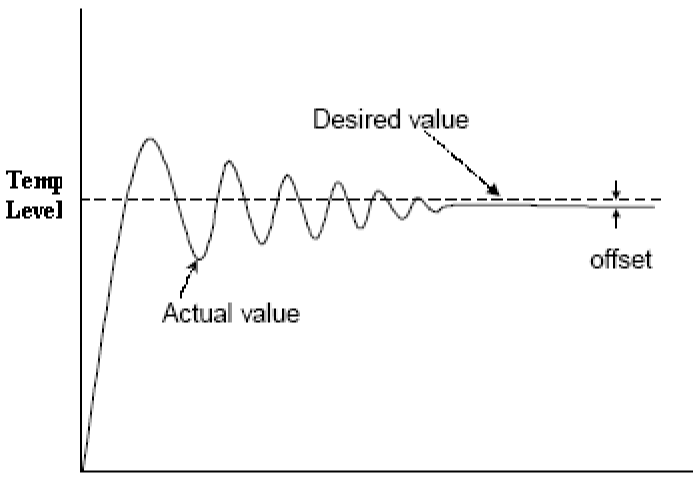
Increasing the gain of a Proportional Controller

The normal method of increasing the response to proportional control is to increase the **Gain** factor **K**. The process appears to have reverted to an oscillatory condition. Upon closer inspection of the graphs below shows that the output does stabilise eventually.

In the proportional control graph above the gain applied was too low resulting in very sluggish response. Imagine that the water heater temperature has dropped slightly. Using standard proportional control without a gain factor this would never reach the desired value leaving an offset. **The system attempts to calculate a Gain K that will stabilise the temperature at the desired level.**



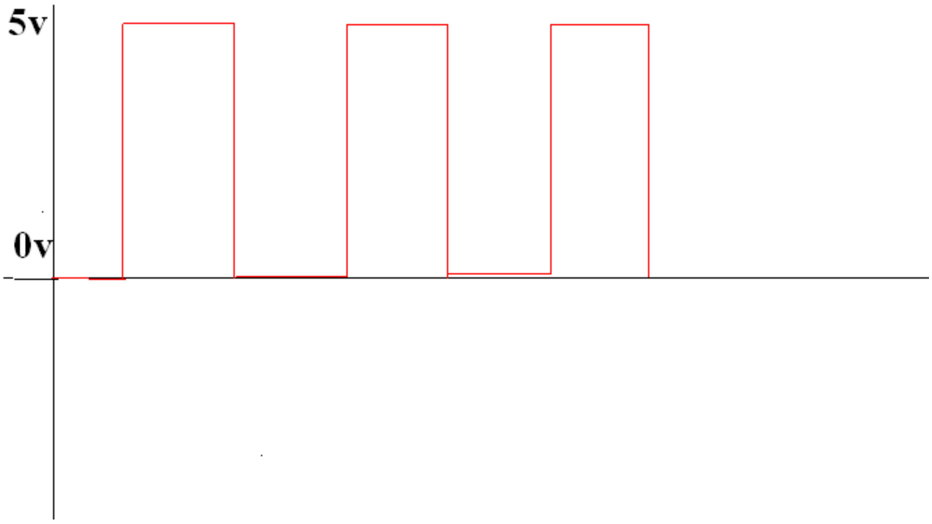
Temp
Level
Desired value
offset
Actual value
Time



Temp
Level
Desired value
offset
Actual value

A/D and D/A Conversion

Within control systems it is necessary to be able to take an analogue value from an input and save it as a digital number. Firstly it is important to understand the difference between digital and analogue and the problems that analogue values pose.



Digital Wave-

Digital is like a simple switch; it is either on or off. All computing operates digitally, storing a series of 1 & 0. We are all familiar with the decimal system where we have ten digits, 0, 1,2,......8,9. We can count into infinity with these 9 digits by simple arranging them in tens, hundreds, thousands and so on. This system is to the base ten.

- 0,1,2,3....8.9
- 10,11,12......20,21...30......98....99
- 100..200....999
- 1000

The digital system counts in a similar way but it is to the base two, using only two digits.0,1. This is known as the binary system.

$2^3 = 8$	$2^2 = 4$	$2^1 = 2$	$2^0 = 1$	Decimal Equivalent
0	0	0	0	0
0	0	0	1	1
0	0	1	0	2
0	0	1	1	3
0	1	0	0	4
0	1	0	1	5
0	1	1	0	6
0	1	1	1	7
1	0	0	0	8
1	0	0	1	9
1	0	1	0	10
1	0	1	1	11
1	1	0	0	12
1	1	0	1	13
1	1	1	0	14
1	1	1	1	15

Binary counting- 4bit

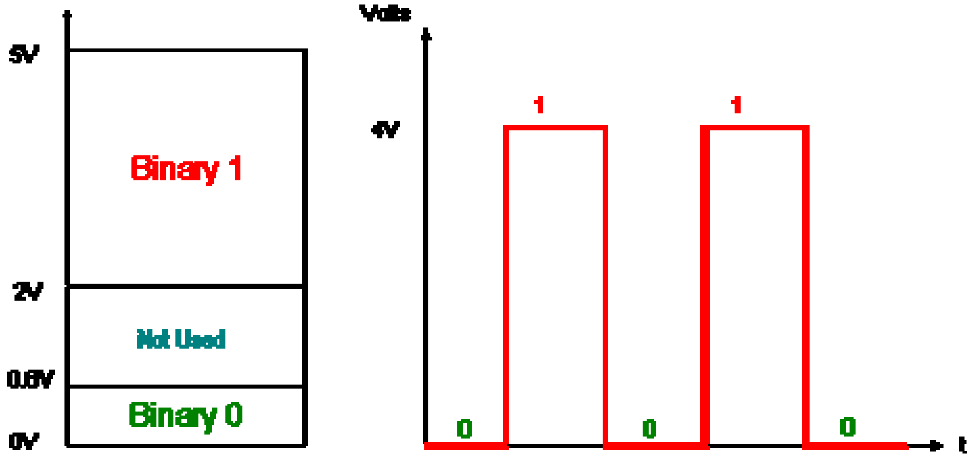
This table shows the counting from 0-15 (16 numbers including 0) in binary. It is not possible to count any higher than 15 because all the four columns have been filled with 1's. This is a **4bit** number, because of the four columns. The table below shows how increasing the columns allows for double the numbers. Each column is adding another bit; **8 bits = 1Bite(256)**

Binary Nember	Decimal Equivalent	Number of Bits	Maximum Number of Values
1	1	1	2
10	2	2	4
11	3		
100	4	3	8
101	5		
110	6		
111	7		
1000	8	4	16
1001	9		
1010	10		
1011	11		
1100	12		
1101	13		
1110	14		
1111	15		
10000	16	5	32
11111	31		
100000	32	6	64
111111	63		
1000000	64	7	128
1111111	127		
10000000	128	8	256
11111111	255		

In an 8 bit system there are 256 max values.

8 bit binary counting

This 8 bit system containing 256 values is important when programming using Pic. In Logicator the range of numbers that can be selected in a compare block or when monitoring an analogue input is between 0 – 255 (256 numbers). This is not coincidence but due to the fact that there are **8 Bits** or **1 Bite** available on the chip to store these numbers. As 1 bite has only 256 numbers this is all that can be stored in the digital system.



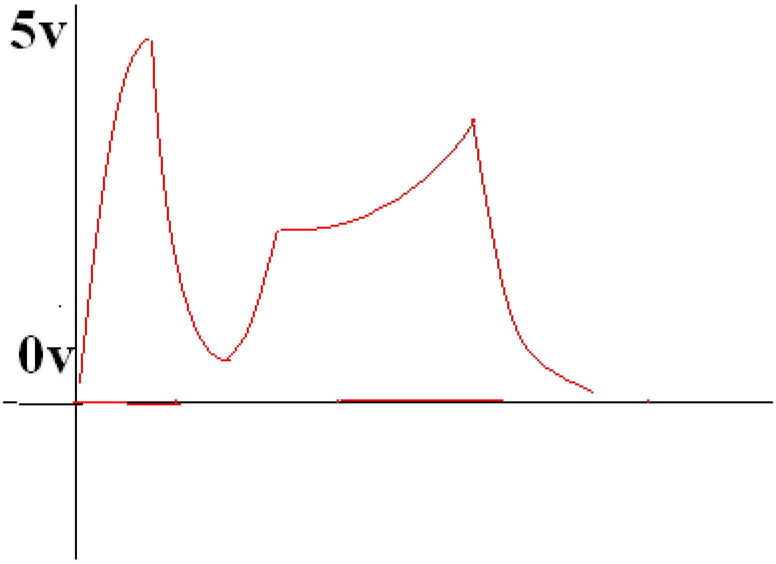
Digital reading

As stated previously digital is either on or off. When a control system reads whether something is 1 or 0 it must decide what voltage signifies a change from 0 to 1. In a perfect system 0 v would be off and 5v would be on. However the voltage may not always drop completely to 0v or rise to 5v. The following is therefore taken as standard;

Binary 1: Any voltage between 2V to 5V
Binary 0: Any voltage between 0V to 0.8V
Not used: Voltage between 0.8V to 2V, this may cause error in a digital circuit.

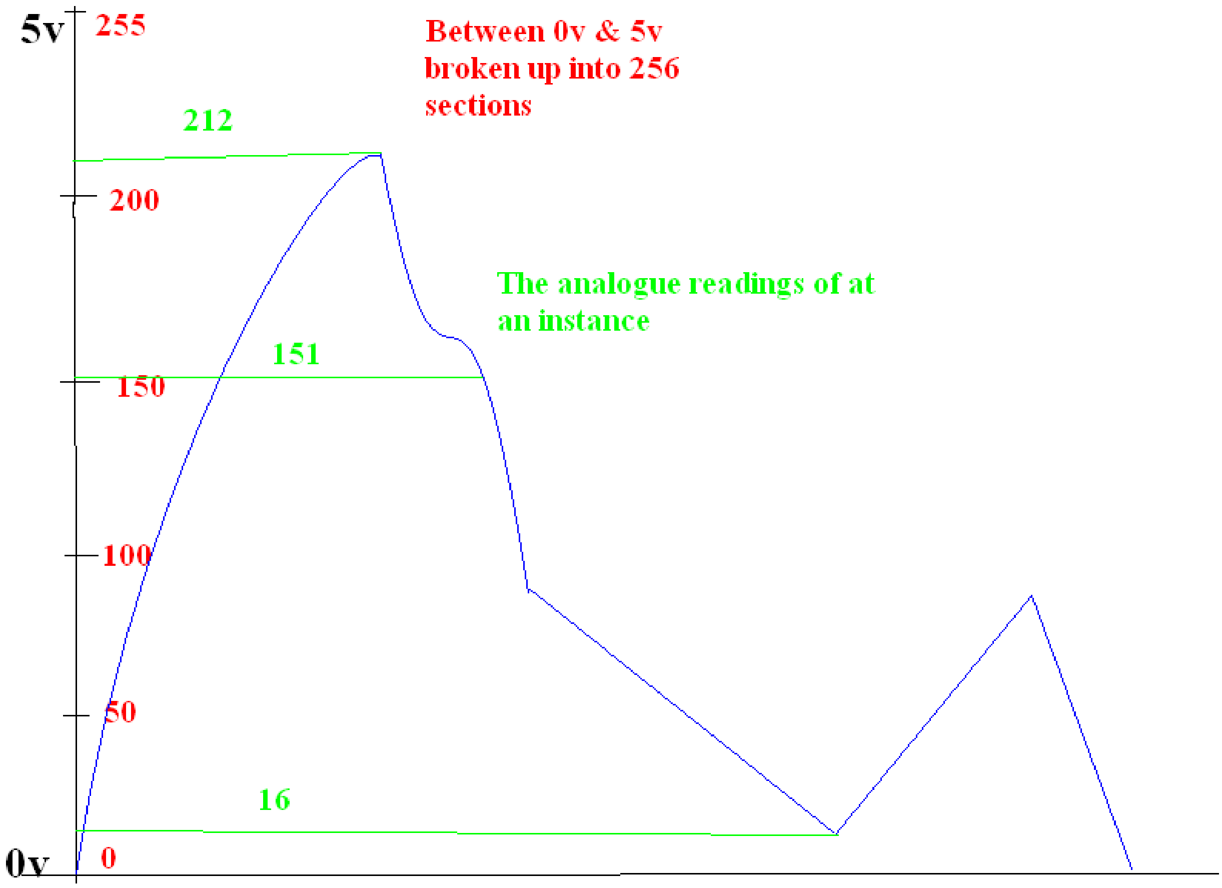
The computer system does not care what the voltage values are between 2v & 5v, just that it is somewhere in-between and is digitally on.

In analogue the exact voltage value is important. This is not a set 0 or 1 but can be any value between 0v and 5v.



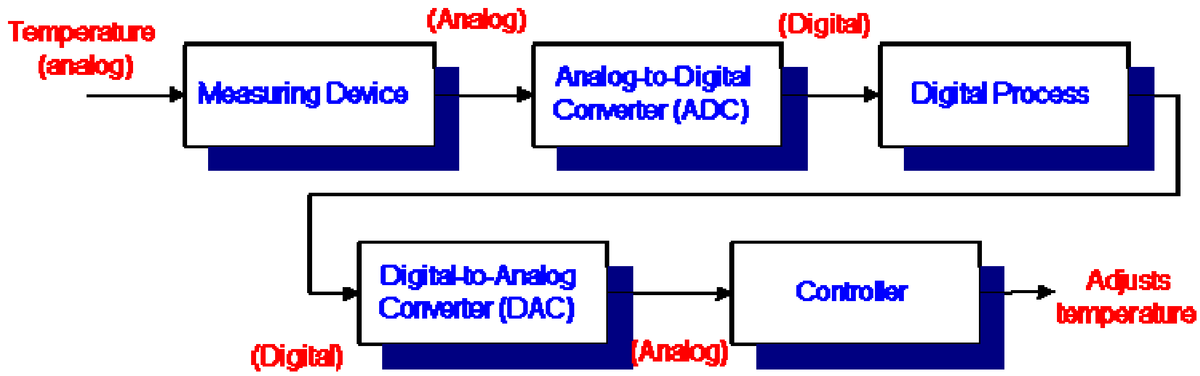
Analogue values

In the T4 training boards as we vary the analogue inputs we change the reading being sent to the Pic chip. Realistically what we are doing is changing the resistance of the Potentiometer or the LDR, this change in resistance cause the voltage across the input to rise and fall between 0v & 5v. The Pic reads the different voltage values. What it does next is converts the analogue readings into digital.



Analogue to digital

The digital values were broken up into three bands, in analogue the 0v -5v is broken up into 256 segments as seen in the red above. As an analogue reading changes it moves between these segments. The Pic chip notes these and can save the value as a binary number in the chip. The number of bits in the chip determines the amount segments that the 0v- 5v can be broken into. The more bits the smaller the segments and the greater accuracy. This is known as the resolution.



A/D D/A

This flow chart shows how a temperature monitoring system operates. The thermometer is a thermister whose resistance changes with a change in temperature. This creates an analogue reading similar to the potentiometer. This reading is broken into the segments as shown previously and converted to a binary number which the control system can read. The binary reading from the thermometer is monitored and if the reading is too hot or cold the control system send a digital signal to alter the temperature. At this stage the digital value must be converted back to analogue. This binary number is compared to the segments and the corresponding voltage the analogue controller needs to operate is found. This voltage is the control voltage that will allow the analogue controller to adjust the temperature.