Electro Mechanical Engineering

Quiana Esposito

First Edition, 2012

ISBN 978-81-323-2744-8

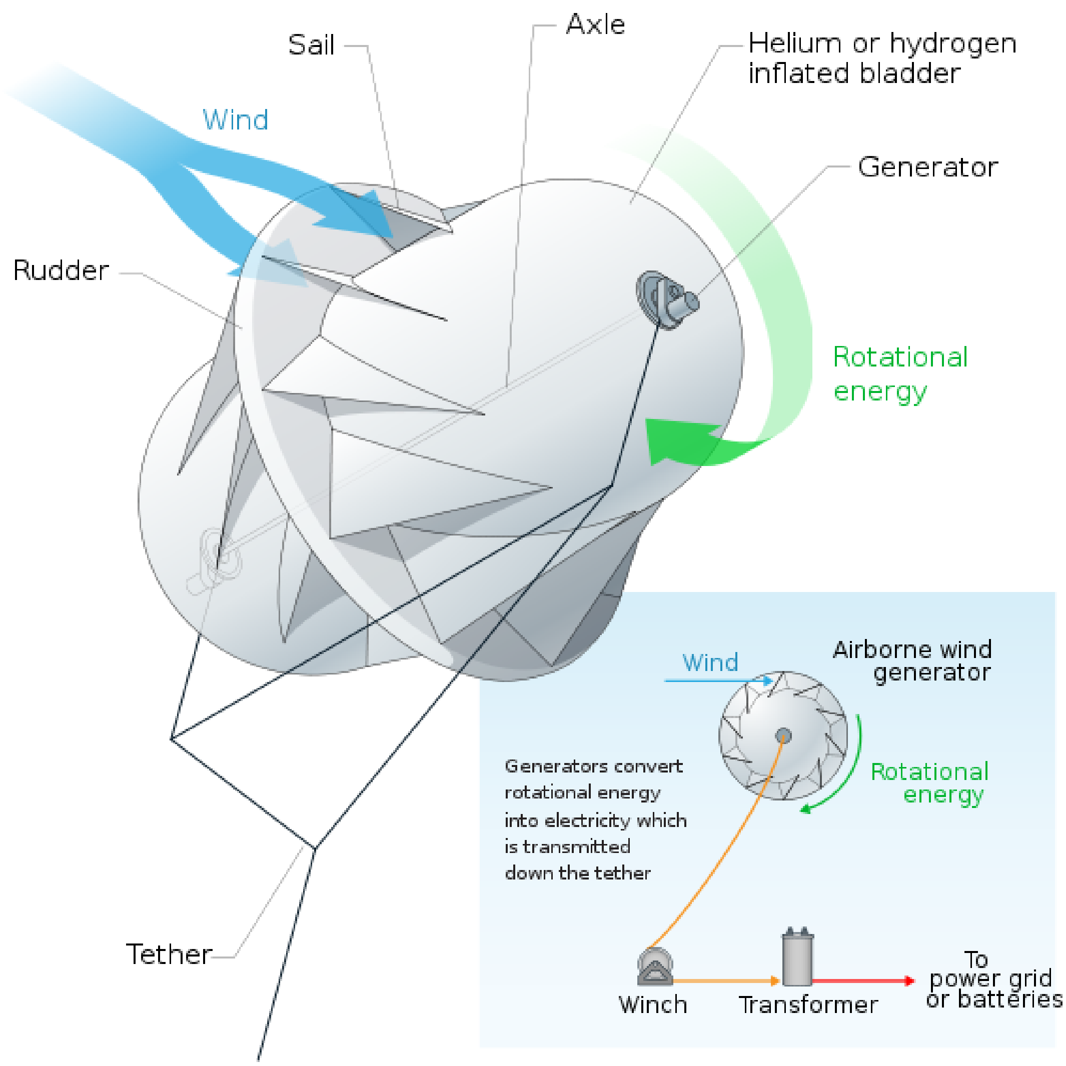
Published by:
Orange Apple
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

Table of Contents

Chapter 1

Airborne Wind Turbine & Yaw Drive

Airborne Wind Turbine



Airborne wind generator of Savonius style

An **airborne wind turbine** is a design concept for a wind turbine that is supported in the air without a tower. Airborne wind turbines may operate in low or high altitudes; they are part of a wider class of airborne wind energy systems (AWE) addressed by high altitude wind power. When the generator is on the ground, then the tethered aircraft need not carry the generator mass or have a conductive tether. When the generator is aloft, then a conductive tether would be used to transmit energy to the ground or used aloft or beamed to receivers using microwave or laser. Airborne turbine systems would have the advantage of tapping an almost constant wind, without requirements for slip rings or yaw mechanism, and without the expense of tower construction. Kites and 'helicopters' come down when there is insufficient wind; kytoons and blimps resolve the matter. Also, bad weather such as lightning or thunderstorms, could temporarily suspend use of the machines, probably requiring them to be brought back down to the ground and covered. Some schemes require a long power cable and, if the turbine is high enough, an aircraft exclusion zone. As of 2008, no commercial airborne wind turbines are in regular operation.

Aerodynamic variety

An aerodynamic airborne wind power system relies on the wind for support.

Bryan Roberts, a professor of engineering at the University of Technology, in Sydney, Australia, has proposed a helicopter-like craft which flies to 15,000 feet (4,600 m) altitude and stays there, held aloft by wings that generate lift from the wind, and held in place by a cable to a ground anchor. According to its designers, while some of the energy in the wind would be 'lost' on lift, the constant and potent winds would allow it to generate constant electricity. Since the winds usually blow horizontally, the turbines would be at an angle from the horizontal, catching winds while still generating lift. Deployment could be done by feeding electricity to the turbines, which would turn them into electric motors, lifting the structure into the sky.

The Dutch ex-astronaut and physicist Wubbo Ockels, working with the Delft University of Technology in the Netherlands, has designed, and demonstrated , an airborne wind turbine he calls a "Laddermill". It consists of an endless loop of kites. The kites lift one end of the endless loop, (the "ladder") up, and the released energy is used to drive an electric generator.

A Sept'09 paper from Carbon Tracking Ltd., Ireland has shown the capacity factor of a kite using ground based generation to be in 52.2% which compare favorably with terrestrial wind-farm capacity factors of 30%.

A team from Worcester Polytechnic Institute in the United States has developed a smaller scale kite power system with an estimated output of about 1 kW. It uses a kiteboarding kite to induce a rocking motion in a pivoting beam.

The Kitegen uses a prototype vertical-axis wind turbine. It is an innovative plan (still in the construction phase) that consists of one wind farm with a vertical spin axis, and employs kites to exploit high-altitude winds. The Kite Wind Generator (KWG) or Kitegen is claimed to eliminate all the static and dynamic problems that prevent the increase of the power (in terms of dimensions) obtainable from the traditional horizontal-axis wind turbine generators. Generating equipment would remain on the ground, only the airfoils are supported by the wind. Such a wind power plant would be capable of producing the energy equivalent to a nuclear power plant, while using an area of few square kilometres, without occupying it exclusively. (The majority of this area can still be used for agriculture, or navigation in the case of an offshore installation.)

KiteLab's Dave Santos of Ilwaco, Washington, has been advancing single-surface wingmills to generate useful electricity with the generator ground-based.

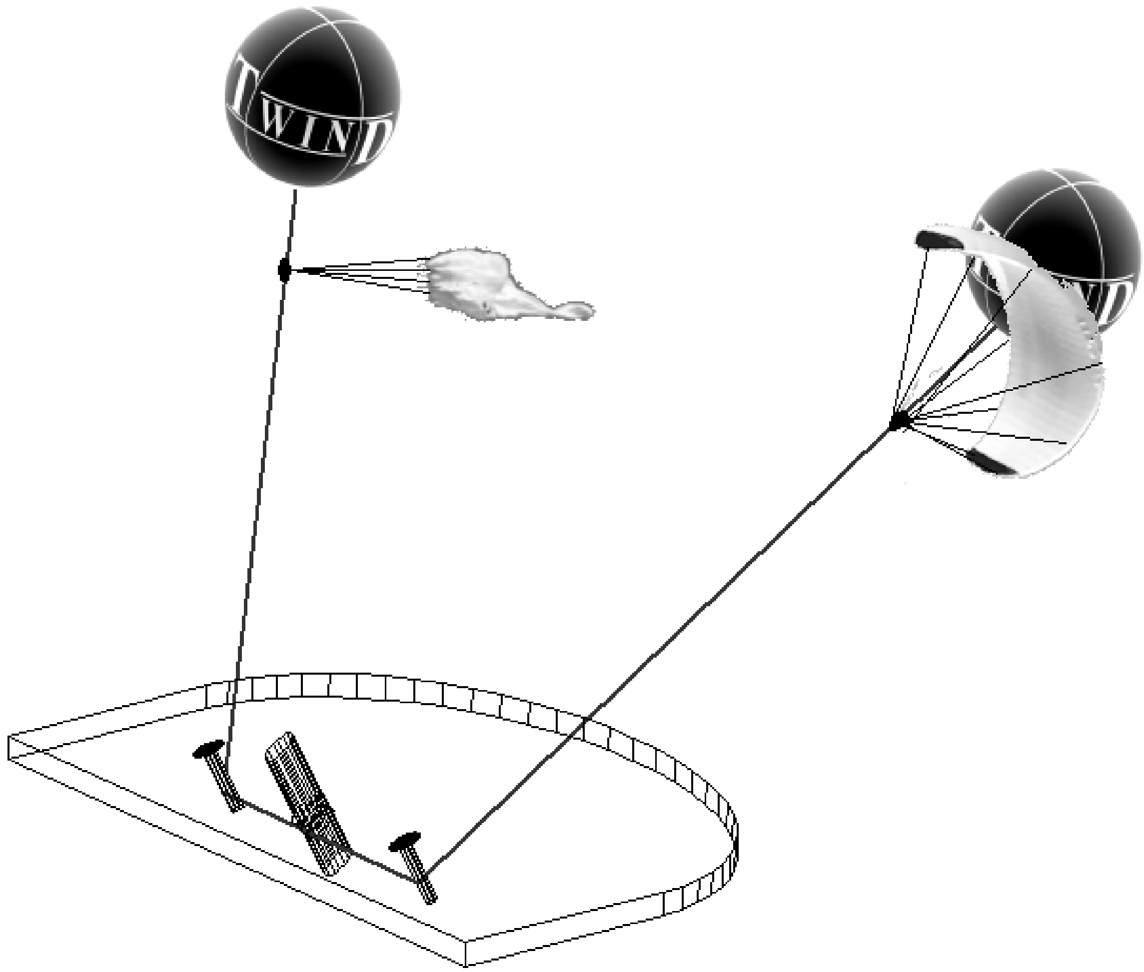
The Rotokite is developed from Gianni Vergnano's idea. It uses aerodynamic profiles similar to kites that have been rotated on their own axis, emulating the performance of a propeller. The use of the rotation principle simplifies the problem of checking the flight of the kites and eliminates the difficulties due to the lengths of cables, enabling the production of wind energy at low cost. The Heli Wind Power is a project of Gianni Vergnano that uses a tethered kite.

Aerostat variety

An aerostat-type wind power system relies at least in part on buoyancy to support the wind-collecting elements. Aerostats vary in their designs and resulting lift-over-drag aerodynamic characteristic; the kiting effect of higher lift-over-drag shapes for the aerostat can effectively keep an airborne turbine aloft; a variety of such kiting balloons were made famous in the kytoon by Domina C. Jalbert.

Balloons can be added to the mix to keep systems up without wind, but balloons leak slowly and have to be resupplied with lifting gas, possibly patched as well. Very large, sun heated balloons may solve the helium or hydrogen leakage problems.

An Ontario based company called Magenn Power Inc. has developed a turbine called the Magenn Air Rotor System (MARS). The 100-foot (30 m)-wide MARS system uses a horizontal rotor in a helium suspended apparatus which is tethered to a transformer on the ground. Magenn states that their technology provides high torque, low starting speeds, and superior overall efficiency thanks to its ability to deploy higher in comparison to non-aerial solutions. The first prototypes were built by TCOM in April 2008.



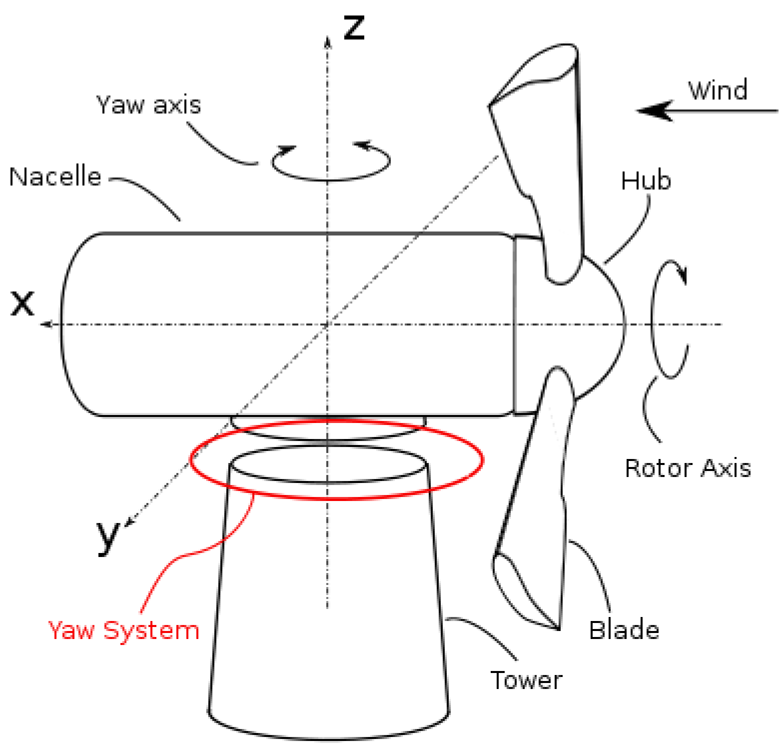
Concept drawing of the Twind technology.

The Twind Technology concept uses a pair of captive balloons at an altitude of 800 meters. The tether cables transmit force to a rotating platform on the ground. Each balloon has a sail connected to it. The two balloons move alternately, the balloon with the sail open moves downwind and draws the other balloon upwind, and then the motion reverses. The tether cable can be used to turn the shaft of a generator to produce electrical energy or perform other works (grinding, sawing, pumping).

Estimated costs

Sky Windpower estimate that their technology will be capable of producing electricity for \$0.02 per KWh, while a system of raising a kite to a high altitude while turning a generator on the ground, and then changing its shape so that it can be drawn back down with less energy than it produced on the way up, has been estimated to be capable of producing electricity for \$0.01 per KWh - both numbers being significantly lower than the current price of non-subsidized electricity.

Yaw Drive



Schematic representation of the main wind turbine components. The yaw system is located between the wind turbine nacelle and tower.

The **yaw drive** is an important component of the horizontal axis wind turbines' yaw system. To ensure the wind turbine is producing the maximal amount of electric energy at all times, the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. This only applies for wind turbines with a horizontal axis rotor. The wind turbine is said to have a yaw error if the rotor is not aligned to the wind. A yaw error implies that a lower share of the energy in the wind will be running through the rotor area. (The generated energy will be proportional the cosine of the yaw error).

History

When the windmills of the 18th century included the feature of rotor orientation via the rotation of the nacelle, an actuation mechanism able to provide that turning moment was necessary. Initially the windmills used ropes or chains extending from the nacelle to the ground in order to allow the rotation of the nacelle by means of human or animal power.

Another historical innovation was the fantail. This device was actually an auxiliary rotor equipped with plurality of blades and located downwind of the main rotor, behind the nacelle in a 90° (approximately) orientation to the main rotor sweep plane. In the event of change in wind direction the fantail would rotate thus transmitting its mechanical power through a gearbox (and via a gear-rim-to-pinion mesh) to the tower of the windmill. The effect of the aforementioned transmission was the rotation of the nacelle towards the direction of the wind, where the fantail would not face the wind thus stop turning (i.e. the nacelle would stop to its new position).

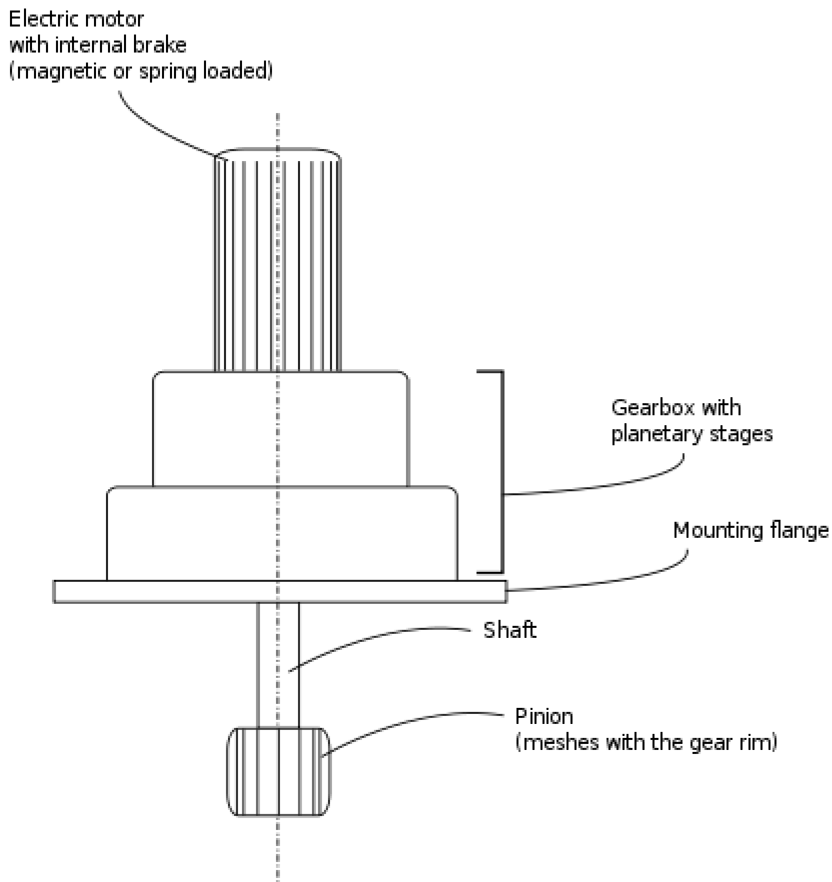
The modern yaw drives, even though electronically controlled and equipped with large electric motors and planetary gearboxes have great similarities to the old windmill concept. They still use a means of mechanical energy "production" (i.e. electric motor), a method to increase the torque (i.e. gearbox) and a gear-rim mounted on the fixed portion of the wind turbine and in constant mesh with the output gear of the said gearbox.

Types

The main categories of yaw drives are:

- The Electric Yaw Drives: Commonly used in almost all modern turbines.
- The Hydraulic Yaw Drive: Hardly ever used anymore on modern wind turbines.

Components

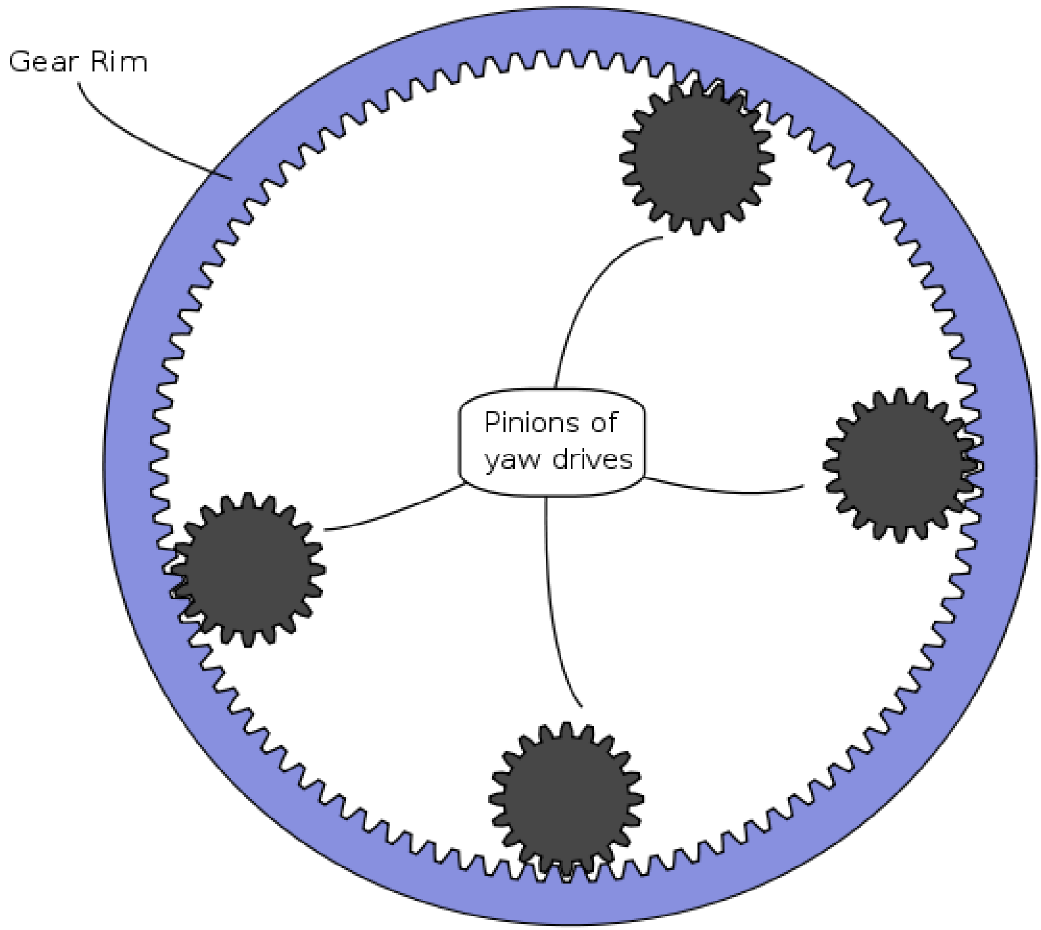


Schematic representation of a typical yaw drive

Gearbox

The gearbox of the yaw drive is a very crucial component since it is required to handle very large moments while requiring the minimal amount of maintenance and perform reliably for the whole life-span of the wind turbine (approx. 20 years). Most of the yaw drive gearboxes have input to output ratios in the range of 2000:1 in order to produce the enormous turning moments required for the rotation of the wind turbine nacelle.

Gear rim and pinions



Schematic representation of a gear rim with teeth on the inner side. The gear rim meshes with four yaw drive pinions.

The gear-rim and the pinions of the yaw drives are the components that finally transmit the turning moment from the yaw drives to the tower in order to turn the nacelle of the wind turbine around the tower axis (z axis). The main characteristics of the gear-rim are its big diameter (often larger than 2 m) and the orientation of its teeth.

The gear-rims with teeth on the outer surface have the advantage of higher reduction ratios in combination with the pinions as well as reduced machining costs over the gear-rims with inner teeth. On the other hand the former configuration requires the yaw drives to be mounted far apart from each other thus increasing the wind turbine main frame dimensions and costs.

Chapter 2

Swing Door Operator

A **swing door operator** (or **swing door opener** or **automatic swing door operator**) is a device that operates a swing door for pedestrian use. It opens or helps open the door automatically, waits, then closes it.

Types

There are 3 basic types of swing door operators:

- Full Energy - It opens and closes the door at full speed.
- Low Energy - It opens and closes the door at reduced speed, in order to limit the kinetic energy of the moving door to levels deemed safe for disabled users.
- Power Assist - This is a version of the Low Energy operator. It doesn't open the door; instead, it lets the user open the door manually at a reduced force, compared to opening against a standard door closer. It closes the door with the same speed limitations as a Low Energy operator.

Uses

Full Energy operators are typically used on the outside doors of medium sized retail businesses. (Larger retail businesses prefer sliding door operators.) Low Energy operators are typically used where a simple door closer is sufficient for abled users, yet it is necessary to add access to disabled users: small businesses, apartments, bathrooms.

Triggering

A door operator may be triggered in various ways:

- Approach Sensor (such as a radar sensor) - the door opens when a user approaches it.

- Pushbutton - the door opens when a user presses a button.
- Push-&-Go - the door opens fully when the user begins opening it.
- Access control - the door opens when the an Access Control System determines the user is authorized to go through.

A trigger from any of the above requests that the door be opened (or reopened if it was closing). The operator will heed that requests only after it is able to do so safely for any other users in the area.

Safety sensors

A door operator may use sensors to prevent the door from coming into contact with a user.

Full Energy operators require at least 3 sensors. Low Energy Operators are not required to have safety sensors, as the door is allowed to come in contact with a user, given that the kinetic energy of the moving door is limited by the reduced moving speed.

Historically, sensors have been simply floor mats that sense the weight of a user, one in the area immediately in front of the door (the approach side) and one in the area behind it (the swing side). The approach side mat is often used as a trigger sensor. The swing side mat prevents the door from starting to open as long as some other person is detected in the swing area; once the door starts opening, this mat is ignored, as it will sense the user going through.

Today, infrared safety sensors are normally used. Four types are commonly used.

- Header mounted presence sensor - Mounted on the jamb above the door, on the approach side, it detects the presence of a person standing in front of the door.
- Approach side, door mounted sensor - Mounted on the approach side of the door itself, used as the door is closing to detect a user in the way of the closing door. In that case, the operator either stops the door or reopens it.
- Swing side, door mounted sensor - Mounted on the swing side of the door itself, used as the door is opening to detect a user in the way of the opening door. In that case, the operator stops the door. This detector's sensitivity must be reduced at the end of the opening angle, if it starts seeing a wall next to the door, so it may not confuse it with a user.
- Safety beam - This beam crosses the path of the user past the swing side. If interrupted, the operator assumes that a person has crossed into the swing area, and it is not safe to open the door at full speed. This sensor is ignored once the door has started to open, as then the operator assumes that it is the user having gone through the door that has interrupted the beam.

Opening technologies

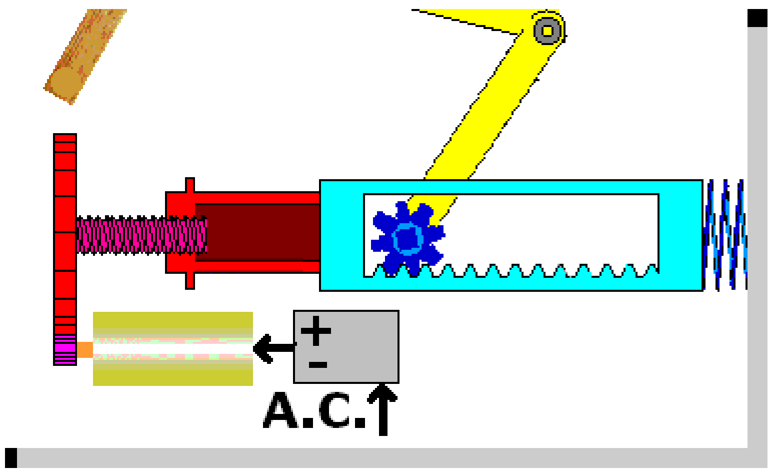
The majority of the operators open the door directly or through an arm.

- Overhead Concealed Mount - the operator is mounted above the door and rotates the door directly, through its pivot.
- Surface Mount, Push (scissor arm) - the operator is mounted on the wall above the door, on the approach side and pushes the door with a linkage of 2 arms.
- Surface Mount, Pull (track) - the operator is mounted on the wall above the door, on the swing side and pulls the door with an arm whose end slides in a track mounted on the door.

Variations on the above exist. There are also rare operators that use a mechanism that is disconnected from the door, and reaches out and pushes on the door itself when it needs to open it.

Internal technologies

Operators are powered by an electric motor. They differ in how they use the motor's energy to open the door.



Disengaging, closer-based, push-mount, electro-mechanical operator. View from above. Shades of blue: standard door closer. Shades of red: opener gears. Gold: motor.

Operators use various internal technologies.

- Some are built on top of a standard door closer. To open the door, the operator forces the closer in the opening direction. Then, the closer closes the door. The user may open the door manually, using just the door closer. In case of power failure while the door is open, the closer itself closes the door.
- Some are built without a door closer. The motor opens and closes the door through reducing gears. The operator may or may not include a return spring to close the door in case of power failure while the door is open.

Operators are often categorized by the means by which the motor's energy is applied.

- Electromechanical - the motor uses purely mechanical means to open the door: gears, cams, levers and such. This is the preferred type in the US.
- Electro-hydraulic - the motor drives a hydraulic pump, which pressurizes the oil in a door closer, which in turn turns the door closer and opens the door. This is the preferred type in Europe. (In the US it has a reputation of being prone to oil leaks.)
- Electro-pneumatic - the motor drives an air compressor and may be located away from the door. The air pressure is used to drive the operator above the door. This type is not common, as it considered to be too noisy.

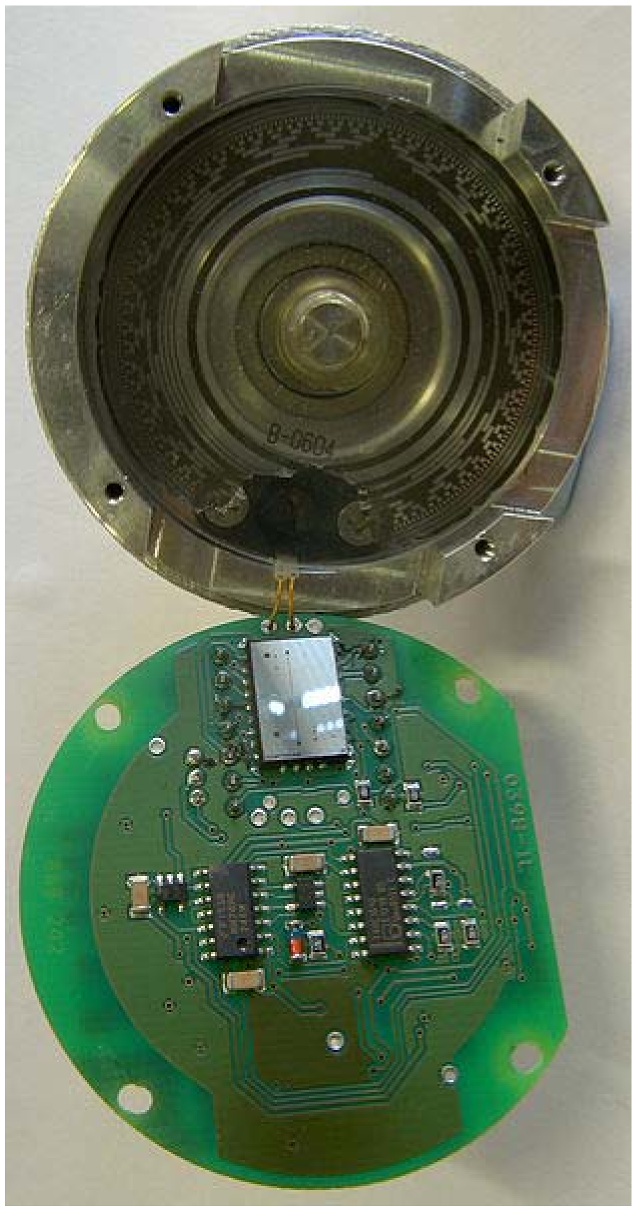
Of the electromechanical types, two approaches are used:

- Disengaging - the motor driven mechanism (the opener portion) is not joined to the closer, but only engages the closer when it is needed to open the door. When opening the door manually, the opener portion is still, so the opening is smooth and quiet.
- Permanently engaged - the motor driven mechanism (the opener portion) is always joined to the closer (if present) and to the door. When opening the door manually, the user is also driving the opener portion, so the opening is rough and noisy.

Electro-hydraulic types are inherently quiet and smooth during manual opening, as the motor and pump are off.

Chapter 3

Rotary Encoder



A Gray code absolute rotary encoder with 13 tracks. At the top can be seen the housing, interrupter disk, and light source; at the bottom can be seen the sensing element and support components.

A **rotary encoder**, also called a **shaft encoder**, is an electro-mechanical device that converts the angular position or motion of a shaft or axle to an analog or digital code. The output of incremental encoders provides information about the *motion* of the shaft which is typically further processed elsewhere into information such as speed, distance, RPM and position. The output of absolute encoders indicates the current position of the shaft, making them angle transducers. Rotary encoders are used in many applications that require precise shaft unlimited rotation—including industrial controls, robotics, special purpose photographic lenses, computer input devices (such as optomechanical mice and trackballs), and rotating radar platforms. There are two main types: absolute and incremental (relative).

Absolute rotary encoder

Absolute rotary encoder ROD 425

Construction

Digital absolute encoders produce a unique digital code for each distinct angle of the shaft. They come in two basic types: optical and mechanical.

Mechanical absolute encoders

A metal disc containing a set of concentric rings of openings is fixed to an insulating disc, which is rigidly fixed to the shaft. A row of sliding contacts is fixed to a stationary object so that each contact wipes against the metal disc at a different distance from the shaft. As the disc rotates with the shaft, some of the contacts touch metal, while others fall in the gaps where the metal has been cut out. The metal sheet is connected to a source of electric current, and each contact is connected to a separate electrical sensor. The metal pattern is designed so that each possible position of the axle creates a unique binary code in which some of the contacts are connected to the current source (i.e. switched on) and others are not (i.e. switched off).

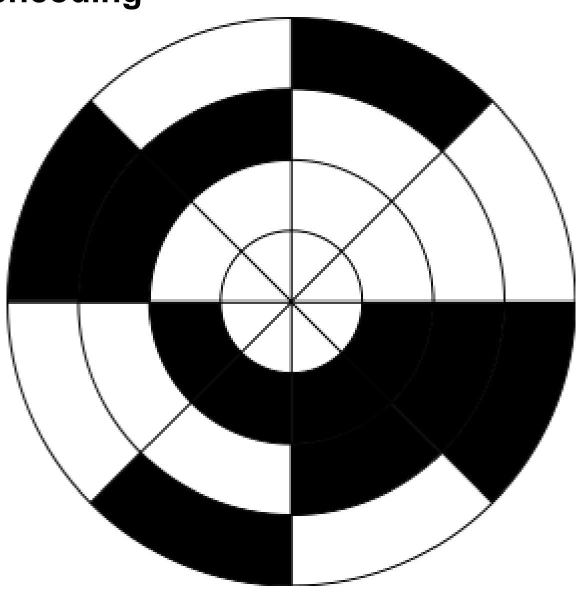
Optical absolute encoders

The optical encoder's disc is made of glass or plastic with transparent and opaque areas. A light source and photo detector array reads the optical pattern that results from the disc's position at any one time.

This code can be read by a controlling device, such as a microprocessor or microcontroller to determine the angle of the shaft.

The absolute analog type produces a unique dual analog code that can be translated into an absolute angle of the shaft (by using a special algorithm).

Standard binary encoding



Rotary encoder for angle-measuring devices marked in 3-bit binary. The inner ring corresponds to Contact 1 in the table. Black sectors are "on". Zero degrees is on the right-hand side, with angle increasing counterclockwise.

An example of a binary code, in an extremely simplified encoder with only three contacts, is shown below.

Standard Binary Encoding

Sector	**Contact 1**	**Contact 2**	**Contact 3**	**Angle**
1	off	off	off	0° to 45°
2	off	off	ON	45° to 90°
3	off	ON	off	90° to 135°
4	off	ON	ON	135° to 180°
5	ON	off	off	180° to 225°
6	ON	off	ON	225° to 270°
7	ON	ON	off	270° to 315°
8	ON	ON	ON	315° to 360°

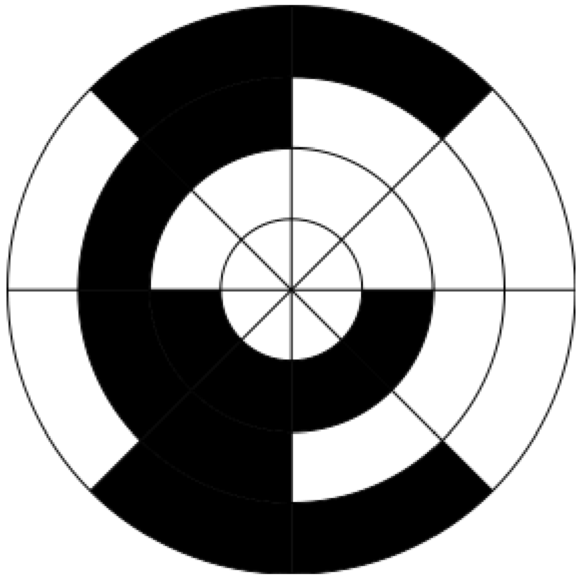
In general, where there are n contacts, the number of distinct positions of the shaft is 2^n. In this example, n is 3, so there are 2^3 or 8 positions.

In the above example, the contacts produce a standard binary count as the disc rotates. However, this has the drawback that if the disc stops between two adjacent sectors, or the contacts are not perfectly aligned, it can be impossible to determine the angle of the shaft. To illustrate this problem, consider what happens when the shaft angle changes from 179.9° to 180.1° (from sector 4 to sector 5). At some instant, according to the above table, the contact pattern changes from off-on-on to on-off-off. However, this is not what happens in reality. In a practical device, the contacts are never perfectly aligned, so each switches at a different moment. If contact 1 switches first, followed by contact 3 and then contact 2, for example, the actual sequence of codes is:

off-on-on (starting position)
on-on-on (first, contact 1 switches on)
on-on-off (next, contact 3 switches off)
on-off-off (finally, contact 2 switches off)

Now look at the sectors corresponding to these codes in the table. In order, they are 4, 8, 7 and then 5. So, from the sequence of codes produced, the shaft appears to have jumped from sector 4 to sector 8, then gone backwards to sector 7, then backwards again to sector 5, which is where we expected to find it. In many situations, this behaviour is undesirable and could cause the system to fail. For example, if the encoder were used in a robot arm, the controller would think that the arm was in the wrong position, and try to correct the error by turning it through 180°, perhaps causing damage to the arm.

Gray encoding



Rotary encoder for angle-measuring devices marked in 3-bit binary-reflected Gray code (BRGC). The inner ring corresponds to Contact 1 in the table. Black sectors are "on". Zero degrees is on the right-hand side, with angle increasing anticlockwise.

To avoid the above problem, Gray encoding is used. This is a system of binary counting in which adjacent codes differ in only one position. For the three-contact example given above, the Gray-coded version would be as follows.

Gray Coding

Sector	**Contact 1**	**Contact 2**	**Contact 3**	**Angle**
1	off	off	off	0° to 45°
2	off	off	ON	45° to 90°
3	off	ON	ON	90° to 135°
4	off	ON	off	135° to 180°
5	ON	ON	off	180° to 225°
6	ON	ON	ON	225° to 270°
7	ON	off	ON	270° to 315°
8	ON	off	off	315° to 360°

In this example, the transition from sector 4 to sector 5, like all other transitions, involves only one of the contacts changing its state from on to off or vice versa. This means that the sequence of incorrect codes shown in the previous illustration cannot happen.

Single-track Gray encoding

If the designer moves a contact to a different angular position (but at the same distance from the center shaft), then the corresponding "ring pattern" needs to be rotated the same angle to give the same output. If the most significant bit (the inner ring in Figure 1) is rotated enough, it exactly matches the next ring out. Since both rings are then identical, the inner ring can be omitted, and the sensor for that ring moved to the remaining, identical ring (but offset at that angle from the other sensor on that ring). Those two sensors on a single ring make a quadrature encoder.

For many years, Torsten Sillke and other mathematicians believed that it was impossible to encode position on a single track so that consecutive positions differed at only a single sensor, except for the two-sensor, one-track quadrature encoder. However, in 1994 N. B. Spedding registered a patent (NZ Patent 264738) showing it was possible with several examples.

Encoder output formats

In commercial absolute encoders there are several formats for transmission of absolute encoder data, including parallel binary, SSI, "BiSS", ISI, Profibus, CAN DeviceNet, CANopen, Endat and Hiperface, depending on the manufacturer of the device

Incremental rotary encoder

Encoder ROD 420

An incremental rotary encoder, also known as a quadrature encoder or a relative rotary encoder, has two outputs called quadrature outputs. They can be either mechanical or optical. In the optical type, there are two gray coded tracks, while the mechanical type has two contacts that are actuated by cams on the rotating shaft. The mechanical type requires debouncing and is typically used as digital potentiometers on equipment including consumer devices. Most modern home and car stereos use mechanical rotary encoders for volume. Due to the fact the mechanical switches require debouncing, the mechanical type are limited in the rotational speeds they can handle. The incremental rotary encoder is the most widely used of all rotary encoders due to its low cost: only two sensors are required.

The fact that incremental encoders use only two sensors does not compromise their accuracy. One can find in the market incremental encoders with up to 10,000 counts per revolution, or more.

There can be an optional third output: reference, which happens once every turn. This is used when there is the need of an absolute reference, such as positioning systems.

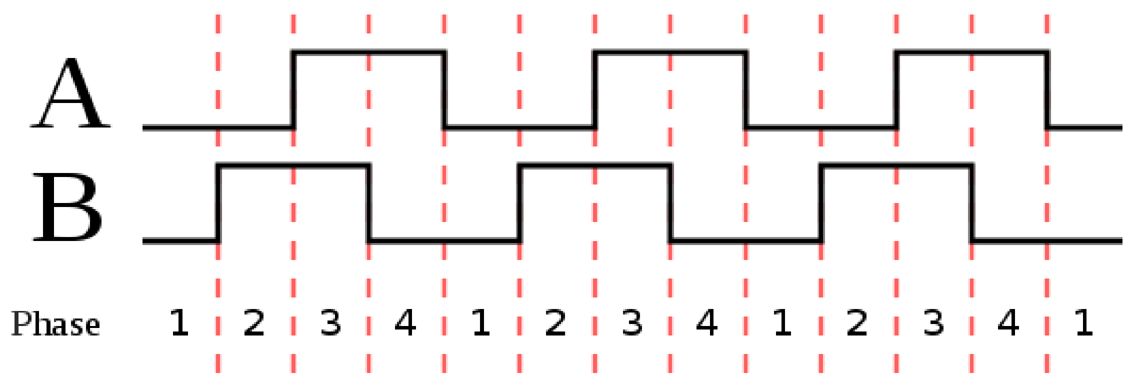
The optical type is used when higher RPMs are encountered or a higher degree of precision is required.

Incremental encoders are used to track motion and can be used to determine position and velocity. This can be either linear or rotary motion. Because the direction can be determined, very accurate measurements can be made.

They employ two outputs called A & B, which are called quadrature outputs, as they are 90 degrees out of phase.

The state diagram:

Gray coding for clockwise rotation			Gray coding for counter-clockwise rotation		
Phase	**A**	**B**	**Phase**	**A**	**B**
1	0	0	1	1	0
2	0	1	2	1	1
3	1	1	3	0	1
4	1	0	4	0	0



Two square waves in quadrature (clockwise rotation).

The two output wave forms are 90 degrees out of phase, which is all that the quadrature term means. These signals are decoded to produce a count up pulse or a count down pulse. For decoding in software, the A & B outputs are read by software, either via an interrupt on any edge or polling, and the above table is used to decode the direction. For example, if the last value was 00 and the current value is 01, the device has moved one half step in the clockwise direction. The mechanical types would be debounced first by requiring that the same (valid) value be read a certain number of times before recognizing a state change.

If the encoder is turning too fast, an invalid transition may occur, such as 00->11. There is no way to know which way the encoder turned; if it was 00->01->11, or 00->10->11.

If the encoder is turning even faster, a backward count may occur. Example: consider the 00->01->11->10 transition (3 steps forward). If the encoder is turning too fast, the system might read only the 00 and then the 10, which yields a 00->10 transition (1 step backward).

This same principle is used in ball mice to track whether the mouse is moving to the right/left or forward/backward.

Rotary sensors with a single output are not encoders and cannot sense direction, but can sense RPM. They are thus called tachometer sensors.

Incremental versus absolute encoder terminology

There seem to be some grey areas as to what constitutes an incremental encoder as opposed to an absolute encoder.

Traditional absolute encoders

Traditional absolute encoders have multiple code rings with various binary weightings which provide a data word representing the absolute position of the encoder within one revolution. This type of encoder is often referred to as a parallel absolute encoder. The distinguishing feature of the absolute encoder is that it reports the absolute position of the encoder to the electronics immediately upon power-up with no need for indexing.

Traditional incremental encoders

A traditional incremental encoder works differently by providing an A and a B pulse output that provide no usable count information in their own right. Rather, the counting is done in the external electronics. The point where the counting begins depends on the counter in the external electronics and not on the position of the encoder. To provide useful position information, the encoder position must be referenced to the device to which it is attached, generally using an index pulse. The distinguishing feature of the incremental encoder is that it reports an incremental change in position of the encoder to the counting electronics.

Battery backed incremental encoders

Some encoder manufacturers, such as Fanuc, have taken a different approach to this terminology. These manufacturers use absolute as their terminology for incremental encoders with a battery backed up memory to store count information and provide an absolute count immediately upon power up.

Sine wave encoder

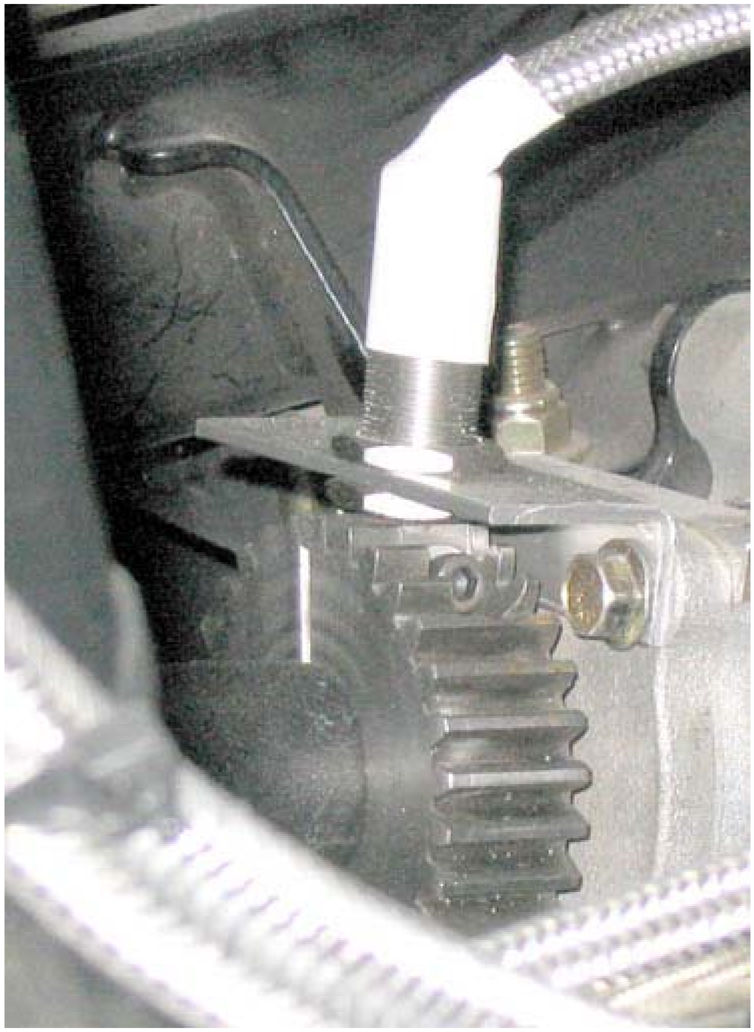
A variation on the Incremental encoder is the Sinewave Encoder. Instead of producing two quadrature square waves, the outputs are quadrature sine waves (a Sine and a Cosine). By performing the arctangent function, arbitrary levels of resolution can be achieved.

Use in industry

Encoders used on servomotors

Rotary encoders are often used to track the position of the motor shaft on permanent magnet brushless motors, which are commonly used on CNC machines, robots, and other industrial equipment. Incremental (Quadrature) encoders are used on Induction Motor type servomotors, but absolute encoders are used in Permanent Magnet Brushless Motors, where applicable. In these applications, the feedback device (encoder) plays a vital role in ensuring that the equipment operates properly. The encoder synchronizes the relative rotor magnet and stator winding positions to the current provided by the drive. Maximum torque results if the current is applied to the windings when the rotor magnets are in a particular position range relative to the stator windings. The motor will perform poorly or not at all if this timing is not adjusted correctly. Improper encoder alignment on the motor can actually cause it to run backwards sometimes resulting in a hazardous run away condition. Correct alignment is absolutely essential to proper operation of these motors.

Encoder technologies



Hall-effect quadrature encoder, sensing gear teeth on the driveshaft of a robot vehicle.

Encoders may be implemented using a variety of technologies:

- Conductive tracks. A series of copper pads etched onto a PCB is used to encode the information. Contact brushes sense the conductive areas. This form of encoder is now rarely seen.
- Optical. This uses a light shining onto a photodiode through slits in a metal or glass disc. Reflective versions also exist. This is one of the most common technologies.
- Magnetic. Strips of magnetised material are placed on the rotating disc and are sensed by a Hall-effect sensor or magnetoresistive sensor. Hall effect sensors are also used to sense gear teeth directly, without the need for a separate encoder disc.

Chapter 4

Biomechatronics & Dynamic Simulation

Biomechatronics

Biomechatronics is an applied interdisciplinary science that aims to integrate mechanical elements, electronics and parts of biological organisms. Biomechatronics includes the aspects of biology, mechanics, and electronics. It also encompasses the fields of robotics and neuroscience. One example of Biomechatronics is a study done by Hugh Herr a professor at M.I.T.. Herr excised the muscles of frog legs, to attach to a mechanical fish and by pulsing electrical current through the muscle fibers, he caused the fish to swim. The goal of these experiments is to make devices that interact with human muscle, skeleton, and nervous systems. The end result is that the devices will help with human motor control that was lost or impaired by trauma, disease or birth defects.

How it works

Biomechatronics devices have to be based on how the human body works. For example, four different steps must occur to be able to lift the foot to walk. First, impulses from the motor center of the brain are sent to the foot and leg muscles. Next the nerve cells in the feet send information to the brain telling it to adjust the muscle groups or amount of force required to walk across the ground. Different amounts of force are applied depending on the type of surface being walked across. The leg's muscle spindle nerve cells then sense and send the position of the floor back up to the brain. Finally, when the foot is raised to step, signals are sent to muscles in the leg and foot to set it down.

Biosensors

Biosensors are used to detect what the user wants to do or their intentions and motions. In some devices the information can be relayed by the user's nervous system or muscle system. This information is related by the biosensor to a controller which can be located inside or outside the biomechatronic device. In addition biosensors receive information about the limb position and force from the limb and actuator. Biosensors come in a variety of forms. They can be wires which detect electrical activity, needle electrodes implanted in muscles, and electrode arrays with nerves growing through them.

Mechanical sensors

The purpose of the mechanical sensors is to measure information about the biomechatronic device and relate that information to the biosensor or controller.

Controller

The controller in a biomechatronic device relays the user's intentions to the actuators. It also interprets feedback information to the user that comes from the biosensors and mechanical sensors. The other function of the controller is to control the biomechatronic device's movements.

Actuator

The actuator is an artificial muscle. Its job is to produce force and movement. Depending on whether the device is orthotic or prosthetic the actuator can be a motor that assists or replaces the user's original muscle.

Research

Biomechatronics is a rapidly growing field but as of now there are very few labs which conduct research. The Rehabilitation Institute of Chicago, University of California at Berkley, MIT, and University of Twente in the Netherlands are the researching leaders in biomechatronics. Three main areas are emphasized the current research.

1. Analyzing human motions, which are complex, to aid in the design of biomechatronic devices
2. Studying how electronic devices can be interfaced with the nervous system.
3. Testing the ways to use living muscle tissue as actuators for electronic devices

Analyzing motions

A great deal of analysis over human motion is needed because human movement is very complex. MIT and the University of Twente are both working to analyze these movements. They are doing this through a combination of computer models, camera systems, and electromyograms.

Interfacing

Interfacing allows biomechatronic devices to connect with the muscle systems and nerves of the user in order send and receive information from the device. This is a technology that is not available in ordinary orthotics and prosthetics devices. Groups at the University of Twente are making drastic steps in this department. Scientists there have developed a device which will help to treat paralysis and stroke victims who are unable to control their foot while walking. The researchers are also nearing a breakthrough which would allow a person with an amputated leg to control their prosthetic leg through their stump muscles.

MIT research

Hugh Herr is the leading biomechatronic scientist at MIT. Herr and his group of researchers are developing a sieve integrated circuit electrode and prosthetic devices that are coming closer to mimicking real human movement. The two prosthetic devices currently in the making will control knee movement and the other will control the stiffness of an ankle joint.

Robotic fish

As mentioned before Herr and his colleagues made a robotic fish that was propelled by living muscle tissue taken from frog legs. The robotic fish was a prototype of a biomechatronic device with a living actuator. The following charactersitics were given to the fish.

- A styrofoam float so the fish can float
- Electrical wires for connections
- A silicone tail that enables force while swimming
- Power provided by lithium batteries
- A microcontroller to control movement
- An infrared sensor enables the microcontroller to communicate with a handheld device
- Muscles stimulated by an electronic unit

Arts research

New media artists at UCSD are using biomechatronics in performance art pieces, such as Technesexual (more information, photos, video), a performance which uses biometric sensors to bridge the performers' real bodies to their Second Life avatars and Slapshock (more information, photos,video), in which medical TENS units are used to explore intersubjective symbiosis in intimate relationships.

Growth

The demand for biomechatronic devices are at an all time high and show no signs of slowing down. Many biomechatronic researchers are closely collaborating with military organizations. The US Department of Veterans Affairs and the Department of Defense are giving funds to different labs to help soldiers and war veterans

Dynamic Simulation

Dynamic simulation is the use of a computer program to model the time varying behavior of a system. The systems are typically described by ordinary differential equations or partial differential equations. As mathematical models incorporate real-world constraints, like gear backlash (engineering) and rebound from a hard stop, equations become nonlinear. This requires numerical methods to solve the equations. A numerical simulation is done by stepping through a time interval and calculating the integral of the derivatives by approximating the area under the derivative curves. Some methods use a fixed step through the interval, and others use an adaptive step that can shrink or grow automatically to maintain an acceptable error tolerance. Industrial uses of dynamic simulation are many and range from nuclear power, steam turbines, 6 degree of freedom vehicle modeling, electric motors, econometric models, biological systems, robot arms, mass spring dampers, hydraulic systems, and drug dose migration through the human body to name a few. These models can often be run in real time to give a virtual response close to the actual system. This is useful in process control and mechatronic systems for tuning the automatic control systems before they are connect to the real system, or for human training before they control the real system. Simulation is also used in computer games and animation and can be accelerated by using a physics engine, the technology used in many powerful computer graphics software programs, like 3ds Max, Maya, Lightwave, and many others to simulate physical characteristics. In computer animation, things like hair, cloth, liquid, fire, and particles can be easily modeled, while the human animator animates simpler objects. Computer-based dynamic animation was first used at a very simple level in the 1989 Pixar Animation Studios short film *Knick Knack* to move the fake snow in the snowglobe and pebbles in a fish tank.

Example of Dynamic simulation

This animation was made with a software system dynamics, with a 3D modeler.
The calculated values are associated with parameters of the rod and crank.
In this example the crank is driving, we vary both the speed of rotation, its radius and the length of the rod, the piston follows.

Chapter 5

Electrical Machine & Major Appliance

Electrical Machine

An **Electrical machine** is the generic name for a device that converts mechanical energy to electrical energy, converts electrical energy to mechanical energy, or changes alternating current from one voltage level to a different voltage level.

Electrical machines are divided into three main categories based on how it converts energy. Generators convert mechanical energy to electrical energy. Motors convert electrical energy to mechanical energy. Transformers change the voltage of alternating current.

Generator

An electric generator is a device that converts mechanical energy to electrical energy. A generator forces electrons to flow through an external electrical circuit. It is somewhat analogous to a water pump, which creates a flow of water but does not create the water inside. The source of mechanical energy, the prime mover, may be a reciprocating or turbine steam engine, water falling through a turbine or waterwheel, an internal combustion engine, a wind turbine, a hand crank, compressed air or any other source of mechanical energy.

There are two main parts of a generator which can be described in either mechanical or electrical terms. In mechanical terms the rotor is the rotating part of an electrical machine, and the stator is the stationary part of an electrical machine. In electrical terms the armature is the power-producing component of an electrical machine and the field is the magnetic field component of an electrical machine. The armature can be on either the rotor or the stator. The magnetic field can be provided by either electromagnets or permanent magnets mounted on either the rotor or the stator. Generators are classified into two types, AC generators and DC generators.

AC Generator

An AC generator converts mechanical energy into alternating current electricity. Because power transferred into the field circuit is much less than power transferred into the armature circuit, AC generators nearly always have the field winding on the rotor and the armature winding on the stator.

AC generators are classified into several types. The first is asynchronous or induction generators, in which stator flux induces currents in the rotor. The prime mover then drives the rotor above the synchronous speed, causing the opposing rotor flux to cut the stator coils producing active current in the stator coils, thus sending power back to the electrical grid. The second type is synchronous generators or alternator, in which the current for the magnetic field is provided by a separate DC current source.

DC Generator

A DC generator produces direct current electrical power from mechanical energy. A DC generator can operate at any speed within mechanical limits and always output a direct current waveform. Direct current generators known as dynamos work on exactly the same principles as alternators, but have a Commutator(electric) on the rotating shaft which convert the alternating current produced by the armature to direct current.

Motor

An electric motor converts electrical energy into mechanical energy. The reverse process of electrical generators, most electric motors operate through interacting magnetic fields and current-carrying conductors to generate rotational force. Motors and generators have many similarities and many types of electric motors can be run as generators, and vice versa.

Electric motors are found in applications as diverse as industrial fans, blowers and pumps, machine tools, household appliances, power tools, and disk drives. They may be powered by direct current or by alternating current which leads to the two main classifications: AC motors and DC motors.

AC Motor

An AC motor converts alternating current into mechanical energy. It commonly consists of two basic parts, an outside stationary stator having coils supplied with alternating current to produce a rotating magnetic field, and an inside rotor attached to the output shaft that is given a torque by the rotating field.

There are two main types of AC motors, depending on the type of rotor used. The first type is the induction motor, which only runs slightly slower or faster than the supply frequency. The magnetic field on the rotor of this motor is created by an induced current. The second type is the synchronous motor, which does not rely on induction and as a result, can rotate exactly at the supply frequency or a sub-multiple of the supply frequency. The magnetic field on the rotor is either generated by current delivered through slip rings or by a permanent magnet.

DC Motor

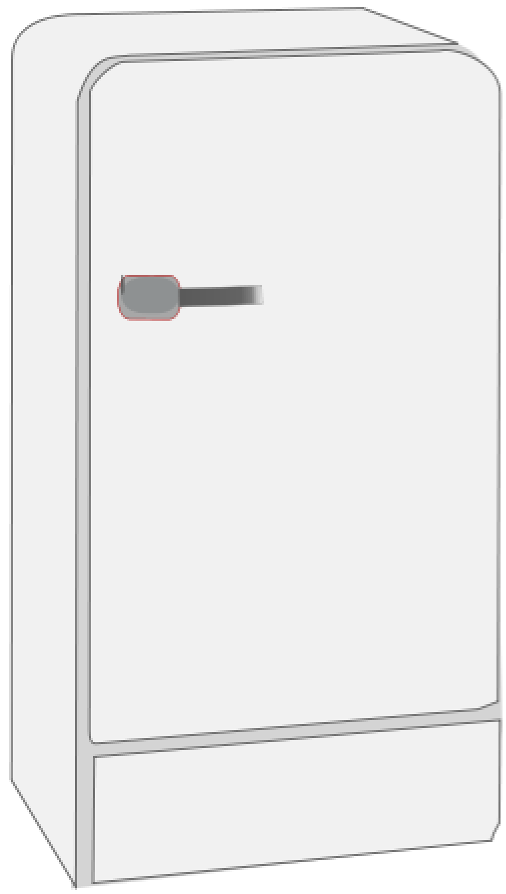
The brushed DC electric motor generates torque directly from DC power supplied to the motor by using internal commutation, stationary permanent magnets, and rotating electrical magnets. Brushes and springs carry the electric current from the commutator to the spinning wire windings of the rotor inside the motor. Brushless DC motors use a rotating permanent magnet in the rotor, and stationary electrical magnets on the motor housing. A motor controller converts DC to AC. This design is simpler than that of brushed motors because it eliminates the complication of transferring power from outside the motor to the spinning rotor.

An example of a brushless, synchronous DC motor is a stepper motor which can divide a full rotation into a large number of steps. The motor's position can be controlled precisely without any feedback mechanism as long as the motor is carefully sized to the application.

Transformer

A transformer is a static device that converts alternating current from one voltage level to another level (higher or lower), or to the same level, without changing the frequency. A transformer transfers electrical energy from one circuit to another through inductively coupled conductors—the transformer's coils. A varying electric current in the first or *primary* winding creates a varying magnetic flux in the transformer's core and thus a varying magnetic field through the *secondary* winding. This varying magnetic field induces a varying electromotive force (EMF) or "voltage" in the secondary winding. This effect is called mutual induction.

Major Appliance



A **major appliance**, or **domestic appliance**, is usually defined as a large machine which accomplishes some routine housekeeping task, which includes purposes such as cooking, or food preservation, whether in a household, institutional, commercial or industrial setting. An appliance is differentiated from a plumbing fixture because it uses an energy input for its operation other than water, generally using electricity or natural gas/propane. An object run by a watermill would also be considered an appliance. The term **white goods** or **whiteware** is also used for these items, primarily where British English is spoken, although definitions for the term "white goods" can differ. In the United States, the term *white goods* more commonly refers to linens rather than appliances.

Major appliances are differentiated from small appliances because they are large, difficult to move, and generally fixed in place to some extent. They are often considered fixtures and part of real estate and as such they are often supplied to tenants as part of otherwise unfurnished rental properties. Another frequent characteristic of major appliances is that they may have substantial electricity requirements that necessitate special electrical wiring to supply higher current than standard electrical outlets can deliver. This limits where they can be placed in a home.

Major Appliance brands include such companies as AEG, Siemens, Bosch, Hitachi, Toshiba, Fujitsu, Haier, Whirlpool, GE, Electrolux, Zanussi, Hotpoint, Mabe Mexico, Inglis, Kenmore, White Westinghouse, Indesit, Fagor, Samsung, Beko, Blomberg, LG,and Fulgor. A smaller number of distributors control groups of these brands.

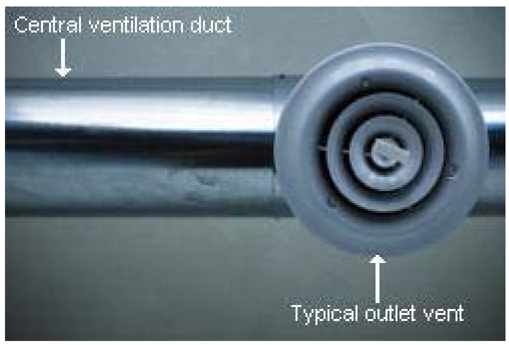
Major appliances have become more technically complex from the control side recently with the introduction of the various Energy Labelling rules across the world. This has meant that the appliances have been forced to become more and more efficient leading to more accurate controllers in order to meet the regulations.

Major appliances may be roughly divided as follows:

- refrigeration equipment
  - freezer
  - refrigerator
- stoves
  - cooker, also known as range, stove, oven, cooking plate, or cooktop
  - microwave oven
- washing equipment
  - washing machine
  - clothes dryer
  - drying cabinet
  - dishwasher
- miscellaneous
  - air conditioner
  - water heater
  - trash compactor

Chapter 6

HVAC

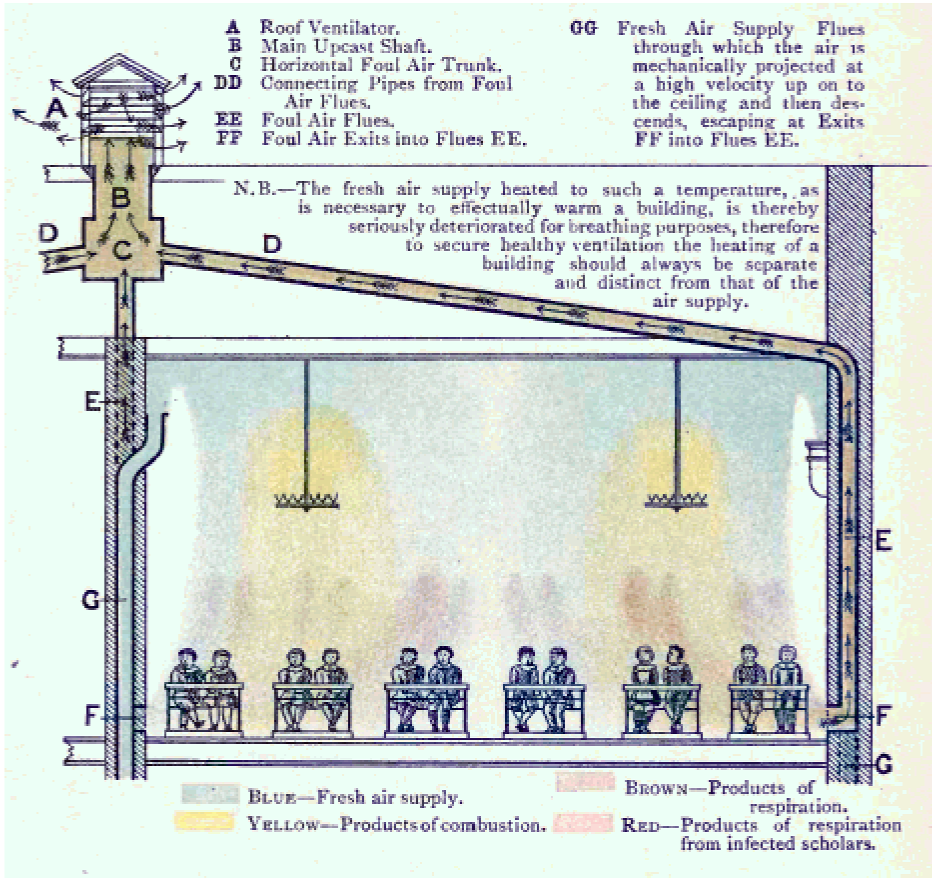


HVAC systems use ventilation air ducts installed throughout a building that supply conditioned air to a room through rectangular or round outlet vents, called diffusers; and ducts that remove air through return-air grilles

HVAC (Heating, Ventilating, and Air Conditioning) refers to technology of indoor or automotive environmental comfort. HVAC system design is a major subdiscipline of mechanical engineering, based on the principles of thermodynamics, fluid mechanics, and heat transfer. Refrigeration is sometimes added to the field's abbreviation as HVAC&R or HVACR, or ventilating is dropped as in HACR (such as the designation of HACR-rated circuit breakers).

HVAC is important in the design of medium to large industrial and office buildings such as skyscrapers and in marine environments such as aquariums, where safe and healthy building conditions are regulated with temperature and humidity, as well as "fresh air" from outdoors.

Background



Ventilation (architecture) on the downdraught system, by impulsion, or the 'plenum' principle, applied to schoolrooms (1899)

Heating, ventilating, and air conditioning is based on inventions and discoveries made by Nikolay Lvov, Michael Faraday, Willis Carrier, Reuben Trane, James Joule, William Rankine, Sadi Carnot, and many others.

The invention of the components of HVAC systems went hand-in-hand with the industrial revolution, and new methods of modernization, higher efficiency, and system control are constantly introduced by companies and inventors all over the world. The three central functions of heating, ventilating, and air-conditioning are interrelated, providing thermal comfort, acceptable indoor air quality, within reasonable installation, operation, and maintenance costs. HVAC systems can provide ventilation, reduce air infiltration, and maintain pressure relationships between spaces. How air is delivered to, and removed from spaces is known as room air distribution.

In modern buildings the design, installation, and control systems of these functions are integrated into one or more HVAC systems. For very small buildings, contractors normally "size" and select HVAC systems and equipment. For larger buildings, building services designers and engineers, such as mechanical, architectural, or building services engineers analyze, design, and specify the HVAC systems, and specialty mechanical contractors build and commission them. Building permits and code-compliance inspections of the installations are normally required for all sizes of buildings.

The HVAC industry is a worldwide enterprise, with career opportunities including operation and maintenance, system design and construction, equipment manufacturing and sales, and in education and research. The HVAC industry had been historically regulated by the manufacturers of HVAC equipment, but Regulating and Standards organizations such as HARDI, ASHRAE, SMACNA, ACCA, Uniform Mechanical Code, International Mechanical Code, and AMCA have been established to support the industry and encourage high standards and achievement.

Design of the HVAC system.

The starting point in carrying out a heat estimate both for cooling and heating will depends on the ambient and inside conditions specified. However before taking up the heat load calculation, it is necessary to work out the fresh air requirement for each area in details, as pressurization is an important requirement.

Heating

Central heating unit

There are many different types of standard heating systems. Central heating is often used in cold climates to heat private houses and public buildings. Such a system contains a boiler, furnace, or heat pump to heat water, steam, or air, all in a central location such as a furnace room in a home or a mechanical room in a large building. The use of water as the heat transfer medium is known as hydronics. The system also contains either ductwork, for forced air systems, or piping to distribute a heated fluid and radiators to transfer this heat to the air. The term *radiator* in this context is misleading since most heat transfer from the heat exchanger is by convection, not radiation. The radiators may be mounted on walls or buried in the floor to give under-floor heat.

In boiler fed or radiant heating systems, all but the simplest systems have a pump to circulate the water and ensure an equal supply of heat to all the radiators. The heated water can also be fed through another (secondary) heat exchanger inside a storage cylinder to provide hot running water.

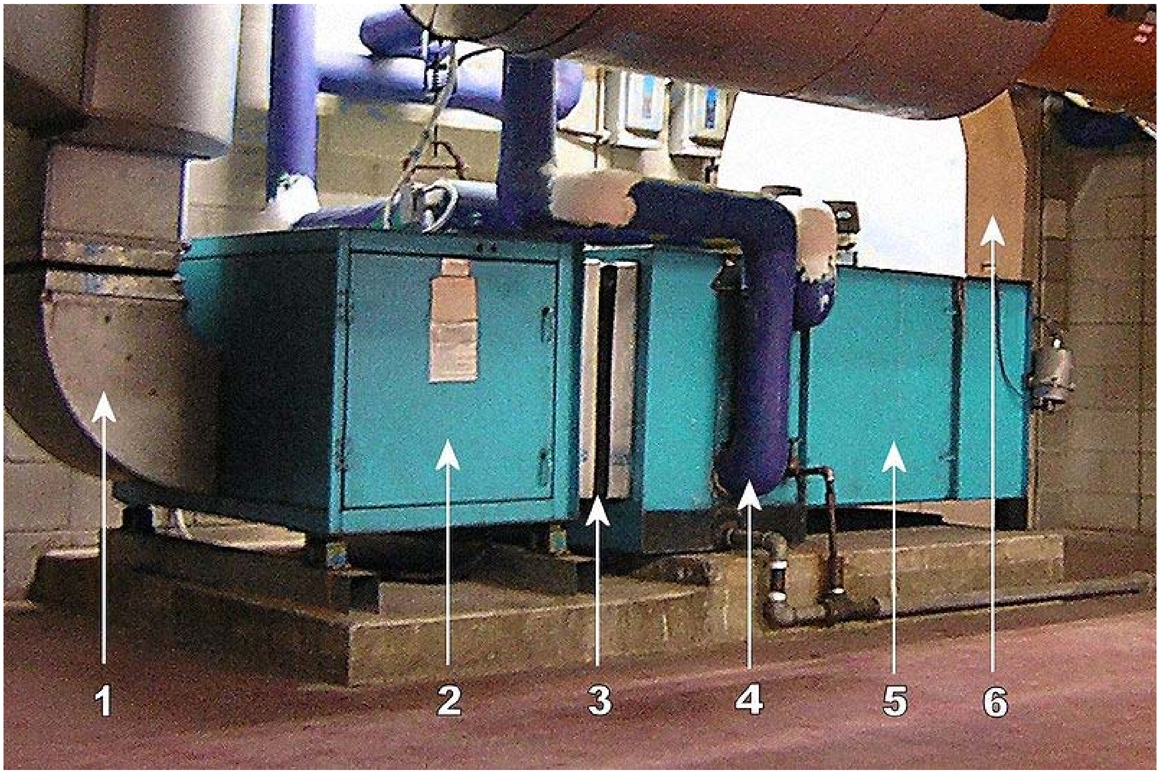
Forced air systems send heated air through ductwork. During warm weather the same ductwork can be used for air conditioning. The forced air can also be filtered or put through air cleaners.

Heating can also be provided from electric, or resistance heating using a filament that becomes hot when electric current is caused to pass through it. This type of heat can be found in electric baseboard heaters, portable electric heaters, and as backup or supplemental heating for heat pump (or reverse heating) system.

The heating elements (radiators or vents) should be located in the coldest part of the room, typically next to the windows to minimize condensation and offset the convective air current formed in the room due to the air next to the window becoming negatively buoyant due to the cold glass. Devices that direct vents away from windows to prevent "wasted" heat defeat this design intent. Cold air drafts can contribute significantly to subjectively feeling colder than the average room temperature. Therefore, it is important to control the air leaks from outside in addition to proper design of the **heating system**.

The invention of central heating is often credited to the ancient Romans, who installed a system of air ducts called a hypocaust in the walls and floors of public baths and private villas.

Ventilating



An air handling unit is used for the heating and cooling of air in a central location.

Ventilating is the process of "changing" or replacing air in any space to control temperature or remove moisture, odors, smoke, heat, dust, airborne bacteria, carbon dioxide, and to replenish oxygen. Ventilation includes both the exchange of air to the outside as well as circulation of air within the building. It is one of the most important factors for maintaining acceptable indoor air quality in buildings. Methods for ventilating a building may be divided into *mechanical/forced* and *natural* types. Ventilation is used to remove unpleasant smells and excessive moisture, introduce outside air, to keep interior building air circulating, and to prevent stagnation of the interior air.

Mechanical or forced ventilation

"Mechanical" or "forced" ventilation is provided by an air handler and used to control indoor air quality. Excess humidity, odors, and contaminants can often be controlled via dilution or replacement with outside air. However, in humid climates much energy is required to remove excess moisture from ventilation air.

Kitchens and bathrooms typically have mechanical exhaust to control odors and sometimes humidity. Factors in the design of such systems include the flow rate (which is a function of the fan speed and exhaust vent size) and noise level. If ducting for the fans traverse unheated space (e.g., an attic), the ducting should be insulated as well to prevent condensation on the ducting. Direct drive fans are available for many applications, and can reduce maintenance needs.

Ceiling fans and table/floor fans circulate air within a room for the purpose of reducing the perceived temperature because of evaporation of perspiration on the skin of the occupants. Because hot air rises, ceiling fans may be used to keep a room warmer in the winter by circulating the warm stratified air from the ceiling to the floor. Ceiling fans do not provide ventilation as defined as the introduction of outside air.

Natural ventilation

Natural ventilation is the ventilation of a building with outside air without the use of a fan or other mechanical system. It can be achieved with openable windows or trickle vents when the spaces to ventilate are small and the architecture permits. In more complex systems warm air in the building can be allowed to rise and flow out upper openings to the outside (stack effect) thus forcing cool outside air to be drawn into the building naturally through openings in the lower areas. These systems use very little energy but care must be taken to ensure the occupants' comfort. In warm or humid months, in many climates, maintaining thermal comfort solely via natural ventilation may not be possible so conventional air conditioning systems are used as backups. Air-side economizers perform the same function as natural ventilation, but use mechanical systems' fans, ducts, dampers, and control systems to introduce and distribute cool outdoor air when appropriate.

Air conditioning

Air conditioning and refrigeration are provided through the removal of heat. The definition of cold is the absence of heat and all air conditioning systems work on this basic principle. Heat can be removed through the process of radiation, convection, and Heat cooling through a process called the refrigeration cycle. The conduction mediums such as water, air, ice, and chemicals are referred to as refrigerants.

An air conditioning system, or a standalone air conditioner, provides cooling, ventilation, and humidity control for all or part of a house or building.

The refrigerant cycle consists of four essential elements to create a cooling effect. The system refrigerant starts its cycle in a gaseous state. The compressor pumps the refrigerant gas up to a high pressure and temperature. From there it enters a heat exchanger (sometimes called a "condensing coil") where it loses energy (heat) to the outside. In the process the refrigerant condenses into a liquid. The liquid refrigerant is returned indoors to another heat exchanger ("evaporating coil"). A metering device allows the liquid to flow in at a low pressure at the proper rate. As the liquid refrigerant evaporates it aborbs energy (heat) from the inside air, returns to the compressor, and the cycle repeats. In the process, heat is absorbed from indoors, and transferred outdoors, resulting in cooling of the building.

Central, 'all-air' air conditioning systems are often installed in modern residences, offices, and public buildings, but are difficult to retrofit (install in a building that was not designed to receive it) because of the bulky air ducts required. A duct system must be carefully maintained to prevent the growth of pathogenic bacteria in the ducts. An alternative to large ducts to carry the needed air to heat or cool an area is the use of remote fan coils or split systems. These systems, although most often seen in residential applications, are gaining popularity in small commercial buildings. The evaporator coil is connected to a remote condenser unit using piping instead of ducts.

Dehumidification in an air conditioning system is provided by the evaporator. Since the evaporator operates at a temperature below dew point, moisture in the air condenses on the evaporator coil tubes. This moisture is collected at the bottom of the evaporator in a condensate pan and is removed by piping it to a central drain or onto the ground outside. A dehumidifier is an air-conditioner-like device that controls the humidity of a room or building. It is often employed in basements which have a higher relative humidity because of their lower temperature (and propensity for damp floors and walls). In food retailing establishments, large open chiller cabinets are highly effective at dehumidifying the internal air. Conversely, a humidifier increases the humidity of a building.

Air-conditioned buildings often have sealed windows, because open windows would disrupt the attempts of the HVAC system to maintain constant indoor air conditions.

All modern air conditioning systems, down to small "window" units, are equipped with internal air filters. These are generally of a light weight gauze-type element, and must be replaced as conditions warrant (some models may be washable). For example, a building in a high-dust environment, or a home with furry pets, will need to have the filters changed more often than buildings without these dirt loads. Failure to replace these filters as needed will contribute to a lower heat-exchange rate, resulting in wasted energy, shortened equipment life, and higher energy bills; also low air flow can result in "iced-up" or "iced-over" evaporator coils, and then there is no air flow at all. Additionally, very dirty or plugged filters can cause overheating during a heating cycle, and can possibly result in damage to the furnace unit or even fire.

It is important to keep in mind that because an air conditioner moves heat from the indoor (evaporator) coil to the outdoor (condenser) coil, the latter must be kept just as clean as the former. This means that, in addition to replacing the air filter at the evaporator coil, it is also necessary to regularly clean the condenser coil. Failure to keep the condenser clean will eventually result in harm to the compressor, because the condenser coil is responsible for discharging both the indoor heat (as picked up by the evaporator) plus the heat generated by the electric motor driving the compressor.

Outside, "fresh" air is generally drawn into the system by a vent into the evaporator section. Adjustment of the percentage of return air made up of fresh air can usually be adjusted by manipulating the opening of this vent.

Energy efficiency

For the last 20 to 30 years, manufacturers of HVAC equipment have been making an effort to make the systems they manufacture more efficient. This was originally driven by rising energy costs, and has more recently been driven by increased awareness of environmental issues. In the USA, the EPA has also imposed tighter restrictions. There are several methods for making HVAC systems more efficient.

Heating energy

Water heating is more efficient for heating buildings and was the standard many years ago. Today forced air systems can double for air conditioning and are more popular.

A couple of benefits of forced air systems, which are now widely applied in churches, schools and high-end residences,are 1) better air conditioned effect 2) up to 15-20% energy saving, and 3) evenly conditioned effect. A drawback is the installation cost, which might be slightly higher than traditional HVAC system.

Energy efficiency can be improved even more in central heating systems by introducing zoned heating. This allows a more granular application of heat, similar to non-central heating systems. Zones are controlled by multiple thermostats. In water heating systems the thermostats control zone valves, and in forced air systems they control zone dampers inside the vents which selectively block the flow of air. In this case, the control system is very critical to maintain a proper temperature.

Geothermal Heat Pump

Geothermal heat pumps are similar to ordinary heat pumps, but instead of using heat found in outside air, they rely on the stable, even heat of the earth to provide heating, air conditioning and, in most cases, hot water. From Montana's −70 °F (−57 °C) temperature, to the highest temperature ever recorded in the U.S.—134 °F (56.7 °C) in Death Valley, California, in 1913—many parts of the country experience seasonal temperature extremes. A few feet below the earth's surface, however, the ground remains at a relatively constant temperature. Although the temperatures vary according to latitude, at 6 feet (1.83 m) underground, temperatures range from 45 to 75 °F (7.2 to 23.9 °C).

While they may be more costly to install initially than regular heat pumps, they can produce markedly lower energy bills—30 percent to 40 percent lower, according to estimates from the U.S. Environmental Protection Agency.

Ventilation energy recovery

Energy recovery systems sometimes utilize heat recovery ventilation or energy recovery ventilation systems that employ heat exchangers or enthalpy wheels to recover sensible or latent heat from exhausted air. This is done by transfer of energy to the incoming outside fresh air.

Air conditioning energy

The performance of vapor compression refrigeration cycles is limited by thermodynamics. These air conditioning and heat pump devices *move* heat rather than convert it from one form to another, so *thermal efficiencies* do not appropriately describe the performance of these devices. The **Coefficient-of-Performance** (COP) measures performance, but this dimensionless measure has not been adopted, but rather the **Energy Efficiency Ratio** (*EER*). EER is the Energy Efficiency Ratio based on a 35 °C (95 °F) outdoor temperature. To more accurately describe the performance of air conditioning equipment over a typical cooling season a modified version of the EER is used, and is the **Seasonal Energy Efficiency Ratio** (*SEER*). SEER ratings are based on seasonal temperature averages instead of a constant 35 °C outdoor temperature. The current industry minimum SEER rating is 13 SEER. The SEER article describes it further, and presents some economic comparisons using this useful performance measure.

Engineers have pointed out some areas where efficiency of the existing hardware could be improved. For example, the fan blades used to move the air are usually stamped from sheet metal, an economical method of manufacture, but as a result they are not aerodynamically efficient. A well-designed blade could reduce electrical power required to move the air by a third.

- Chilled beam
- Circulator pump
- Cooling tower
- Damper (flow)
- Dedicated outdoor air system
- Diffuser
- Displacement Ventilation
- Duct
- Economizer
- Evaporative cooler
- Fan coil unit
- Fan (mechanical)
- Heater
- Heat exchanger, including 'coils'
- Heat Pump
- Heat recovery ventilator
- Humidifier / Dehumidifier
- HVAC control system
- Piping
- Valve
- Variable air volume
- Variable-frequency drive, for fine control of pumps
- Underfloor air distribution

HVAC industry and standards

North America

USA

In the United States, HVAC engineers generally are members of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). ASHRAE is an international technical society for all individuals and organizations interested in HVAC. The Society, organized into Regions, Chapters, and Student Branches, allows exchange of HVAC knowledge and experiences for the benefit of the field's practitioners and the public. ASHRAE provides many opportunities to participate in the development of new knowledge via, for example, research and its many Technical Committees. These committees meet typically twice per year at the ASHRAE Annual and Winter Meetings. A popular product show, the AHR Expo, is held in conjunction with each Winter Meeting. The Society has approximately 50,000 members and has headquarters at Atlanta, Georgia, USA.

The most recognized standards for HVAC design is based on ASHRAE data. ASHRAE is the American Society of Heating, Refrigerating and Air-Conditioning Engineers. The ASHRAE Handbook's most general volume, of four, is Fundamentals; it includes heating and cooling calculations. Each volume of the ASHRAE Handbook is updated every four years. The design professional must consult ASHRAE data for the standards of design and care as the typical building codes provides little to no information on HVAC design practices; such codes, such as the UMC and IMC, do include much details on installation requirements, however. Other useful reference materials include items from SMACNA, ACCA, and technical trade journals.

American design standards are legislated in the Uniform Mechanical Code or International Mechanical Code. In certain states, counties, or cities, either of these codes may be adopted and amended via various legislative processes. These codes are updated and published by the International Association of Plumbing and Mechanical Officials (IAPMO) or the International Code Council (ICC) respectively, on a 3-year code development cycle. Typically, local Building Permit Departments are charged with enforcement of these standards on private and certain public properties.

In the United States, as well as throughout the world, HVAC contractors and companies are members of NADCA, the National Air Duct Cleaners Association. NADCA was formed in 1989 as a non-profit association of companies engaged in the cleaning of HVAC systems. Its mission was to promote source removal as the only acceptable method of cleaning and to establish industry standards for the association. NADCA has expanded its mission to include the representation of qualified companies engaged in the assessment, cleaning, and restoration of HVAC systems, and to assist its members in providing high quality service to their customers. The goal of the association is to be the number one source for the HVAC cleaning and restoration services: first time, every time. NADCA has experienced phenomenal membership growth and has been extremely successful with the training and certification of air systems cleaning specialists, mold remediators, and HVAC inspectors. The association has also published important standards and guidelines, educational materials, and other useful information for the consumer and members of NADCA. Their headquarters are located in Washington, D.C.

Europe

United Kingdom

The Chartered Institute of Building Services Engineers is a body that covers the essential Service (systems architecture) that allow buildings to operate. It includes the electrotechnical, heating, ventilating, air conditioning, refrigeration and plumbing industries. To train as a building services engineer, the academic requirement are GCSEs (A-C) / Standard Grades (1-3) in Maths and Science, which are important in measurements, planning and theory. Employers will often want a degree in a branch of engineering, such as building environment engineering, electrical engineering or mechanical engineering. To become a full member of CIBSE, and so also to be registered by the Engineering Council UK as a chartered engineer, one must also attain an Honours Degree and a Masters Degree in a relevent engineering subject.

CIBSE publishes several guides to HVAC design relevent to the UK market, and also the Republic of Ireland, Australia, New Zealand and Hong Kong. These guides include for various recommended design criteria and standards, some of which are cited within the UK building regulations, and therefore form a legislative requirment for major building services works. The main guides are:

- Guide A: Environmental Design
- Guide B: Heating, Ventilating, Air Conditioning and Refrigeration
- Guide C: Reference Data
- Guide D: Transportation systems in Buildings
- Guide E: Fire Safety Engineering
- Guide F: Energy Efficiency in Buildings
- Guide G: Public Health Engineering
- Guide H: Building Control Systems
- Guide J: Weather, Solar and Illuminance Data
- Guide K: Electricity in Buildings
- Guide L: Sustainability
- Guide M: Maintenance ENgineering and Management

Within the construction sector, it is the job of the building services engineer to design and oversee the installation and maintenance of the essential services such as gas, electricity, water, heating and lighting, as well as many others. These all help to make buildings comfortable and healthy places to live and work in. Building Services is part of a sector that has over 51,000 businesses and employs represents 2%-3% of the GDP.

Australia

Air Conditioning and Mechanical Contractors Association of Australia (AMCA)
Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH),
CIBSE

Asia

India

The Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE) was established to promote the HVAC industry in India. ISHRAE is an associate of

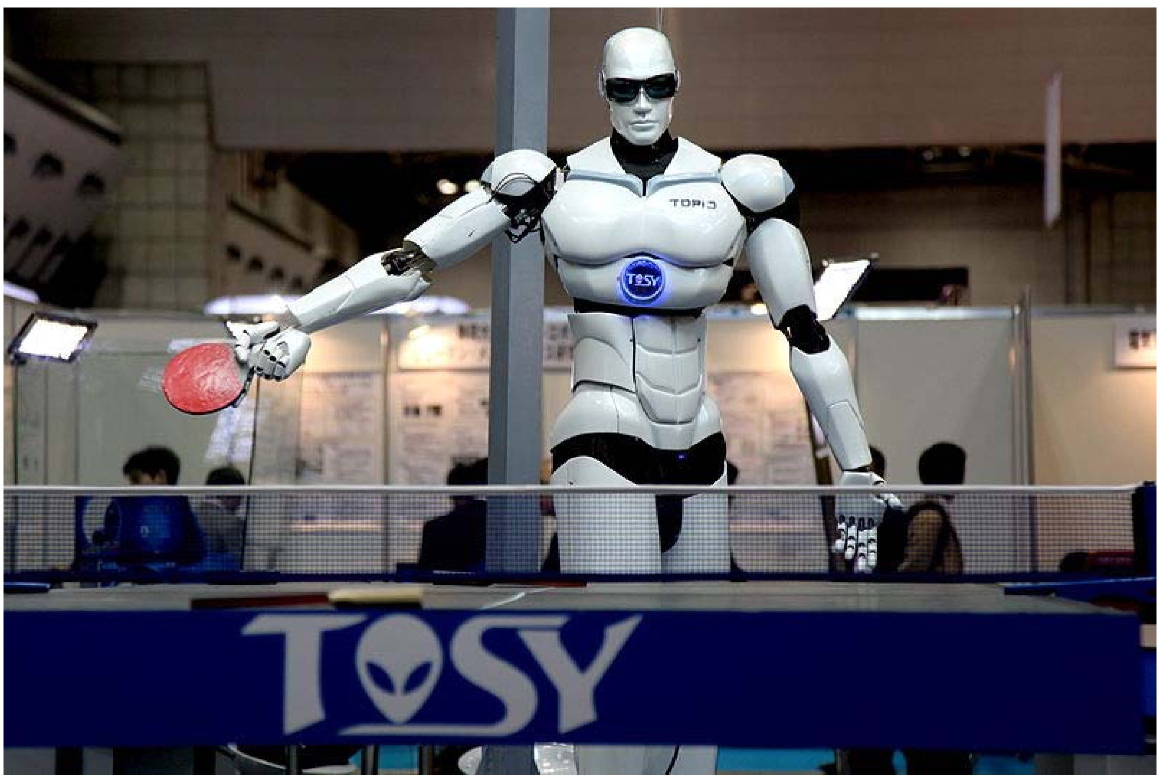
ASHRAE. ISHRAE was started at Delhi in 1981 and a chapter was started in Bangalore in 1989. Between 1989 & 1993, ISHRAE chapters were formed in all major cities in India and also in the Middle East.

Pakistan

Air-conditioning technology has been in use in Pakistan since 1947, the time of its independence. At that point local expertise was dependent on the supply and installation of imported equipment in accordance with the system designs from abroad. Once Pakistani engineers recognized the importance of the field they became active in developing expertise in design, manufacture, installation, operation, and maintenance. In 1995 the Pakistan HVACR Society was formed. Since then, the Society started organizing various disciplines of the field under its umbrella.

Chapter 7

Robotics



TOPIO, a humanoid robot, played ping pong at Tokyo International Robot Exhibition (IREX) 2009.

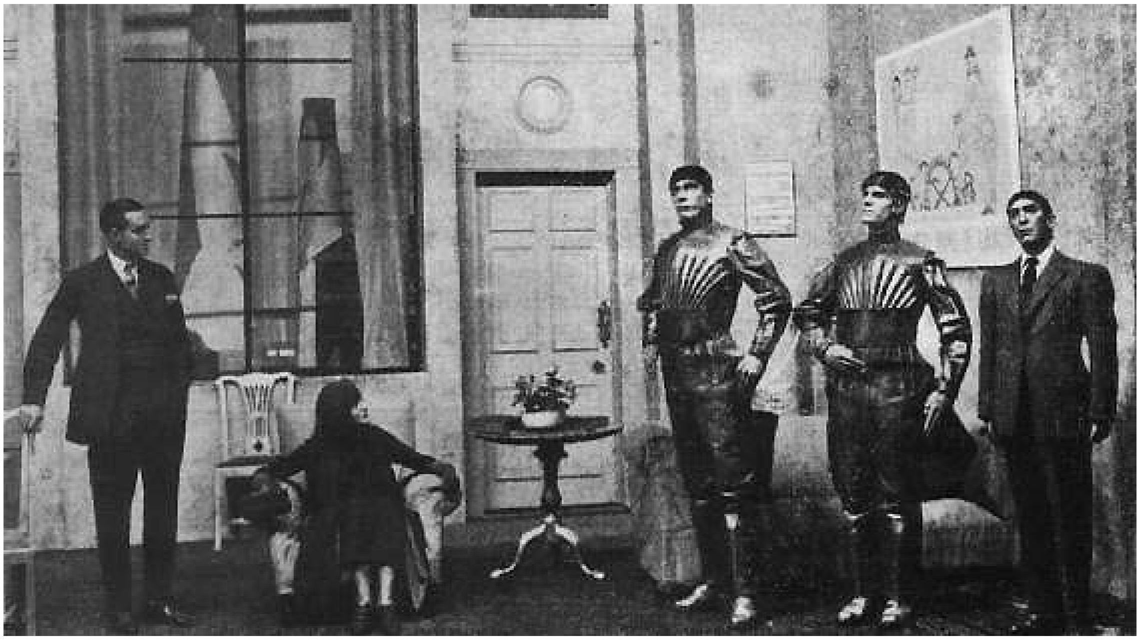
The Shadow robot hand system

A Pick and Place robot in a factory

Robotics is the branch of technology that deals with the design, construction, operation, structural disposition, manufacture and application of robots. Robotics is related to the sciences of electronics, engineering, mechanics, and software. The word "robot" was introduced to the public by Czech writer Karel Čapek in his play R.U.R. (Rossum's Universal Robots), published in 1920. The term "robotics" was coined by Isaac Asimov in his 1941 science fiction short-story "Liar!"

History

Stories of artificial helpers and companions and attempts to create them have a long history.



A scene from Karel Čapek's 1920 play R.U.R. (Rossum's Universal Robots), showing three robots

The word *robot* was introduced to the public by the Czech writer Karel Čapek in his play *R.U.R. (Rossum's Universal Robots)*, published in 1920. The play begins in a factory that makes artificial people called *robots* creatures who can be mistaken for humans - though they are closer to the modern ideas of androids. Karel Čapek himself did not coin the word. He wrote a short letter in reference to an etymology in the *Oxford English Dictionary* in which he named his brother Josef Čapek as its actual originator.

In 1927 the *Maschinenmensch* ("machine-human") gynoid humanoid robot (also called "Parody", "Futura", "Robotrix", or the "Maria impersonator") was the first and perhaps the most memorable depiction of a robot ever to appear on film was played by German actress Brigitte Helm) in Fritz Lang's film Metropolis.

In 1942 the science fiction writer Isaac Asimov formulated his Three Laws of Robotics and, in the process of doing so, coined the word "robotics".

In 1948 Norbert Wiener formulated the principles of cybernetics, the basis of practical robotics.

Fully autonomous robots only appeared in the second half of the 20th century. The first digitally operated and programmable robot, the Unimate, was installed in 1961 to lift hot pieces of metal from a die casting machine and stack them. Commercial and industrial robots are widespread today and used to perform jobs more cheaply, or more accurately and reliably, than humans. They are also employed in jobs which are too dirty, dangerous, or dull to be suitable for humans. Robots are widely used in manufacturing, assembly, packing and packaging, transport, earth and space exploration, surgery, weaponry, laboratory research, safety, and the mass production of consumer and industrial goods.

Date	Significance	Robot Name	Inventor
First century A.D. and earlier	Descriptions of more than 100 machines and automata, including a fire engine, a wind organ, a coin-operated machine, and a steam-powered engine, in *Pneumatica* and *Automata* by Heron of Alexandria		Ctesibius, Philo of Byzantium, Heron of Alexandria, and others
1206	Created early humanoid automata, programmable automaton band	Robot band, hand-washing automaton, automated moving peacocks	Al-Jazari
1495	Designs for a humanoid robot	Mechanical knight	Leonardo da Vinci
1738	Mechanical duck that was able to eat, flap its wings, and excrete	Digesting Duck	Jacques de Vaucanson
1898	Nikola Tesla demonstrates first radio-controlled vessel.	Teleautomaton	Nikola Tesla
1921	First fictional automatons called "robots" appear in the play *R.U.R.*	Rossum's Universal Robots	Karel Čapek
1930s	Humanoid robot exhibited at the 1939 and 1940 World's Fairs	Elektro	Westinghouse Electric Corporation
1948	Simple robots exhibiting biological behaviors	Elsie and Elmer	William Grey Walter
1956	First commercial robot, from the Unimation company founded by George Devol and Joseph Engelberger, based on Devol's patents	Unimate	George Devol
1961	First installed industrial robot.	Unimate	George Devol
1963	First palletizing robot	Palletizer	Fuji Yusoki Kogyo
1973	First industrial robot with six electromechanically driven axes	Famulus	KUKA Robot Group
1975	Programmable universal manipulation arm, a Unimation product	PUMA	Victor Scheinman

Etymology

According to the *Oxford English Dictionary*, the word *robotics* was first used in print by Isaac Asimov, in his science fiction short story "Liar!", published in May 1941 in *Astounding Science Fiction*. Asimov was unaware that he was coining the term; since the science and technology of electrical devices is *electronics*, he assumed *robotics* already referred to the science and technology of robots. However, in some of Asimov's other works, he states that the first use of the word *robotics* was in his short story *Runaround* (Astounding Science Fiction, March 1942). The word *robotics* was derived from the word *robot*, which was introduced to the public by Czech writer Karel Čapek in his play *R.U.R. (Rossum's Universal Robots)*, which premiered in 1921.

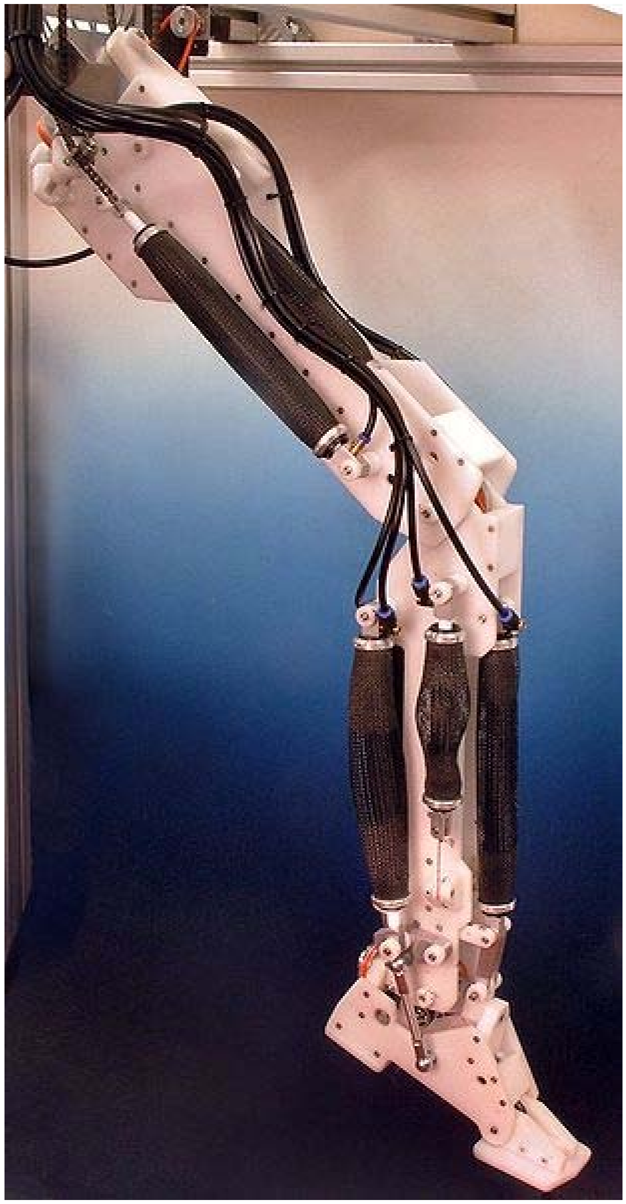
Components

Power source

At present; mostly (lead-acid) batteries are used, but potential power sources could be:

- pneumatic (compressed gases)
- hydraulics (compressed liquids)
- flywheel energy storage
- organic garbage (through anaerobic digestion)
- faeces (human, animal); may be interesting in a military context as faeces of small combat groups may be reused for the energy requirements of the robot assistant
- still unproven energy sources: for example Nuclear fusion, as yet not used in nuclear reactors whereas Nuclear fission is proven (although there are not many robots using it as a power source apart from the Chinese rover tests.).
- radioactive source (such as with the proposed Ford car of the '50s); to those proposed in movies such as *Red Planet*

Actuation



A robotic leg powered by Air Muscles

Actuators are like the "muscles" of a robot, the parts which convert stored energy into movement. By far the most popular actuators are electric motors that spin a wheel or gear, and linear actuators that control industrial robots in factories. But there are some recent advances in alternative types of actuators, powered by electricity, chemicals, or compressed air:

- Electric motors: The vast majority of robots use electric motors, often brushed and brushless DC motors in portable robots or AC motors in industrial robots and CNC machines.

- Linear Actuators: Various types of linear actuators move in and out instead of by spinning, particularly when very large forces are needed such as with industrial robotics. They are typically powered by compressed air (pneumatic actuator) or an oil (hydraulic actuator).
- Series Elastic Actuators: A spring can be designed as part of the motor actuator, to allow improved force control. It has been used in various robots, particularly walking humanoid robots.
- Air muscles: (Also known as Pneumatic Artificial Muscles) are special tubes that contract (typically up to 40%) when air is forced inside it. They have been used for some robot applications.
- Muscle wire: (Also known as Shape Memory Alloy, Nitinol or Flexinol Wire) is a material that contracts slightly (typically under 5%) when electricity runs through it. They have been used for some small robot applications.
- Electroactive Polymers: (EAPs or EPAMs) are a new plastic material that can contract substantially (up to 400%) from electricity, and have been used in facial muscles and arms of humanoid robots, and to allow new robots to float, fly, swim or walk.
- Piezo motor: A recent alternative to DC motors are piezo motors or ultrasonic motors. These work on a fundamentally different principle, whereby tiny piezoceramic elements, vibrating many thousands of times per second, cause linear or rotary motion. There are different mechanisms of operation; one type uses the vibration of the piezo elements to walk the motor in a circle or a straight line. Another type uses the piezo elements to cause a nut to vibrate and drive a screw. The advantages of these motors are nanometer resolution, speed, and available force for their size. These motors are already available commercially, and being used on some robots.
- Elastic nanotubes: These are a promising artificial muscle technology in early-stage experimental development. The absence of defects incarbon nanotubes enables these filaments to deform elastically by several percent, with energy storage levels of perhaps 10 J/cm^3 for metal nanotubes. Human biceps could be replaced with an 8 mm diameter wire of this material. Such compact "muscle" might allow future robots to outrun and outjump humans.

Sensing

Touch

Current robotic and prosthetic hands receive far less tactile information than the human hand. Recent research has developed a tactile sensor array that mimics the mechanical properties and touch receptors of human fingertips. The sensor array is constructed as a rigid core surrounded by conductive fluid contained by an elastomeric skin. Electrodes are mounted on the surface of the rigid core and are connected to an impedance-measuring device within the core. When the artificial skin touches an object the fluid path around the electrodes is deformed, producing impedance changes that map the forces received from the object. The researchers expect that an important function of such artificial fingertips will be adjusting robotic grip on held objects.

Scientists from several European countries and Israel developed a prosthetic hand in 2009, called SmartHand, which functions like a real one—allowing patients to write with it, type on a keyboard, play piano and perform other fine movements. The prosthesis has sensors which enable the patient to sense real feeling in its fingertips.

Vision

Computer vision is the science and technology of machines that see. As a scientific discipline, computer vision is concerned with the theory behind artificial systems that extract information from images. The image data can take many forms, such as video sequences and views from cameras.

In most practical computer vision applications, the computers are pre-programmed to solve a particular task, but methods based on learning are now becoming increasingly common.

Computer vision systems rely on image sensors which detect electromagnetic radiation which is typically in the form of either visible light or infra-red light. The sensors are designed using solid-state physics. The process by which light propagates and reflects off surfaces is explained using optics. Sophisticated image sensors even require quantum mechanics to provide a complete understanding of the image formation process.

There is a subfield within computer vision where artificial systems are designed to mimic the processing and behavior of biological systems, at different levels of complexity. Also, some of the learning-based methods developed within computer vision have their background in biology.

Manipulation

Robots which must work in the real world require some way to manipulate objects; pick up, modify, destroy, or otherwise have an effect. Thus the "hands" of a robot are often referred to as *end effectors*, while the "arm" is referred to as a *manipulator*. Most robot arms have replaceable effectors, each allowing them to perform some small range of tasks. Some have a fixed manipulator which cannot be replaced, while a few have one very general purpose manipulator, for example a humanoid hand.

- Mechanical Grippers: One of the most common effectors is the gripper. In its simplest manifestation it consists of just two fingers which can open and close to pick up and let go of a range of small objects. Fingers can for example be made of a chain with a metal wire run through it.
- Vacuum Grippers: Pick and place robots for electronic components and for large objects like car windscreens, will often use very simple vacuum grippers. These are very simple astrictive devices, but can hold very large loads provided the prehension surface is smooth enough to ensure suction.
- General purpose effectors: Some advanced robots are beginning to use fully humanoid hands, like the Shadow Hand, MANUS, and the Schunk hand. These

highly dexterous manipulators, with as many as 20 degrees of freedom and hundreds of tactile sensors.

For the definitive guide to all forms of robot end-effectors, their design, and usage consult the book "Robot Grippers".

Locomotion

Rolling robots

Segway in the Robot museum in Nagoya.

For simplicity most mobile robots have four wheels or a number of continuous tracks. Some researchers have tried to create more complex wheeled robots with only one or two wheels. These can have certain advantages such as greater efficiency and reduced parts, as well as allowing a robot to navigate in confined places that a four wheeled robot would not be able to.

- Two-wheeled balancing: Balancing robots generally use a gyroscope to detect how much a robot is falling and then drive the wheels proportionally in the opposite direction, to counter-balance the fall at hundreds of times per second, based on the dynamics of an inverted pendulum. Many different balancing robots have been designed. While the Segway is not commonly thought of as a robot, it can be thought of as a component of a robot, such as NASA's Robonaut that has been mounted on a Segway.
- One-wheeled balancing: A one-wheeled balancing robot is an extension of a two-wheeled balancing robot so that it can move in any 2D direction using a round ball as its only wheel. Several one-wheeled balancing robots have been designed recently, such as Carnegie Mellon University's "Ballbot" that is the approximate height and width of a person, and Tohoku Gakuin University's "BallIP". Because of the long, thin shape and ability to maneuver in tight spaces, they have the potential to function better than other robots in environments with people.
- Spherical orb robots: Several attempts have been made in robots that are completely inside a spherical ball, either by spinning a weight inside the ball, or by rotating the outer shells of the sphere. These have also been referred to as an orb bot or a ball bot
- Six-wheeled robots: Using six wheels instead of four wheels can give better traction or grip in outdoor terrain such as on rocky dirt or grass.
- Tracked robots: Tank tracks provide even more traction than a six-wheeled robot. Tracked wheels behave as if they were made of hundreds of wheels, therefore are very common for outdoor and military robots, where the robot must drive on very rough terrain. However, they are difficult to use indoors such as on carpets and smooth floors. Examples include NASA's Urban Robot "Urbie".

Walking robots

iCub robot, designed by the RobotCub Consortium

Walking is a difficult and dynamic problem to solve. Several robots have been made which can walk reliably on two legs, however none have yet been made which are as robust as a human. Many other robots have been built that walk on more than two legs, due to these robots being significantly easier to construct. Hybrids too have been proposed in movies such as I, Robot, where they walk on 2 legs and switch to 4 (arms+legs) when going to a sprint. Typically, robots on 2 legs can walk well on flat floors and can occasionally walk up stairs. None can walk over rocky, uneven terrain. Some of the methods which have been tried are:

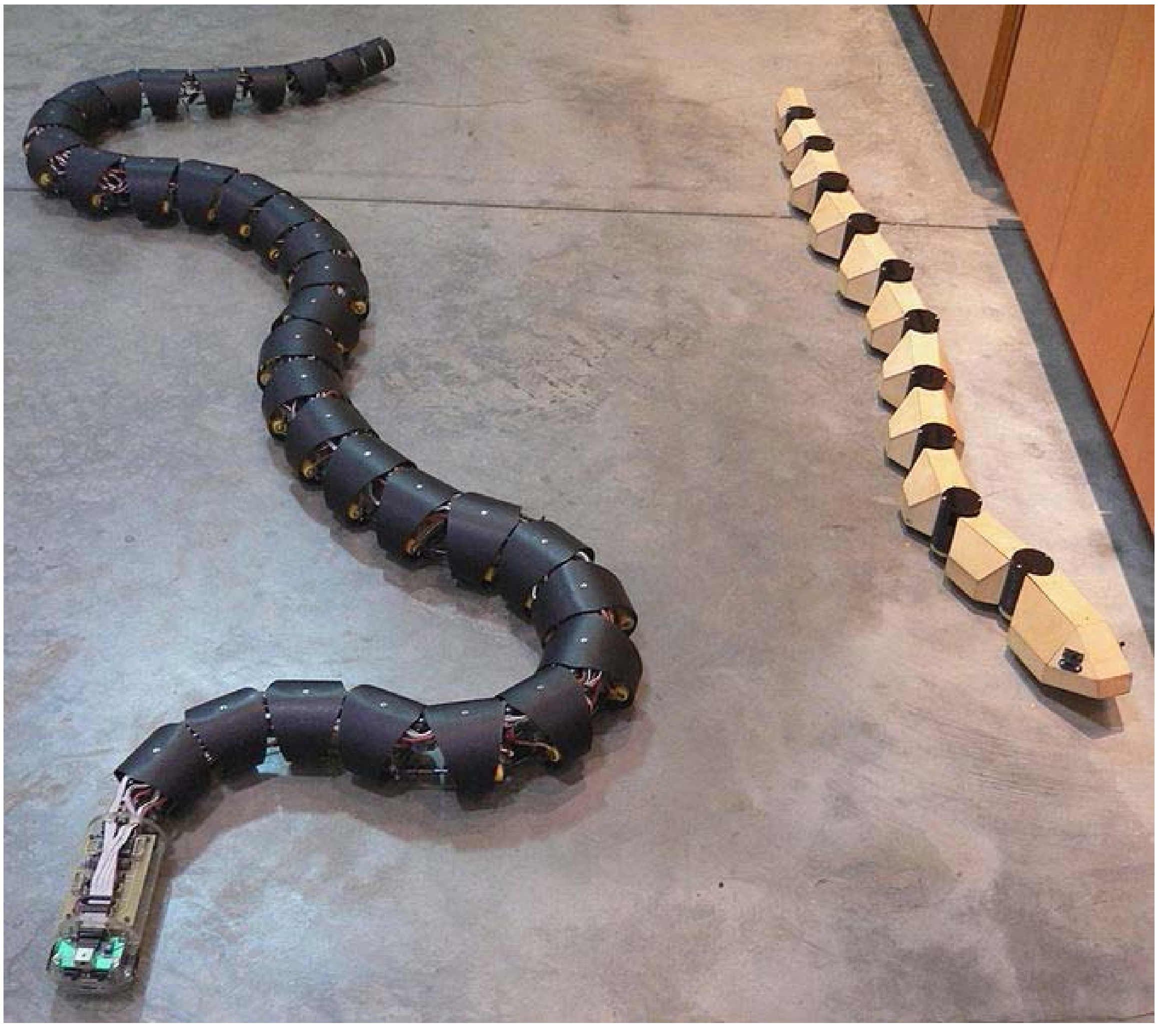
- ZMP Technique: The Zero Moment Point (ZMP) is the algorithm used by robots such as Honda's ASIMO. The robot's onboard computer tries to keep the total inertial forces (the combination of earth's gravity and the acceleration and deceleration of walking), exactly opposed by the floor reaction force (the force of the floor pushing back on the robot's foot). In this way, the two forces cancel out, leaving no moment (force causing the robot to rotate and fall over). However, this is not exactly how a human walks, and the difference is obvious to human observers, some of whom have pointed out that ASIMO walks as if it needs the lavatory. ASIMO's walking algorithm is not static, and some dynamic balancing is used. However, it still requires a smooth surface to walk on.
- Hopping: Several robots, built in the 1980s by Marc Raibert at the MIT Leg Laboratory, successfully demonstrated very dynamic walking. Initially, a robot with only one leg, and a very small foot, could stay upright simply by hopping. The movement is the same as that of a person on a pogo stick. As the robot falls to one side, it would jump slightly in that direction, in order to catch itself. Soon, the algorithm was generalised to two and four legs. A bipedal robot was demonstrated running and even performing somersaults. A quadruped was also demonstrated which could trot, run, pace, and bound.

- Dynamic Balancing or controlled falling: A more advanced way for a robot to walk is by using a dynamic balancing algorithm, which is potentially more robust than the Zero Moment Point technique, as it constantly monitors the robot's motion, and places the feet in order to maintain stability. This technique was recently demonstrated by Anybots' Dexter Robot, which is so stable, it can even jump. Another example is the TU Delft Flame.
- Passive Dynamics: Perhaps the most promising approach utilizes passive dynamics where the momentum of swinging limbs is used for greater efficiency. It has been shown that totally unpowered humanoid mechanisms can walk down a gentle slope, using only gravity to propel themselves. Using this technique, a robot need only supply a small amount of motor power to walk along a flat surface or a little more to walk up a hill. This technique promises to make walking robots at least ten times more efficient than ZMP walkers, like ASIMO.

Other methods of locomotion

RQ-4 Global Hawk unmanned aerial vehicle

- Flying: A modern passenger airliner is essentially a flying robot, with two humans to manage it. The autopilot can control the plane for each stage of the journey, including takeoff, normal flight, and even landing. Other flying robots are uninhabited, and are known as unmanned aerial vehicles (UAVs). They can be smaller and lighter without a human pilot onboard, and fly into dangerous territory for military surveillance missions. Some can even fire on targets under command. UAVs are also being developed which can fire on targets automatically, without the need for a command from a human. Other flying robots include cruise missiles, the Entomopter, and the Epson micro helicopter robot. Robots such as the Air Penguin, Air Ray, and Air Jelly have lighter-than-air bodies, propelled by paddles, and guided by sonar.



Two robot snakes. Left one has 64 motors (with 2 degrees of freedom per segment), the right one 10.

- Snaking: Several snake robots have been successfully developed. Mimicking the way real snakes move, these robots can navigate very confined spaces, meaning they may one day be used to search for people trapped in collapsed buildings. The Japanese ACM-R5 snake robot can even navigate both on land and in water.
- Skating: A small number of skating robots have been developed, one of which is a multi-mode walking and skating device. It has four legs, with unpowered wheels,

which can either step or roll. Another robot, Plen, can use a miniature skateboard or rollerskates, and skate across a desktop.

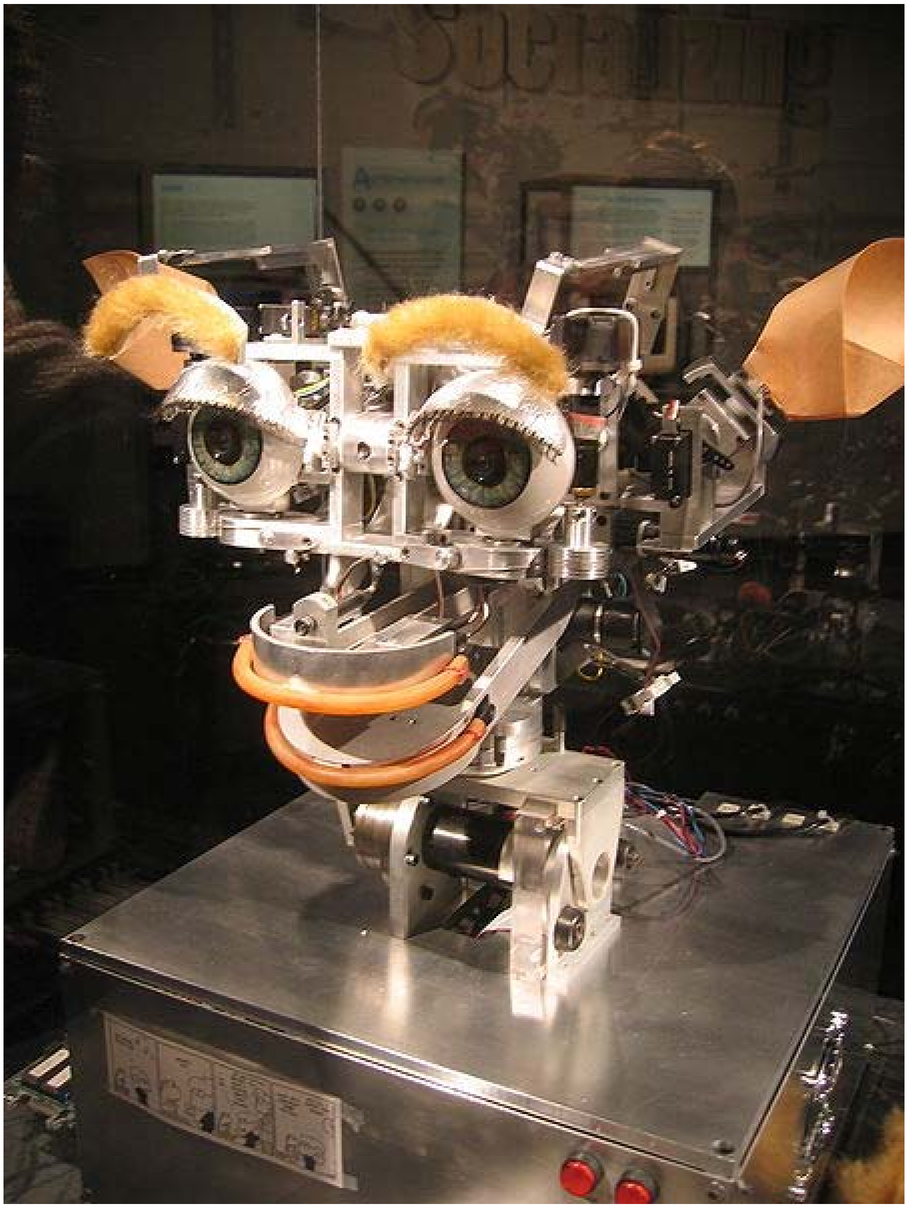
- Climbing: Several different approaches have been used to develop robots that have the ability to climb vertical surfaces. One approach mimicks the movements of a human climber on a wall with protrusions; adjusting the center of mass and moving each limb in turn to gain leverage. An example of this is Capuchin, built by Stanford University, California. Another approach uses the specialised toe pad method of wall-climbing geckoes, which can run on smooth surfaces such as vertical glass. Examples of this approach include Wallbot and Stickybot. China's "Technology Daily" November 15, 2008 reported New Concept Aircraft (ZHUHAI) Co., Ltd. Dr. Li Hiu Yeung and his research group have recently successfully developed the bionic gecko robot "Speedy Freelander".According to Dr. Li introduction, this gecko robot can rapidly climbing up and down in a variety of building walls, ground and vertical wall fissure or walking upside down on the ceiling, it is able to adapt on smooth glass, rough or sticky dust walls as well as the various surface of metallic materials and also can automatically identify obstacles, circumvent the bypass and flexible and realistic movements. Its flexibility and speed are comparable to the natural gecko. A third approach is to mimick the motion of a snake climbing a pole.
- Swimming: It is calculated that when swimming some fish can achieve a propulsive efficiency greater than 90%. Furthermore, they can accelerate and maneuver far better than any man-made boat or submarine, and produce less noise and water disturbance. Therefore, many researchers studying underwater robots would like to copy this type of locomotion. Notable examples are the Essex University Computer Science Robotic Fish, and the Robot Tuna built by the Institute of Field Robotics, to analyze and mathematically model thunniform motion. The Aqua Penguin, designed and built by Festo of Germany, copies the streamlined shape and propulsion by front "flippers" of penguins. Festo have also built the Aqua Ray and Aqua Jelly, which emulate the locomotion of manta ray, and jellyfish, respectively.

Environmental interaction and navigation

RADAR, GPS, LIDAR, ... are all combined to provide proper navigation and obstacle avoidance

Though a significant percentage of robots in commission today are either human controlled, or operate in a static environment, there is an increasing interest in robots that can operate autonomously in a dynamic environment. These robots require some combination of navigation hardware and software in order to traverse their environment. In particular unforeseen events (e.g. people and other obstacles that are not stationary) can cause problems or collisions. Some highly advanced robots as ASIMO, EveR-1, Meinü robot have particularly good robot navigation hardware and software. Also, self-controlled cars, Ernst Dickmanns' driverless car, and the entries in the DARPA Grand Challenge, are capable of sensing the environment well and subsequently making navigational decisions based on this information. Most of these robots employ a GPS navigation device with waypoints, along with radar, sometimes combined with other sensory data such as LIDAR, video cameras, and inertial guidance systems for better navigation between waypoints.

Human-robot interaction



Kismet can produce a range of facial expressions.

If robots are to work effectively in homes and other non-industrial environments, the way they are instructed to perform their jobs, and especially how they will be told to stop will be of critical importance. The people who interact with them may have little or no training in robotics, and so any interface will need to be extremely intuitive. Science fiction authors also typically assume that robots will eventually be capable of communicating with humans through speech, gestures, and facial expressions, rather than a command-line interface. Although speech would be the most natural way for the human to communicate, it is unnatural for the robot. It will probably be a long time before robots interact as naturally as the fictional C-3PO.

- Speech recognition: Interpreting the continuous flow of sounds coming from a human (speech recognition), in real time, is a difficult task for a computer, mostly because of the great variability of speech. The same word, spoken by the same person may sound different depending on local acoustics, volume, the previous word, whether or not the speaker has a cold, etc.. It becomes even harder when the speaker has a different accent. Nevertheless, great strides have been made in the field since Davis, Biddulph, and Balashek designed the first "voice input system" which recognized "ten digits spoken by a single user with 100% accuracy" in 1952. Currently, the best systems can recognize continuous, natural speech, up to 160 words per minute, with an accuracy of 95%.
- Robotic voice: other hurdles exist when allowing the robot to use voice for interacting with humans. For social reasons, synthetic voice proves suboptimal as a communication medium, making it necessary to develop the emotional component of robotic voice through various techniques.
- Gestures: One can imagine, in the future, explaining to a robot chef how to make a pastry, or asking directions from a robot police officer. In both of these cases, making hand gestures would aid the verbal descriptions. In the first case, the robot would be recognizing gestures made by the human, and perhaps repeating them for confirmation. In the second case, the robot police officer would gesture to indicate "down the road, then turn right". It is likely that gestures will make up a part of the interaction between humans and robots. A great many systems have been developed to recognize human hand gestures.
- Facial expression: Facial expressions can provide rapid feedback on the progress of a dialog between two humans, and soon it may be able to do the same for humans and robots. Robotic faces have been constructed by Hanson Robotics using their elastic polymer called Frubber, allowing a great amount of facial expressions due to the elasticity of the rubber facial coating and imbedded subsurface motors (servos) to produce the facial expressions. The coating and servos are built on a metal skull. A robot should know how to approach a human, judging by their facial expression and body language. Whether the person is happy, frightened, or crazy-looking affects the type of interaction expected of the robot. Likewise, robots like Kismet and the more recent addition, Nexi can produce a range of facial expressions, allowing it to have meaningful social exchanges with humans.
- Artificial emotions: Artificial emotions can also be imbedded and are composed of a sequence of facial expressions and/or gestures. As can be seen from the movie Final Fantasy: The Spirits Within, the programming of these artificial emotions is complex and requires a great amount of human observation. To simplify this programming in the movie, presets were created together with a special software program. This decreased the amount of time needed to make the film. These presets could possibly be transferred for use in real-life robots.
- Personality: Many of the robots of science fiction have a personality, something which may or may not be desirable in the commercial robots of the future. Nevertheless, researchers are trying to create robots which appear to have a personality: i.e. they use sounds, facial expressions, and body language to try to convey an internal state, which may be joy, sadness, or fear. One commercial

example is Pleo, a toy robot dinosaur, which can exhibit several apparent emotions.

Control

A robot-manipulated marionette, with complex control systems

The mechanical structure of a robot must be controlled to perform tasks. The control of a robot involves three distinct phases - perception, processing, and action (robotic paradigms). Sensors give information about the environment or the robot itself (e.g. the position of its joints or its end effector). This information is then processed to calculate the appropriate signals to the actuators (motors) which move the mechanical.

The processing phase can range in complexity. At a reactive level, it may translate raw sensor information directly into actuator commands. Sensor fusion may first be used to estimate parameters of interest (e.g. the position of the robot's gripper) from noisy sensor data. An immediate task (such as moving the gripper in a certain direction) is inferred from these estimates. Techniques from control theory convert the task into commands that drive the actuators.

At longer time scales or with more sophisticated tasks, the robot may need to build and reason with a "cognitive" model. Cognitive models try to represent the robot, the world, and how they interact. Pattern recognition and computer vision can be used to track objects. Mapping techniques can be used to build maps of the world. Finally, motion planning and other artificial intelligence techniques may be used to figure out how to act. For example, a planner may figure out how to achieve a task without hitting obstacles, falling over, etc.

Autonomy levels

Control systems may also have varying levels of autonomy.

1. Direct interaction is used for haptic or tele-operated devices, and the human has nearly complete control over the robot's motion.
2. Operator-assist modes have the operator commanding medium-to-high-level tasks, with the robot automatically figuring out how to achieve them.
3. An autonomous robot may go for extended periods of time without human interaction. Higher levels of autonomy do not necessarily require more complex cognitive capabilities. For example, robots in assembly plants are completely autonomous, but operate in a fixed pattern.

Another classification takes into account the interaction between human control and the machine motions.

1. Teleoperation. A human controls each movement, each machine actuator change is specified by the operator.
2. Supervisory. A human specifies general moves or position changes and the machine decides specific movements of its actuators.
3. Task-level autonomy. The operator specifies only the task and the robot manages itself to complete it.
4. Full autonomy. The machine will create and complete all its tasks without human interaction.

Dynamics and kinematics

The study of motion can be divided into kinematics and dynamics. Direct kinematics refers to the calculation of end effector position, orientation, velocity, and acceleration when the corresponding joint values are known. Inverse kinematics refers to the opposite case in which required joint values are calculated for given end effector values, as done in path planning. Some special aspects of kinematics include handling of redundancy (different possibilities of performing the same movement), collision avoidance, and singularity avoidance. Once all relevant positions, velocities, and accelerations have been calculated using kinematics, methods from the field of dynamics are used to study the effect of forces upon these movements. Direct dynamics refers to the calculation of accelerations in the robot once the applied forces are known. Direct dynamics is used in computer simulations of the robot. Inverse dynamics refers to the calculation of the actuator forces necessary to create a prescribed end effector acceleration. This information can be used to improve the control algorithms of a robot.

In each area mentioned above, researchers strive to develop new concepts and strategies, improve existing ones, and improve the interaction between these areas. To do this, criteria for "optimal" performance and ways to optimize design, structure, and control of robots must be developed and implemented.

Robot research

Much of the research in robotics focuses not on specific industrial tasks, but on investigations into new types of robots, alternative ways to think about or design robots, and new ways to manufacture them but other investigations, such as MIT's cyberflora project, are almost wholly academic.

A first particular new innovation in robot design is the opensourcing of robot-projects. To describe the level of advancement of a robot, the term "Generation Robots" can be used. This term is coined by Professor Hans Moravec, Principal Research Scientist at the Carnegie Mellon University Robotics Institute in describing the near future evolution of robot technology. *First generation* robots, Moravec predicted in 1997, should have an intellectual capacity comparable to perhaps a lizard and should become available by 2010. Because the *first generation* robot would be incapable of learning, however, Moravec predicts that the *second generation* robot would be an improvement over the *first* and become available by 2020, with an intelligence maybe comparable to that of a mouse. The *third generation* robot should have an intelligence comparable to that of a monkey. Though *fourth generation* robots, robots with human intelligence, professor Moravec predicts, would become possible, he does not predict this happening before around 2040 or 2050.

The second is Evolutionary Robots. This is a methodology that uses evolutionary computation to help design robots, especially the body form, or motion and behavior controllers. In a similar way to natural evolution, a large population of robots is allowed to compete in some way, or their ability to perform a task is measured using a fitness function. Those that perform worst are removed from the population, and replaced by a new set, which have new behaviors based on those of the winners. Over time the population improves, and eventually a satisfactory robot may appear. This happens without any direct programming of the robots by the researchers. Researchers use this method both to create better robots, and to explore the nature of evolution. Because the process often requires many generations of robots to be simulated, this technique may be run entirely or mostly in simulation, then tested on real robots once the evolved algorithms are good enough. Currently, there are about 1 million industrial robots toiling around the world, and Japan is the top country having high density of utilizing robots in its manufacturing industry.

Education and training

The SCORBOT-ER 4u - educational robot.

Robots recently became a popular tool in raising interests in computing for middle and high school students. First year computer science courses at several universities were developed which involves the programming of a robot instead of the traditional software engineering based coursework.

Career training

Universities offer Bachelors, Masters and Doctoral degrees in the field of robotics. Select Private Career Colleges and vocational schools offer robotics training to train individuals towards being job ready and employable in the emerging robotics industry.

Certification

The Robotics Certification Standards Alliance (RCSA) is an international robotics certification authority who confers various industry and educational related robotics certifications.

Employment in robotics

A robot technician builds small all-terrain robots. (Courtesy: MobileRobots Inc)

Robotics is an essential component in any modern manufacturing environment. As factories increase their use of robots, the number of robotics related jobs grow and have been observed to be on a steady rise.

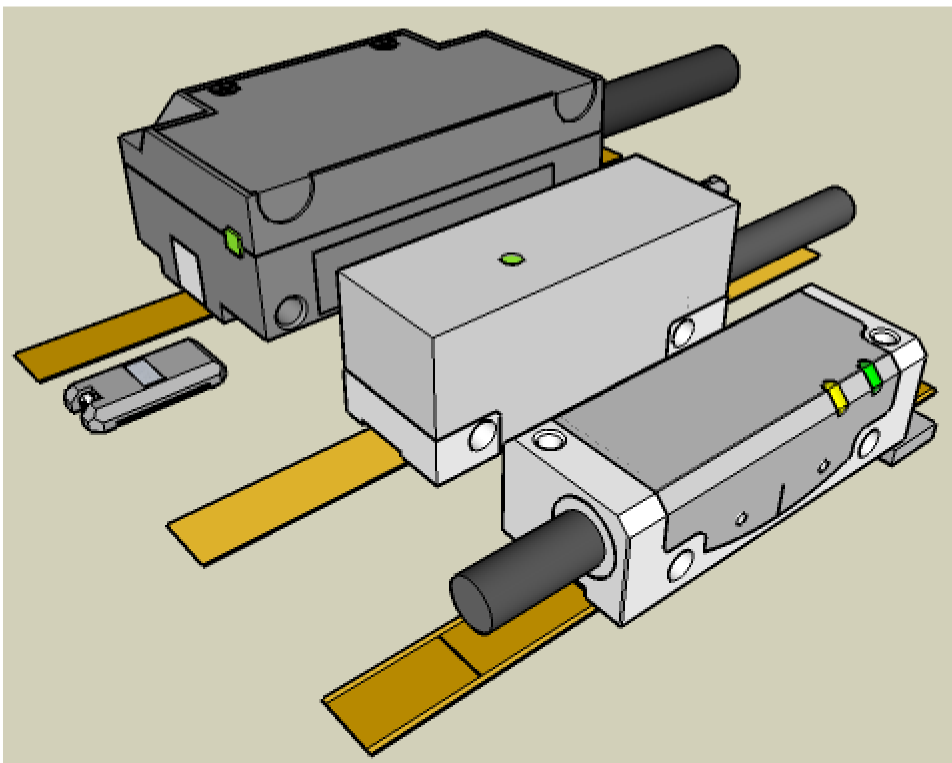
Relationship to unemployment

Some analysts, such as Martin Ford, argue that robots and other forms of automation will ultimately result in significant unemployment as machines begin to match and exceed the capability of workers to perform most jobs. At present the negative impact is only on menial and repetitive jobs, and there is actually a positive impact on the number of jobs for highly skilled technicians, engineers, and specialists. However, these highly skilled jobs are not sufficient in number to offset the greater decrease in employment among the general population, causing structural unemployment in which overall (net) unemployment rises.

As robotics and artificial intelligence develop further, some worry even many skilled jobs may be threatened. In conventional economic theory this should merely cause an increase in the productivity of the involved industries, resulting in higher demand for other goods, and hence higher labour demand in these sectors, off-setting whatever negatives are caused. Conventional theory describes the past well but may not describe the future due to shifts in the parameter values that shape the context.

Chapter 8

Linear Encoder



Typical linear optical encoders.

A **linear encoder** is a sensor, transducer or readhead paired with a scale that encodes position. The sensor reads the scale in order to convert the encoded position into an analog or digital signal, which can then be decoded into position by a digital readout (DRO) or motion controller. The encoder can be either *incremental* or *absolute*. Motion can be determined by change in position over time. Linear encoder technologies include optical, magnetic, inductive, capacitive and eddy current. Optical technologies include shadow, self imaging and interferometric. Linear encoders are used in metrology instruments, motion systems and high precision machining tools ranging from digital calipers to coordinate measuring machines.

Physical principle

Linear encoders are transducers that employ many different physical properties in order to encode position.

Optical

Optical linear encoders , dominate the high resolution market and may employ shuttering / Moiré, diffraction or holographic principles. Typical incremental scale periods vary from hundreds down to a few microns and following interpolation can provide resolutions as fine as a nanometre. Light sources used include infrared LEDs, visible LEDs, miniature light-bulbs and laser diodes.

Magnetic

Magnetic linear encoders employ either active (magnetized) or passive (variable reluctance) scales and position may be sensed using sense-coils, Hall Effect or magnetoresistive readheads. With coarser scale periods than optical encoders (typically a few hundred microns to several millimeters) resolutions in the order of a micron are the norm.

Inductive

A popular application of the inductive measuring principle is the Inductosyn . In effect it is a resolver unwound into a linear system.
The Spherosyn encoder is based on the principle of electromagnetic induction and uses coils to sense nickel-chrome ball-bearings mounted within a tube.

Capacitive

Capacitive linear encoders work by sensing the capacitance between a reader and scale. Typical applications are digital calipers.

Eddy current

US Patent 3820110, "Eddy current type digital encoder and position reference", gives an example of this type of encoder, which uses a scale coded with high and low permeability, non-magnetic materials, which is detected and decoded by monitoring changes in inductance of an AC circuit that includes an inductive coil sensor. Maxon makes an example (rotary encoder) product (the MILE encoder).

Applications

There are two main areas of application for linear encoders:-

Measurement

Measurement application include coordinate-measuring machines (CMM), laser scanners, calipers, gear measurement , tension testers and Digital read outs (DROs).

Motion systems

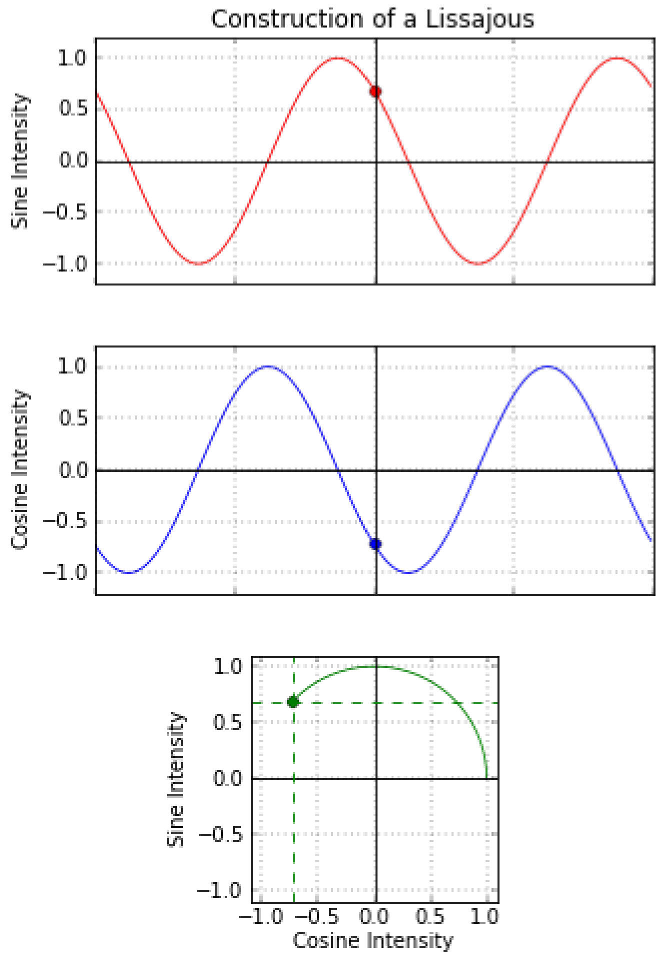
Servo controlled motion systems employ linear encoder so as to provide accurate, high-speed movement. Typical applications include robotics, machine tools, pick-and-place PCB assembly equipment; semiconductors handling and test equipment, wire bonders, printers and digital presses.

Output format

Linear encoders either have analogue or digital outputs.

Analogue

Incremental signals



The sine and cosine outputs.

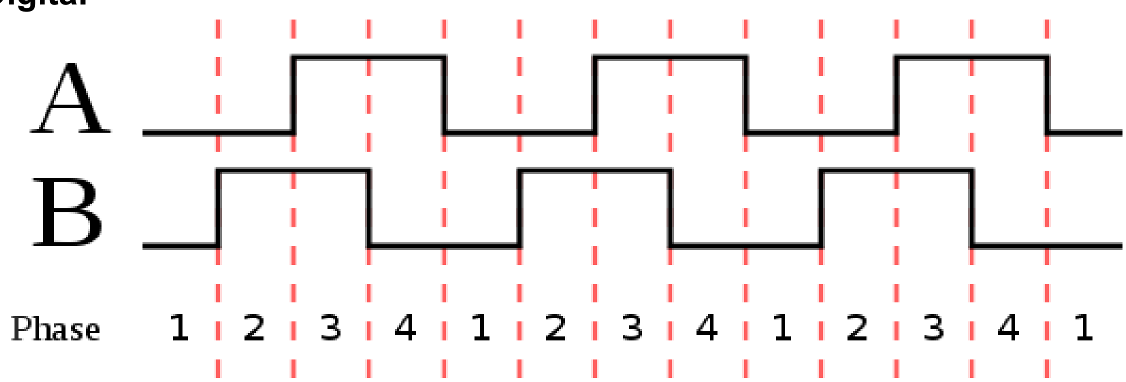
The industry standard, analogue output for linear encoders is sine and cosine quadrature signals. These are usually transmitted differentially so as to improve noise immunity. An early industry standard was 12 µA peak-peak current signals but more recently this has been replaced with 1V peak to peak voltage signals. Compared to digital transmission, the analogue signals' lower bandwidth helps to minimise emc emissions.
Quadrature sine/cosine signals can be monitored easily by using an oscilloscope in XY mode to display a circular Lissajous Figure. Highest accuracy signals are obtained if the Lissajous Figure is circular (no gain or phase error) and perfectly centred. Modern encoder systems employ circuitry to trim these error mechanisms automatically. The overall accuracy of the linear encoder is a combination of the scale accuracy and errors

introduced by the readhead. Scale contributions to the error budget include linearity and slope (scaling factor error). Readhead error mechanisms are usually described as *cyclic error* or *sub-divisional error (SDE)* as they repeat every scale period. The largest contributor to readhead inaccuracy is signal offset, followed by signal imbalance (ellipticity) and phase error (the quadrature signals not being exactly 90° apart). Overall signal size does not affect encoder accuracy, however, signal-to-noise and jitter performance may degrade with smaller signals. Automatic signal compensation mechanisms can include *automatic offset compensation (AOC), automatic balance compensation (ABC) and automatic gain control (AGC)*. Phase is more difficult to compensate dynamically and is usually applied as one time compensation during installation or calibration. Other forms of inaccuracy include signal distortion (frequently harmonic distortion of the sine/cosine signals).

Reference mark

Most incremental, linear encoders can produce an index or reference mark pulse providing a datum position along the scale for use at power-up or following a loss of power. This index signal must be able to identify position within one, unique period of the scale. The reference mark may comprise a single feature on the scale, an autocorrelator pattern (typically a Barker code) or a chirp pattern.
Distance coded reference marks (DCRM) are placed onto the scale in a unique pattern allowing a minimal movement (typically moving past two reference marks) to define the readhead's position. Multiple, equally spaced reference marks may also be placed onto the scale such that following installation, the desired marker can be selected - usually via a magnet or optically.

Digital



The A and B quadrature channels.

Many linear encoders interpolate the analogue sine/cosine signals in order to sub-divide the scale period, providing a higher measurement resolution. The output of the interpolation process is quadrature squarewaves - the distance between edges of the two channels being the resolution of the encoder. The reference mark or index pulse will also be processed digitally and will be a pulse, usually one to four units-of-resolution wide. The major advantage of encoders with built-in interpolation and digital signal

transmission is improved noise immunity. However, the high frequency, fast edge speed signals may produce more emc emissions.
Incremental encoders with built-in digital processing make it possible to transmit position to any subsequent electronics such as a position counter.
As well as traditional incremental, linear encoders, linear encoders may be *absolute* in nature. With suitably encoded scales (multitrack, vernier or pseudorandom) an encoder can determine its position without movement or needing to find a reference position. Such absolute encoders also communicate using serial communication protocols.
Many of these protocols are proprietry - Fanuc, Mitsubishi, EnDat, DriveCliq, Panasonic, Yaskawa - but open standards such as BiSS are now appearing, which avoid tying users to a particular supplier.

Limit switches

Many linear encoders include built-in limit switches - either optical or magnetic. Two limit switches are frequently included such that on power-up the controller can determine if the encoder is at an end-of-travel and in which direction to drive the axis.

Physical arrangement / protection

Linear encoders may be either *enclosed* or *open*. Enclosed linear encoders are employed in dirty, hostile environments such as machine-tools. They typically comprise an aluminium extrusion enclosing a glass or metal scale. Flexible lip seals allow an internal, guided readhead to read the scale. Accuracy is limited due to the friction and hysteresis imposed by this mechanical arrangement.
For the highest accuracy, lowest measurement hysteresis and lowest friction applications, open linear encoders are used.
Linear encoders may use transmissive (glass) or reflective scales, employing Ronchi or phase gratings. Scale materials include chrome on glass, metal (stainless steel, gold plated steel, Invar), ceramics (Zerodur) and plastics. The scale may be self supporting, be thermally mastered to the substrate (via adhesive or adhesive tape) or *track* mounted. Track mounting may allow the scale to maintain its own coefficient of thermal expansion and allows large equipment to be broken down for shipment.

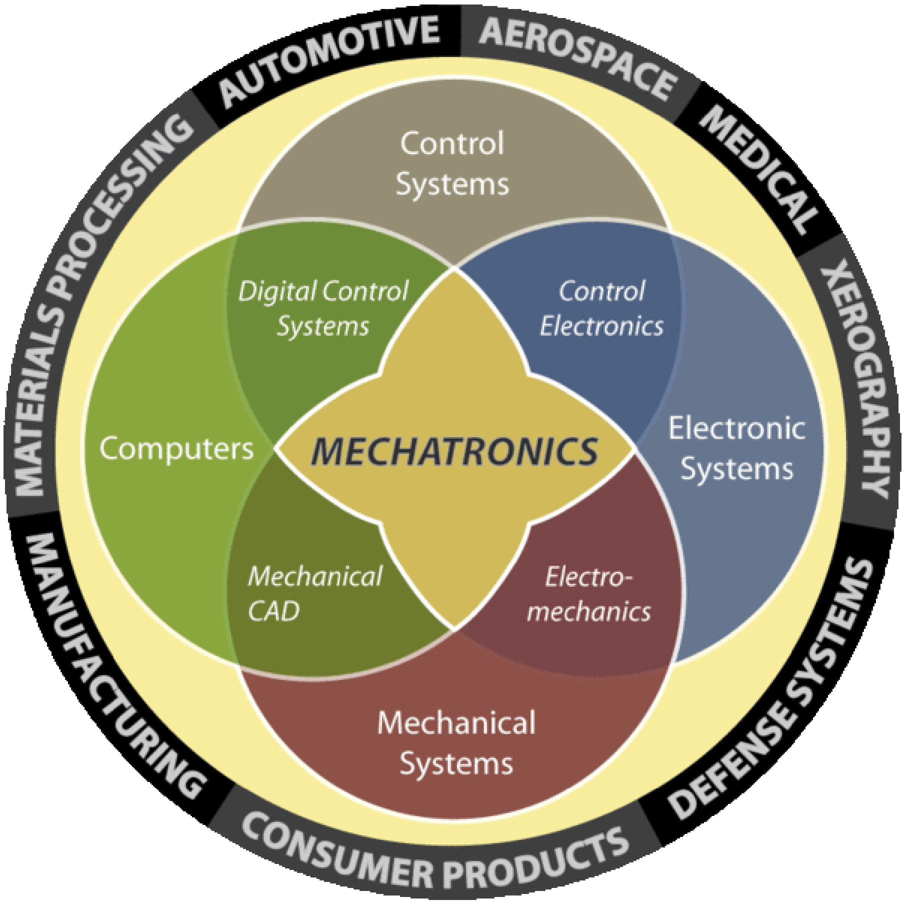
Chapter 9

Mechatronics

Mechatronics is the combination of Mechanical engineering, Electronic engineering, Computer engineering, Control engineering, and Systems Design engineering in order to design, and manufacture useful products. Mechatronics is a multidisciplinary engineering system design, that is to say it rejects splitting engineering into separate disciplines.

French standard NF E 01-010 gives the following definition: “approach aiming at the synergistic integration of mechanics, electronics, control theory, and computer science within product design and manufacturing, in order to improve and/or optimize its functionality".

Description



Aerial Venn diagram from RPI's website describes the various fields that make up Mechatronics

A mechatronics engineer unites the principles of mechanics, electronics, and computing to generate a simpler, more economical and reliable system. Mechatronics is centered on mechanics, electronics, computing, control engineering, molecular engineering (from nanochemistry and biology), and optical engineering, which, combined, make possible the generation of simpler, more economical, reliable and versatile systems. The portmanteau "mechatronics" was coined by Tetsuro Mori, the senior engineer of the Japanese company Yaskawa in 1969. An industrial robot is a prime example of a mechatronics system; it includes aspects of electronics, mechanics, and computing to do its day-to-day jobs.

Engineering cybernetics deals with the question of control engineering of mechatronic systems. It is used to control or regulate such a system. Through collaboration, the mechatronic modules perform the production goals and inherit flexible and agile manufacturing properties in the production scheme. Modern production equipment consists of mechatronic modules that are integrated according to a control architecture. The most known architectures involve hierarchy, polyarchy, heterarchy, and hybrid. The methods for achieving a technical effect are described by control algorithms, which might or might not utilize formal methods in their design. Hybrid systems important to mechatronics include production systems, synergy drives, planetary exploration rovers, automotive subsystems such as anti-lock braking systems and spin-assist, and every-day equipment such as autofocus cameras, video, hard disks, and CD players.

Course structure

Mechatronic students take courses from across the various fields listed below:

- Mechanical engineering and materials science subjects
- Electronic engineering subjects
- Computer engineering subjects
- Computer science subjects
- Systems and control engineering subjects
- Optomechanics (optical engineering) subjects
- Robotics subjects

Application

- Machine vision
- Automation and robotics
- Servo-mechanics
- Sensing and control systems
- Automotive engineering, automotive equipment in the design of subsystems such as anti-lock braking systems
- Computer-machine controls, such as computer driven machines like IE CNC milling machines
- Expert systems
- Industrial goods
- Consumer products
- Mechatronics systems
- Medical mechatronics, medical imaging systems
- Structural dynamic systems
- Transportation and vehicular systems
- Mechatronics as the new language of the automobile
- Diagnostic, reliability, and control system techniques
- Computer aided and integrated manufacturing systems
- Computer-aided design
- Engineering and manufacturing systems
- Packaging

Physical implementations

For most mechatronic systems, the main issue is no more how to implement a control system, but how to implement actuators and what is the energy source. Within the mechatronic field, mainly two technologies are used to produce the movement: the piezo-electric actuators and motors, or the electromagnetic actuators and motors. Maybe the most famous mechatronics systems are the well known camera autofocus system or camera anti-shake systems.

Concerning the energy sources, most of the applications use batteries. But a new trend is arriving and is the energy harvesting, allowing transforming into electricity mechanical energy from shock, vibration, or thermal energy from thermal variation, and so on.

Variant of the field

An emerging variant of this field is biomechatronics, whose purpose is to integrate mechanical parts with a human being, usually in the form of removable gadgets such as an exoskeleton. Such an entity is often identified in science fiction as a cyborg. This is the "real-life" version of cyberware.

Another emerging variant is Electronical or electronics design centric ECAD/MCAD co-design. Electronical is where the integration and co-design between the design team and design tools of an electronics centric system and the design team and design tools of that systems physical/mechanical enclosure takes place.

Education

Countries offering education in mechatronics are India, Pakistan, México, Chile Colombia, Japan, Malaysia, France, Germany, United States, UK, Sweden, Canada, Australia, Ireland Singapore,Iran , and Hungary among others.

Chapter 10

Heliostat

A **heliostat** (from *helios*, the Greek word for *sun*, and *stat*, as in stationary) is a device that includes a plane mirror which turns so as to keep reflecting sunlight toward a predetermined target, compensating for the sun's apparent motions in the sky. The target may be a physical object, distant from the heliostat, or a direction in space. To do this, the reflective surface of the mirror is kept perpendicular to the bisector of the angle between the directions of the sun and the target as seen from the mirror. In almost every case, the target is stationary relative to the heliostat, so the light is reflected in a fixed direction.

Most modern heliostats are controlled by computers. The computer is given the latitude and longitude of the heliostat's position on the earth and the time and date. From these, using astronomical theory, it calculates the direction of the sun as seen from the mirror, e.g. its compass bearing and angle of elevation. Then, given the direction of the target, the computer calculates the direction of the required angle-bisector, and sends control signals to motors, often stepper motors, so they turn the mirror to the correct alignment. This sequence of operations is repeated frequently to keep the mirror properly oriented.

Large installations such as solar-thermal power stations include **fields of heliostats** comprising many mirrors. Usually, all the mirrors in such a field are controlled by a single computer.

There are older types of heliostat which do not use computers, including ones that are partly or wholly operated by hand or by clockwork, or are controlled by light-sensors. These are now quite rare.

Heliostats should be distinguished from solar trackers or sun-trackers, which always point directly at the sun in the sky. However, some older types of heliostat incorporate solar trackers, together with additional components to bisect the sun-mirror-target angle.

Nowadays, most heliostats are used for daylighting or for solar power generation. A few are used experimentally, or to reflect motionless beams of sunlight into solar telescopes. In poor countries, heliostats are sometimes used in solar cooking. Before the availability of lasers and other electric lights, heliostats were widely used to produce intense, stationary beams of light for scientific and other purposes.

A heliostat at the THÉMIS experimental station in France. The mirror rotates on an altazimuth mount.

A **siderostat** is a similar device which is designed to follow a fainter star, rather than the sun.

The Solar Two solar-thermal power project. Every mirror in the field of heliostats reflects sunlight continuously onto the receiver on the tower.

Large-scale projects

The 11MW PS10 near Seville in Spain. When this picture was taken, dust in the air made the converging light visible.

In a solar-thermal power plant, like those of The Solar Project or the PS10 plant in Spain, a wide field of heliostats focuses the sun's power onto a single collector to heat a medium such as water or molten salt. The medium travels through a heat exchanger to heat water, produce steam, and then generate electricity through a steam turbine.

The solar furnace at Odeillo in the Pyrenees-Orientales in France can reach temperatures up to 3,500 °C (6,330 °F)

A somewhat different arrangement of heliostats in a field is used at experimental solar furnaces, such as the one at Odeillo, in France. All the heliostat mirrors send accurately parallel beams of light into a large paraboloidal reflector which brings them to a precise focus. The mirrors have to be located close enough to the axis of the paraboloid to reflect sunlight into it along lines parallel to the axis, so the field of heliostats has to be narrow. A closed loop control system is used. Sensors determine if any of the heliostats is slightly misaligned. If so, they send signals to correct it.

It has been proposed that the high temperatures generated could be used to split water producing hydrogen sustainably.

Small-scale projects

Smaller heliostats are used for daylighting, also called natural lighting. Instead of many large heliostats focusing on a single target to concentrate solar power (as in a solar power tower plant), a single heliostat usually about 1 or 2 square meters in size reflects non-concentrated sunlight through a window or skylight. The small heliostat, installed outside on the ground or on a building structure like a roof, moves on two axes (up/down and left/right) in order to compensate for the constant movement of the sun. In this way, the reflected sunlight stays fixed on the target (e.g. window).

Companies that manufacture small heliostats for natural lighting include EGIS GmbH and BOMIN SOLAR (member of the Colt Group companies), both in Germany. Genzyme Center, the global corporate headquarters of Genzyme Corp. in Cambridge, Massachusetts (NASDAQ: GENZ), uses BOMIN heliostats on the roof to direct sunlight into the 12-story atrium. After opening in November 2003, the building received the highest rating issued by the U.S. Green Building Council, a Platinum certification under the Council’s LEED (Leadership in Energy and Environmental Design) Green Building Rating System.

In 2009, a Boston Massachusetts-based manufacturing company called Practical Solar, Inc. began selling a small heliostat system for natural lighting. The company claims theirs is the first computer-controlled heliostat system in the world that can be installed by hand. The company’s web site states that customers also use their heliostats for direct space heating, drying mould, melting ice dams on roofs, and melting snow.

In the Spring 2009 edition of Northeast Sun, (the flagship publication of the New England Sustainable Energy Association, NESEA), Practical Solar’s founder Bruce Rohr suggested that small heliostats can also be used like a solar power tower system. Instead of occupying hundreds of acres, the system would fit in a much smaller area, like the flat rooftop of a commercial building, he said. The system would use the power in sunlight to heat and cool a building, or to provide input for thermal industrial processes like processing food. The cooling would be performed with an absorption chiller, which runs off of heat. Mr. Rohr proposed that the system would be “more reliable and more cost-effective per square meter of reflective area” than large solar power tower plants, in part because it would not be sacrificing 80 percent of the power collected in the process of converting it to electricity. This conversion loss is a function of Carnot's theorem, a thermodynamic principle.

Design

Heliostat costs represent 30-50% of the initial capital investment for solar power tower power plants depending on the energy policy and economic framework in the location country. It is of interest to design more inexpensive heliostats for large scale manufacturing, so that solar power tower power plants may produce electricity at costs more competitive to conventional coal or nuclear power plants costs.

Besides cost, percent solar reflectivity (i.e. albedo) and environmental durability are factors that should be considered when comparing heliostat designs.

One way that engineers and researchers are attempting to lower the costs of heliostats is by replacing the conventional heliostat design with one that uses fewer, lighter materials. A conventional design for the heliostat's reflective components utilizes a second surface mirror. The sandwich-like mirror structure generally consists of a steel structural support, an adhesive layer, a protective copper layer, a layer of reflective silver, and a top protective layer of thick glass. This conventional heliostat is often referred to as a glass/metal heliostat. Alternative designs incorporate recent adhesive, composite, and thin film research to bring about materials costs and weight reduction. Some examples of alternative reflector designs are silvered polymer reflectors, glass fiber reinforced polyester sandwiches (GFRPS), and aluminized reflectors. Problems with these more recent designs include delamination of the protective coatings, reduction in percent solar reflectivity over long periods of sun exposure, and high manufacturing costs.

Chapter 11

Spinmechatronics

Spinmechatronics is neologism referring to an emerging field of research concerned with the exploitation of spin-dependent phenomena and established spintronic methodologies and technologies in conjunction with electro-mechanical, magno-mechanical, acousto-mechanical and opto-mechanical systems. Most especially, spinmechatronics (or spin mechatronics) concerns the integration of micro- and nano-mechatronic systems with spin physics and spintronics.

History and origins

While spinmechatronics has been recognised only recently (2008) as an independent field, hybrid spin-mechanical system development dates back to the early nineteen-nineties, with devices combining spintronics and micromechanics emerging at the turn of the twenty-first century.

One of the longest established spinmechatronic systems is the Magnetic Resonance Force Microscope or MRFM. First proposed by J. A. Sidles in a seminal paper of 1991 – and since extensively developed both theoretically and experimentally by a number of international research groups – the MRFM operates by coupling a magnetically loaded micro-mechanical cantilever to an excited nuclear, proton or electron spin system. The MRFM concept effectively combines scanning atomic force microscopy (AFM) with magnetic resonance spectroscopy to provide a spectroscopic tool of unparalleled sensitivity. Nanometre resolution is possible, and the technique potentially forms the basis for ultra-high sensitivity, ultra-high resolution magnetic, biochemical, biomedical, and clinical diagnostics.

The synergy of micromechanics and established spintronic technologies for sensing applications is one of the most significant spinmechatronic developments of the last decade. At the beginning of this century, strain sensors incorporating magnetoresistive technologies emerged and a wide range of devices exploiting similar principles are likely to realize research and commercial potential by 2015.

Contemporary innovation in spinmechatronics drives forward the independent advancement of cutting-edge science in spin physics, spintronics and micro- and nano-mechatronics and catalyses the development of wholly new instrumentation, control and fabrication techniques to facilitate and exploit their integration.

Key constitutive technologies

Micro- and nano- mechatronics

MEMS: micro-electromechanical systems are the key ingredient of micro-mechatronics. Micro-electromechanical systems are – as the name suggests – devices with significant dimensions in the micrometre regime or less . Highly suited to integration with electronic and microwave circuitry, they provide the key to electro-mechanical functionalities unachievable with classical precision mechatronics. Commercialisation of mass produced Microelectromechanical systems products is rapidly picking up pace and includes printer ink-jet technology, 3D accelerometers, integrated pressure sensors, and Digital Light Processing (DLP) displays. At the cutting edge of Microelectromechanical systems fabrication and integration technologies are nano- electromechanical systems (NEMS). Typical examples are micrometres long, tens of nanometres thick, and have mechanical resonance frequencies approaching 100 MHz. Their small physical dimensions and mass (of order pico-grams) makes them highly sensitive to changes in stiffness; this, their synergy with mechanical and data processing systems, and the option of attaching chemical/ biological molecules, makes them ideal for ultra high-performance mechanical, chemical and biological sensing applications.

Spin physics

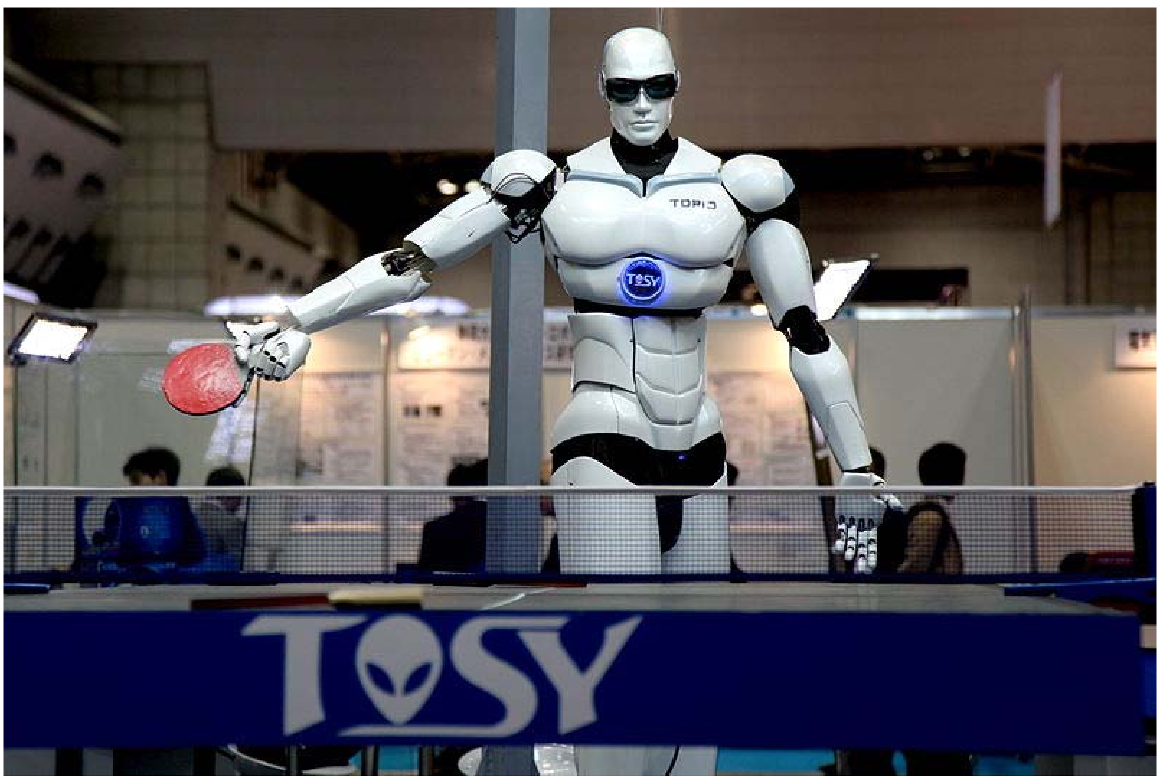
Spin physics is a broad and active area of condensed-matter physics research. ‘Spin’ in this context refers to a quantum mechanical property of certain elementary particles and nuclei, and should not be confused with the classical (and better-known) concept of rotation. Spin physics spans studies of nuclear, electron and proton magnetic resonance, magnetism, and certain areas of optics. Spintronics is a branch of spin physics. Perhaps the two best known applications of spin physics are Magnetic Resonance Imaging (or MRI) and the spintronic giant-magnetoresistive (GMR) hard disk read head.

Spintronics

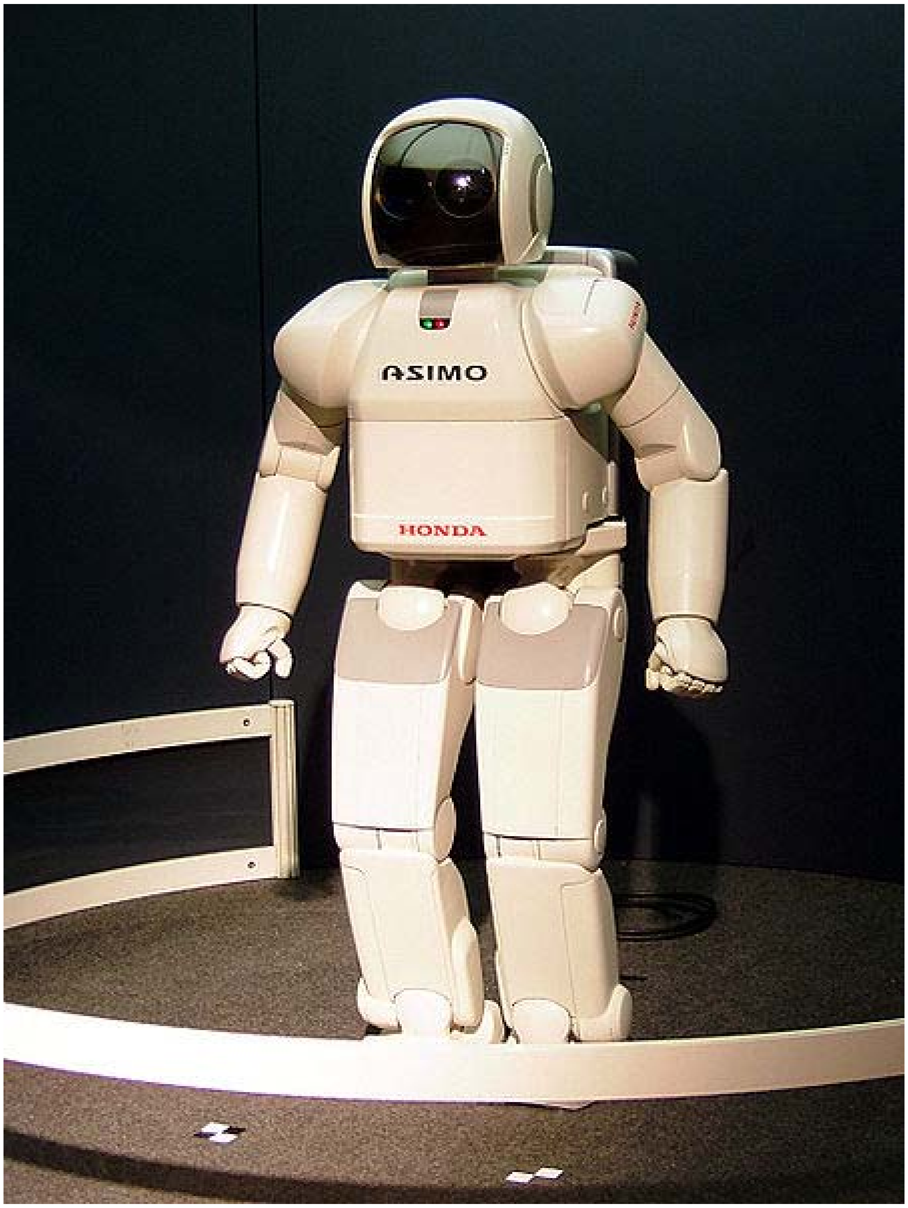
Spintronic magnetoresistance is a major scientific and commercial success story. Today, most families own a spintronic device: the giant-magnetoresistive (GMR) hard disk read head in their computer. The science that gave rise to this phenomenal business opportunity – and earned the 2007 Nobel Prize for Physics – was the recognition that electrical carriers are characterized by both charge and spin. Today, tunnelling-magnetoresistance (TMR) – which uses the electron spin as a label to allow or forbid electron tunnelling – dominates the hard disk market and is rapidly establishing itself in areas as diverse as magnetic logic devices and biosensors . Ongoing development is pushing the frontiers of TMR devices towards the nanoscale.

Chapter 12

Robot



TOPIO, a humanoid robot, played ping pong at Tokyo International Robot Exhibition (IREX) 2009.



ASIMO (2000) at the Expo 2005, a humanoid robot

A **robot** is a mechanical intelligent agent which can perform tasks on its own, or with guidance. The term **robot** can also apply to a virtual agent. In practice it is usually an electro-mechanical machine which is guided by computer or electronic programming. Robots can be autonomous or semi-autonomous and come in those two basic types: those which are used for research into human-like systems, such as ASIMO and TOPIO, as well as those into more defined and specific roles, such as Nano robots and Swarm robots; and helper robots which are used to make or move things or perform menial or dangerous tasks, such as Industrial robots or mobile or servicing robots. Another common characteristic is that, by its appearance or movements, a robot often conveys a sense that it has intent or agency of its own.

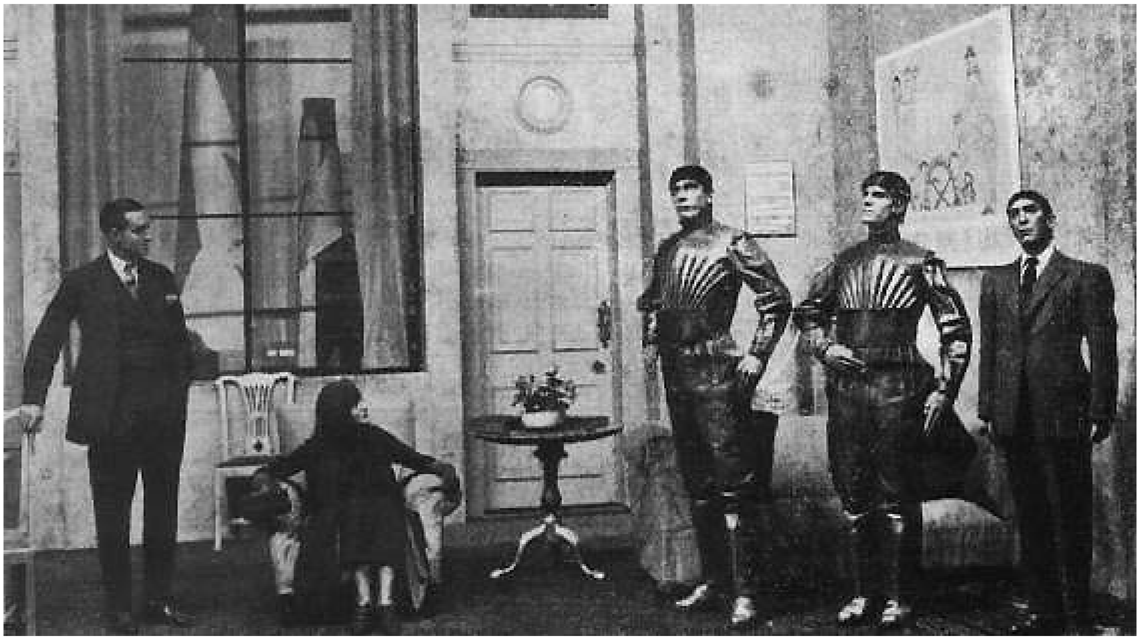
When societies began developing nearly all production and effort was the result of human labour. As mechanical means of performing functions were discovered, and mechanics and complex mechanisms were developed, the need for human labour was reduced. Machinery was initially used for repetitive functions, such as lifting water and grinding grain. With technological advances more complex machines were slowly developed, such as those invented by Hero of Alexandria in the 4th century BC, and the first half of the second millennium AD, such as the Automata of Al Jazari in the 10th century AD. They were not widely adopted as human labour, particularly slave labour, was still inexpensive compared to the capital-intensive machines.

Men such as Leonardo Da Vinci in 1495 through to Jacques de Vaucanson in 1739, as well as rediscovering the Greek engineering methods, have made plans for and built automata and robots leading to books of designs such as the Japanese *Karakuri zui* (*Illustrated Machinery*) in 1796. As mechanical techniques developed through the Industrial age we find more practical applications such as Nikola Tesla in 1898, who designed a radio-controlled torpedo, and the Westinghouse Electric Corporation creation of Televox in 1926. From here we also find a more android development as designers tried to mimic more human-like features including designs such as those of biologist Makoto Nishimura in 1929 and his creation Gakutensoku, which cried and changed its facial expressions, and the more crude Elektro from Westinghouse in 1938.

Electronics then became the driving force of development instead of mechanics, with the advent of the first electronic autonomous robots created by William Grey Walter in Bristol, England, in 1948. The first digital and programmable robot was invented by George Devol in 1954 and was ultimately called the Unimate. Devol sold the first Unimate to General Motors in 1960 where it was used to lift pieces of hot metal from die casting machines in a plant in Trenton, New Jersey. Since then we have seen robots finally reach a more true assimilation of all technologies to produce robots such as ASIMO which can walk and move like a human. Robots have replaced slaves in the assistance of performing those repetitive and dangerous tasks which humans prefer not to do, or are unable to do due to size limitations, or even those such as in outer space or at the bottom of the sea where humans could not survive the extreme environments.

Man has developed an awareness of the problems associated with autonomous robots and how they may act in society. Fear of robot behaviour, such as Shelley's Frankenstein and the EATR, drive current practice in establishing what autonomy a robot should and should not be capable of. Thinking has developed through discussion of robot control and artificial intelligence (AI) and how its application should benefit society, such as those based around Asimov's three laws. Practicality still drives development forwards and robots are used in an increasingly wide variety of tasks such as vacuuming floors, mowing lawns, cleaning drains, investigating other planets, building cars, in entertainment and in warfare.

Etymology



A scene from Karel Čapek's 1920 play R.U.R. (Rossum's Universal Robots), showing three robots

The word *robot* was introduced to the public by the Czech interwar writer Karel Čapek in his play *R.U.R. (Rossum's Universal Robots)*, published in 1920. The play begins in a factory that makes artificial people called *robots*, though they are closer to the modern ideas of androids, creatures who can be mistaken for humans. They can plainly think for themselves, though they seem happy to serve. At issue is whether the *robots* are being exploited and the consequences of their treatment.

Karel Čapek himself did not coin the word. He wrote a short letter in reference to an etymology in the *Oxford English Dictionary* in which he named his brother, the painter and writer Josef Čapek, as its actual originator.

In an article in the Czech journal *Lidové noviny* in 1933, he explained that he had originally wanted to call the creatures *laboři* ("workers", from Latin *labor*). However, he did not like the word, and sought advice from his brother Josef, who suggested "roboti". The word *robota* means literally "work", "labor" or "corvée", "serf labor", and figuratively "drudgery" or "hard work" in Czech and many Slavic languages. Traditionally the *robota* was the work period a serf (corvée) had to give for his lord, typically 6 months of the year. The origin of the word is the Old Church Slavonic *rabota* "servitude" ("work" in contemporary Bulgarian and Russian), which in turn comes from the Indo-European root **orbh-*. Serfdom was outlawed in 1848 in Bohemia, so at the time Čapek wrote *R.U.R.*, usage of the term *robota* had broadened to include various types of work, but the obsolete sense of "serfdom" would still have been known.

The word robotics, used to describe this field of study, was coined by the science fiction writer Isaac Asimov. Asimov and John W. Campbell created the "*Three Laws of Robotics*" which are a recurring theme in his books. These have since been used by many others to define laws used in fact and fiction. Introduced in his 1942 short story "Runaround" the Laws state the following:

> “
> 1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
> 2. A robot must obey any orders given to it by human beings, except where such orders would conflict with the First Law.
> 3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.
>
> ”

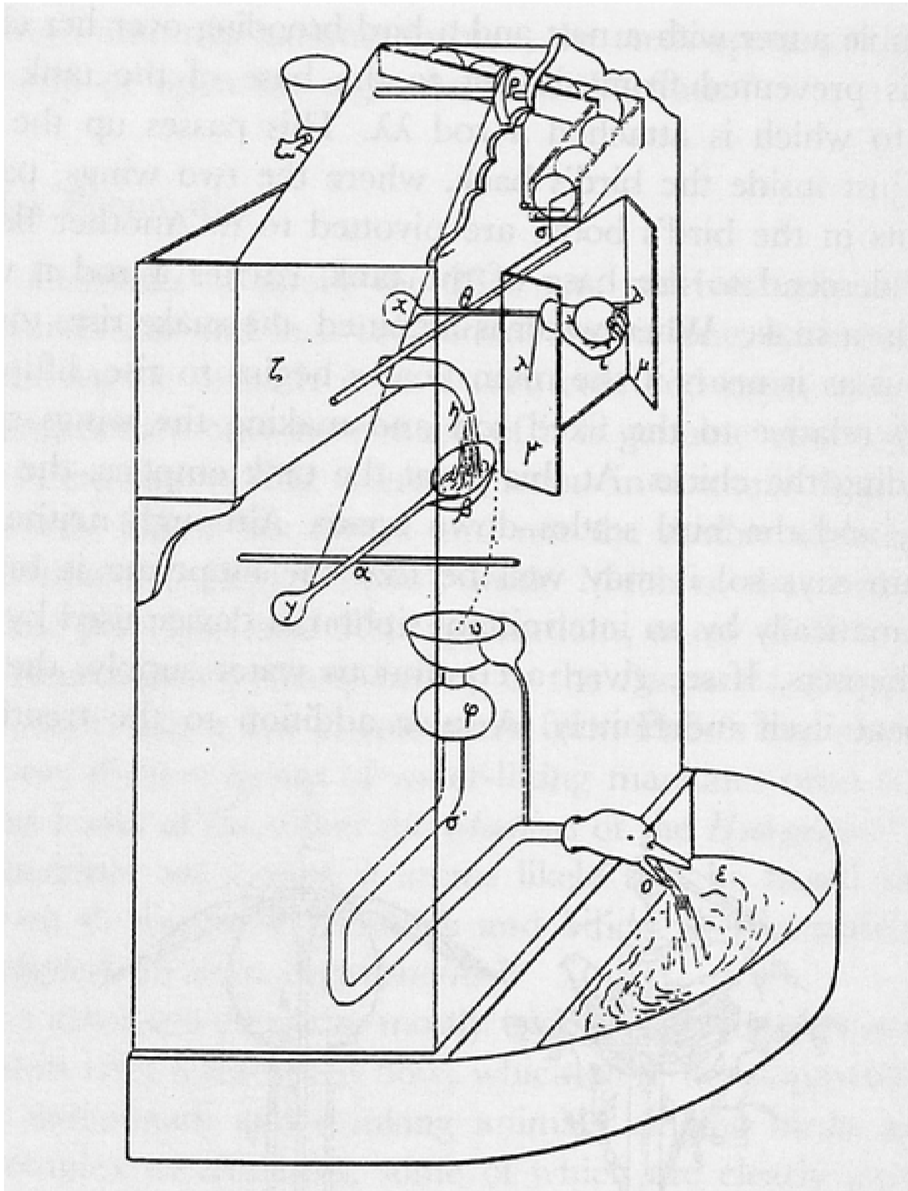
History

Many ancient mythologies include artificial people, such as the mechanical servants built by the Greek god Hephaestus (Vulcan to the Romans), the clay golems of Jewish legend and clay giants of Norse legend, and Galatea, the mythical statue of Pygmalion that came to life. In Greek drama, Deus Ex Machina was contrived as a dramatic device that usually involved lowering a deity by wires into the play to solve a seemingly impossible problem.

According to Mark E. Rosheim, "The beginning of robots may be traced to the great Greek engineer Ctesibius (c. 270 BC). ... Ctesibius applied a knowledge of pneumatics and hydraulics to produce the first organ and water clocks with moving figures." In the 4th century BC, the Greek mathematician Archytas of Tarentum postulated a mechanical steam-operated bird he called "The Pigeon". Hero of Alexandria (10–70 AD), a Greek mathematician and inventor, created numerous user-configurable automated devices, and described machines powered by air pressure, steam and water. Su Song built a clock tower in China in 1088 featuring mechanical figurines that chimed the hours.

In the 3rd century BC text of the Lie Zi, there is a curious account on automata involving a much earlier encounter between King Mu of Zhou (Chinese emperor 10th century BC) and a mechanical engineer known as Yan Shi , an 'artificer'. The latter proudly presented the king with a life-size, human-shaped figure of his mechanical 'handiwork' made of leather, wood, and artificial organs.

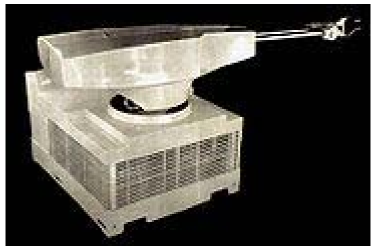
Al-Jazari (1136–1206), a Muslim inventor during the Artuqid dynasty, designed and constructed a number of automated machines, including kitchen appliances, musical automata powered by water, and programmable automata. The robots appeared as four musicians on a boat in a lake, entertaining guests at royal drinking parties. His mechanism had a programmable drum machine with pegs (cams) that bumped into little levers that operated percussion instruments. The drummer could be made to play different rhythms and different drum patterns by moving the pegs to different locations.



Reconstruction of a washstand automaton with escapement mechanism, the earliest known, as described by the Greek engineer Philo of Byzantium (3rd century BC)

Al-Jazari's programmable automata

Tea-serving karakuri, with mechanism, 19th century. Tokyo National Science Museum.



Unimate was the first industrial robot, which worked on a General Motors assembly line in New Jersey, in 1961.

Early modern developments

Leonardo da Vinci (1452–1519) sketched plans for a humanoid robot around 1495. Da Vinci's notebooks, rediscovered in the 1950s, contain detailed drawings of a mechanical knight now known as Leonardo's robot, able to sit up, wave its arms and move its head and jaw. The design was probably based on anatomical research recorded in his *Vitruvian Man*. It is not known whether he attempted to build it. In 1738 and 1739, Jacques de Vaucanson exhibited several life-sized automatons: a flute player, a pipe player and a duck. The mechanical duck could flap its wings, crane its neck, and swallow food from the exhibitor's hand, and it gave the illusion of digesting its food by excreting matter stored in a hidden compartment. Complex mechanical toys and animals built in Japan in the 18th century were described in the *Karakuri zui* (*Illustrated Machinery*, 1796)

Modern developments

The Japanese craftsman Hisashige Tanaka (1799–1881), known as "Japan's Edison" or "Karakuri Giemon", created an array of extremely complex mechanical toys, some of which served tea, fired arrows drawn from a quiver, and even painted a Japanese *kanji* character. In 1898 Nikola Tesla publicly demonstrated a radio-controlled torpedo. Based on patents for "teleautomation", Tesla hoped to develop it into a weapon system for the US Navy.

In 1926, Westinghouse Electric Corporation created Televox, the first robot put to useful work. They followed Televox with a number of other simple robots, including one called Rastus, made in the crude image of a black man. In the 1930s, they created a humanoid robot known as Elektro for exhibition purposes, including the 1939 and 1940 World's Fairs. In 1928, Japan's first robot, Gakutensoku, was designed and constructed by biologist Makoto Nishimura.

The first electronic autonomous robots were created by William Grey Walter of the Burden Neurological Institute at Bristol, England in 1948 and 1949. They were named *Elmer* and *Elsie*. These robots could sense light and contact with external objects, and use these stimuli to navigate.

The first truly modern robot, digitally operated and programmable, was invented by George Devol in 1954 and was ultimately called the Unimate. Devol sold the first

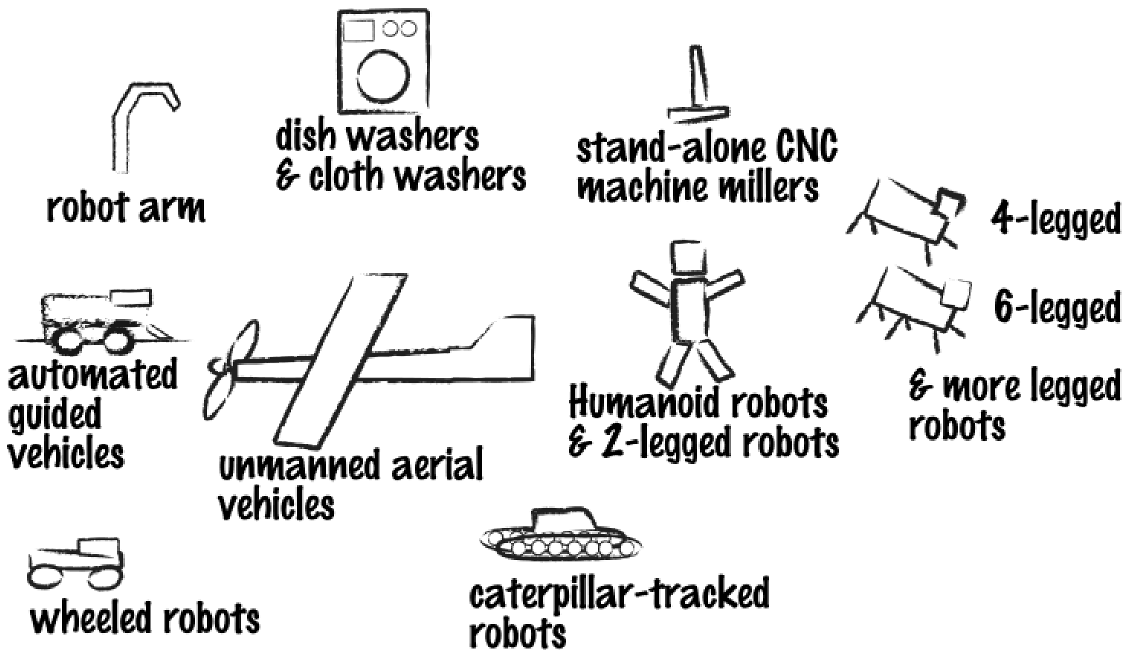
Unimate to General Motors in 1960, and it was installed in 1961 in a plant in Trenton, New Jersey to lift hot pieces of metal from a die casting machine and stack them. Devol's patent for the first digitally operated programmable robotic arm represents the foundation of the modern robotics industry.

Commercial and industrial robots are now in widespread use performing jobs more cheaply or with greater accuracy and reliability than humans. They are also employed for jobs which are too dirty, dangerous or dull to be suitable for humans. Robots are widely used in manufacturing, assembly and packing, transport, earth and space exploration, surgery, weaponry, laboratory research, and mass production of consumer and industrial goods.

Definitions

The word *robot* can refer to both physical robots and virtual software agents, but the latter are usually referred to as bots. There is no consensus on which machines qualify as robots but there is general agreement among experts, and the public, that robots tend to do some or all of the following: move around, operate a mechanical limb, sense and manipulate their environment, and exhibit intelligent behavior — especially behavior which mimics humans or other animals.

There is no one definition of robot which satisfies everyone and many people have their own. For example Joseph Engelberger, a pioneer in industrial robotics, once remarked: "I can't define a robot, but I know one when I see one." According to the Encyclopaedia Britannica a robot is "any automatically operated machine that replaces human effort, though it may not resemble human beings in appearance or perform functions in a humanlike manner". Merriam-Webster describes a robot as a "machine that looks like a human being and performs various complex acts (as walking or talking) of a human being", or a "device that automatically performs complicated often repetitive tasks", or a "mechanism guided by automatic controls".



The various types of robots

KITT (a fictitious robot) is mentally anthropomorphic

ASIMO is physically anthropomorphic

Defining characteristics

While there is no single correct definition of "robot," a typical robot will have several, or possibly all, of the following characteristics.

It is an electric machine which has some ability to interact with physical objects and to be given electronic programming to do a specific task or to do a whole range of tasks or actions. It may also have some ability to perceive and absorb data on physical objects, or on its local physical environment, or to process data, or to respond to various stimuli. This is in contrast to a simple mechanical device such as a gear or a hydraulic press or any other item which has no processing ability and which does tasks through purely mechanical processes and motion.

Mental agency

For robotic engineers, the physical appearance of a machine is less important than the way its actions are controlled. The more the control system seems to have agency of its own, the more likely the machine is to be called a robot. An important feature of agency is the ability to make choices. Higher-level cognitive functions, though, are not necessary, as shown by ant robots.

- A clockwork car is never considered a robot.

- A mechanical device able to perform some preset motions but with no ability to adapt (an automaton) is rarely considered a robot.
- A remotely-operated vehicle is sometimes considered a robot (or telerobot).
- A car with an onboard computer, like Bigtrak, which could drive in a programmable sequence, might be called a robot.
- A self-controlled car which could sense its environment and make driving decisions based on this information, such as the 1990s driverless cars of Ernst Dickmanns or the entries in the DARPA Grand Challenge, would quite likely be called a robot.
- A sentient car, like the fictional KITT, which can make decisions, navigate freely and converse fluently with a human, is usually considered a robot.

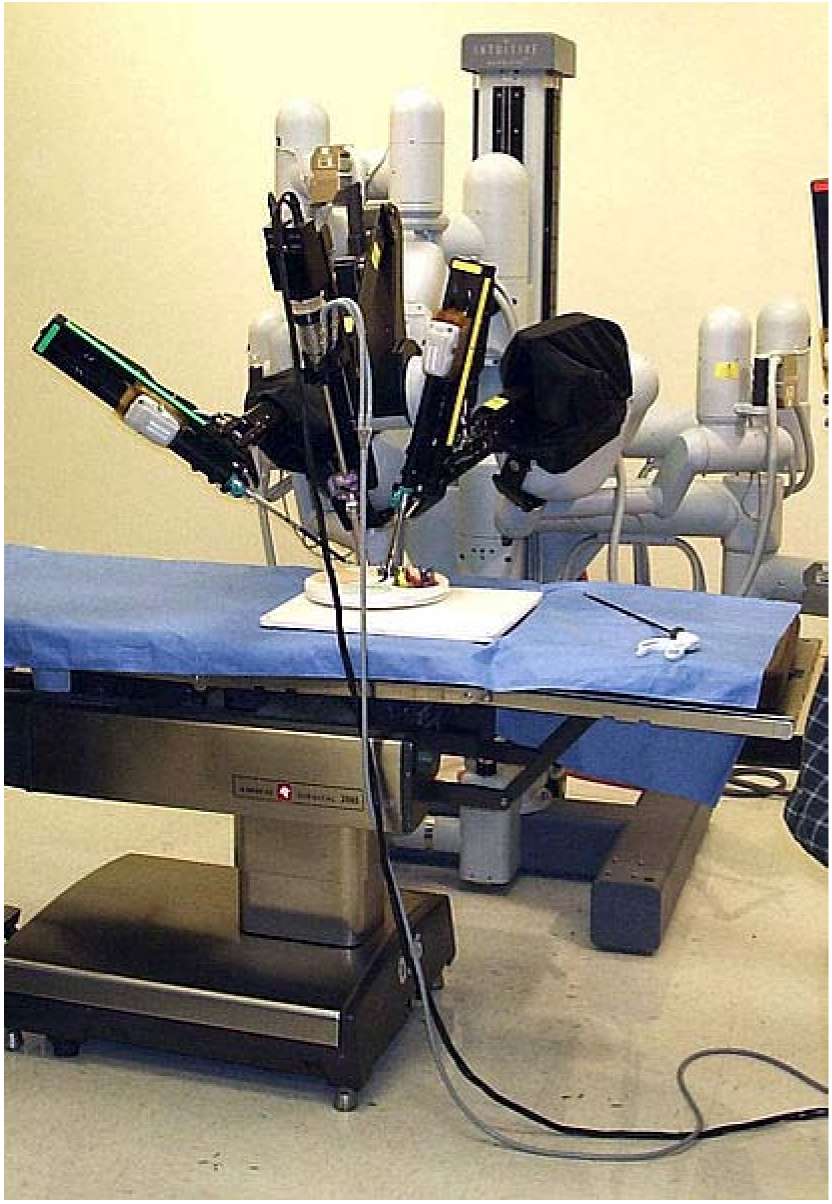
Physical agency

However, for many laymen, if a machine appears to be able to control its arms or limbs, and especially if it appears anthropomorphic or zoomorphic (e.g. ASIMO or Aibo), it would be called a robot.

- A player piano is rarely characterized as a robot.
- A CNC milling machine is very occasionally characterized as a robot.
- A factory automation arm is almost always characterized as an industrial robot.
- An autonomous wheeled or tracked device, such as a self-guided rover or self-guided vehicle, is almost always characterized as a mobile robot or service robot.
- A zoomorphic mechanical toy, like Roboraptor, is usually characterized as a robot.
- A mechanical humanoid, like ASIMO, is almost always characterized as a robot, usually as a service robot.

Even for a 3-axis CNC milling machine using the same control system as a robot arm, it is the arm which is almost always called a robot, while the CNC machine is usually just a machine. Having eyes can also make a difference in whether a machine is called a robot, since humans instinctively connect eyes with sentience. However, simply being anthropomorphic is not a sufficient criterion for something to be called a robot. A robot must do something; an inanimate object shaped like ASIMO would not be considered a robot.

Modern robots



A laparoscopic robotic surgery machine

Mobile robot

Mobile robots have the capability to move around in their environment and are not fixed to one physical location. An example of a mobile robot that is in common use today is the *automated guided vehicle* or *automatic guided vehicle* (AGV). An AGV is a mobile robot that follows markers or wires in the floor, or uses vision or lasers.

Mobile robots are also found in industry, military and security environments. They also appear as consumer products, for entertainment or to perform certain tasks like vacuum cleaning. Mobile robots are the focus of a great deal of current research and almost every major university has one or more labs that focus on mobile robot research.

Modern robots are usually used in tightly controlled environments such as on assembly lines because they have difficulty responding to unexpected interference. Because of this most humans rarely encounter robots. However domestic robots for cleaning and maintenance are increasingly common in and around homes in developed countries. Robots can also be found in military applications.

Industrial robots (manipulating)

Industrial robots usually consist of a jointed arm (multi-linked manipulator) and end effector that is attached to a fixed surface. One of the most common type of end effector is a gripper assembly.

The International Organization for Standardization gives a definition of a manipulating industrial robot in ISO 8373:

"an automatically controlled, reprogrammable, multipurpose, manipulator programmable in three or more axes, which may be either fixed in place or mobile for use in industrial automation applications."

This definition is used by the International Federation of Robotics, the European Robotics Research Network (EURON) and many national standards committees.

A Pick and Place robot in a factory

Service robot

Most commonly industrial robots are fixed robotic arms and manipulators used primarily for production and distribution of goods. The term "service robot" is less well-defined. IFR has proposed a tentative definition, "A service robot is a robot which operates semi- or fully- autonomously to perform services useful to the well-being of humans and equipment, excluding manufacturing operations."

In South Africa *robot* is an informal and commonly used term for a set of traffic lights.

Social impact

Roughly half of all the robots in the world are in Asia, 32% in Europe, and 16% in North America, 1% in Australasia and 1% in Africa. 30% of all the robots in the world are in Japan, making Japan the country with the highest number of robots.

Regional perspectives

In Japan and South Korea, ideas of future robots have been mainly positive, and the start of the pro-robotic society there is thought to be possibly due to the famous 'Astro Boy'. Asian societies such as Japan, South Korea, and more recently, China, believe robots to be more equal to humans, having them care for old people, play with or teach children, or replace pets etc. The general view in Asian cultures is that the more robots advance, the better.

"This is the opening of an era in which human beings and robots can co-exist," says Japanese firm Mitsubishi about one of the many humanistic robots in Japan. South Korea aims to put a robot in every house there by 2015-2020 in order to help catch up technologically with Japan.

Western societies are more likely to be against, or even fear the development of robotics, through much media output in movies and literature that they will replace humans. Some believe that the West regards robots as a 'threat' to the future of humans, partly due to religious beliefs about the role of humans and society. Obviously, these boundaries are not clear, but there is a significant difference between the two cultural viewpoints.

Autonomy and ethical questions

As robots have become more advanced and sophisticated, experts and academics have increasingly explored the questions of what ethics might govern robots' behavior, and whether robots might be able to claim any kind of social, cultural, ethical or legal rights. One scientific team has said that it is possible that a robot brain will exist by 2019. Others predict robot intelligence breakthroughs by 2050. Recent advances have made robotic behavior more sophisticated.

Vernor Vinge has suggested that a moment may come when computers and robots are smarter than humans. He calls this "the Singularity". He suggests that it may be somewhat or possibly very dangerous for humans. This is discussed by a philosophy called Singularitarianism.

In 2009, experts attended a conference hosted by the Association for the Advancement of Artificial Intelligence (AAAI) to discuss whether computers and robots might be able to acquire any autonomy, and how much these abilities might pose a threat or hazard. They noted that some robots have acquired various forms of semi-autonomy, including being able to find power sources on their own and being able to independently choose targets to attack with weapons. They also noted that some computer viruses can evade elimination and have achieved "cockroach intelligence." They noted that self-awareness as depicted in science-fiction is probably unlikely, but that there were other potential hazards and pitfalls. Various media sources and scientific groups have noted separate trends in differing areas which might together result in greater robotic functionalities and autonomy, and which pose some inherent concerns.

Military robots

Some experts and academics have questioned the use of robots for military combat, especially when such robots are given some degree of autonomous functions. There are also concerns about technology which might allow some armed robots to be controlled mainly by other robots. The US Navy has funded a report which indicates that as military robots become more complex, there should be greater attention to implications of their ability to make autonomous decisions. One researcher states that autonomous robots might be more humane, as they could make decisions more effectively. However, other experts question this.

Some public concerns about autonomous robots have received media attention. One robot in particular, the EATR, has generated concerns over its fuel source as it can continually refuel itself using organic substances. Although the engine for the EATR is designed to run on biomass and vegetation specifically selected by its sensors which can find on battlefields or other local environments the project has stated that chicken fat can also be used.

Contemporary uses

At present there are 2 main types of robots, based on their use: general-purpose autonomous robots and dedicated robots.

Robots can be classified by their specificity of purpose. A robot might be designed to perform one particular task extremely well, or a range of tasks less well. Of course, all robots by their nature can be re-programmed to behave differently, but some are limited by their physical form. For example, a factory robot arm can perform jobs such as cutting, welding, gluing, or acting as a fairground ride, while a pick-and-place robot can only populate printed circuit boards.

General-purpose autonomous robots

General-purpose autonomous robots can perform a variety of functions independently. General-purpose autonomous robots typically can navigate independently in known spaces, handle their own re-charging needs, interface with electronic doors and elevators and perform other basic tasks. Like computers, general-purpose robots can link with networks, software and accessories that increase their usefulness. They may recognize people or objects, talk, provide companionship, monitor environmental quality, respond to alarms, pick up supplies and perform other useful tasks. General-purpose robots may perform a variety of functions simultaneously or they may take on different roles at different times of day. Some such robots try to mimic human beings and may even resemble people in appearance; this type of robot is called a humanoid robot.

A general-purpose robot acts as a guide during the day and a security guard at night

Factory robots

Car production

Over the last three decades automobile factories have become dominated by robots. A typical factory contains hundreds of industrial robots working on fully automated production lines, with one robot for every ten human workers. On an automated production line, a vehicle chassis on a conveyor is welded, glued, painted and finally assembled at a sequence of robot stations.

An intelligent AGV drops-off goods without needing lines or beacons in the workspace

Packaging

Industrial robots are also used extensively for palletizing and packaging of manufactured goods, for example for rapidly taking drink cartons from the end of a conveyor belt and placing them into boxes, or for loading and unloading machining centers.

Electronics

Mass-produced printed circuit boards (PCBs) are almost exclusively manufactured by pick-and-place robots, typically with SCARA manipulators, which remove tiny electronic components from strips or trays, and place them on to PCBs with great accuracy. Such robots can place hundreds of thousands of components per hour, far out-performing a human in speed, accuracy, and reliability.

Automated guided vehicles (AGVs)

Mobile robots, following markers or wires in the floor, or using vision or lasers, are used to transport goods around large facilities, such as warehouses, container ports, or hospitals.

> Early AGV-Style Robots
> Limited to tasks that could be accurately defined and had to be performed the same way every time. Very little feedback or intelligence was required, and the robots needed only the most basic exteroceptors (sensors). The limitations of these AGVs are that their paths are not easily altered and they cannot alter their paths if obstacles block them. If one AGV breaks down, it may stop the entire operation.
> Interim AGV-Technologies
> Developed to deploy triangulation from beacons or bar code grids for scanning on the floor or ceiling. In most factories, triangulation systems tend to require moderate to high maintenance, such as daily cleaning of all beacons or bar codes.

Also, if a tall pallet or large vehicle blocks beacons or a bar code is marred, AGVs may become lost. Often such AGVs are designed to be used in human-free environments.

Intelligent AGVs (i-AGVs)

A U.S. Marine Corps technician prepares to use a telerobot to detonate a buried improvised explosive device near Camp Fallujah, Iraq

Such as SpeciMinder, ADAM, Tug and MT 400 with Motivity are designed for people-friendly workspaces. They navigate by recognizing natural features. 3D scanners or other means of sensing the environment in two or three dimensions help to eliminate cumulative errors in dead-reckoning calculations of the AGV's current position. Some AGVs can create maps of their environment using scanning lasers with simultaneous localization and mapping (SLAM) and use those maps to navigate in real time with other path planning and obstacle avoidance algorithms. They are able to operate in complex environments and perform non-repetitive and non-sequential tasks such as transporting photomasks in a semiconductor lab, specimens in hospitals and goods in warehouses. For dynamic areas, such as warehouses full of pallets, AGVs require additional strategies using three-dimensional sensors such as time-of-flight or stereovision cameras.

Dirty, dangerous, dull or inaccessible tasks

There are many jobs which humans would rather leave to robots. The job may be boring, such as domestic cleaning, or dangerous, such as exploring inside a volcano. Other jobs are physically inaccessible, such as exploring another planet, cleaning the inside of a long pipe, or performing laparoscopic surgery.

Space probes

Almost every unmanned space probe ever launched was a robot. Some were launched in the 1960s with more limited abilities, but their ability to fly and to land (in the case of Luna 9) is an indication of their status as a robot. This includes the Voyager probes and the Galileo probes, as well as other probes.

Telerobots

When a human cannot be present on site to perform a job because it is dangerous, far away, or inaccessible, teleoperated robots, or telerobots are used. Rather than following a predetermined sequence of movements, a telerobot is controlled from a distance by a human operator. The robot may be in another room or another country, or may be on a very different scale to the operator. For instance, a laparoscopic surgery robot allows the surgeon to work inside a human patient on a relatively small scale compared to open surgery, significantly shortening recovery time. When disabling a bomb, the operator sends a small robot to disable it. Several authors have been using a device called the Longpen to sign books remotely. Teleoperated robot aircraft, like the Predator Unmanned Aerial Vehicle, are increasingly being used by the military. These pilotless drones can search terrain and fire on targets. Hundreds of robots such as iRobot's Packbot and the Foster-Miller TALON are being used in Iraq and Afghanistan by the U.S. military to defuse roadside bombs or Improvised Explosive Devices (IEDs) in an activity known as explosive ordnance disposal (EOD).

Automated fruit harvesting machines

The Roomba domestic vacuum cleaner robot does a single, menial job

Used to pick fruit on orchards at a cost lower than that of human pickers.

In the home

As prices fall and robots become smarter and more autonomous, simple robots dedicated to a single task work in over a million homes. They are taking on simple but unwanted jobs, such as vacuum cleaning and floor washing, and lawn mowing. Some find these robots to be cute and entertaining, which is one reason that they can sell very well.

Duct cleaning

The ANATROLLER ARI-100 is a modular mobile robot used for cleaning hazardous environments

In the hazardous and tight spaces of a building's duct work, many hours can be spent cleaning relatively small areas if a manual brush is used. Robots have been used by many duct cleaners primarily in the industrial and institutional cleaning markets, as they allow the job to be done faster, without exposing workers to the harmful enzymes released by dust mites. For cleaning high-security institutions such as embassies and prisons, duct cleaning robots are vital, as they allow the job to be completed without compromising the security of the institution. Hospitals and other government buildings with hazardous and cancerogenic environments such as nuclear reactors legally must be cleaned using duct cleaning robots, in countries such as Canada, in an effort to improve workplace safety in duct cleaning.

Military robots

Military robots include the SWORDS robot which is currently used in ground-based combat. It can use a variety of weapons and there is some discussion of giving it some degree of autonomy in battleground situations.

Unmanned combat air vehicles (UCAVs), which are an upgraded form of UAVs, can do a wide variety of missions, including combat. UCAVs are being designed such as the Mantis UCAV which would have the ability to fly themselves, to pick their own course and target, and to make most decisions on their own. The BAE Taranis is a UCAV built by Great Britain which can fly across continents without a pilot and has new means to avoid detection. Flight trials are expected to begin in 2011.

The AAAI has studied this topic in depth and its president has commissioned a study to look at this issue.

Some have suggested a need to build "Friendly AI", meaning that the advances which are already occurring with AI should also include an effort to make AI intrinsically friendly and humane. Several such measures reportedly already exist, with robot-heavy countries such as Japan and South Korea having begun to pass regulations requiring robots to be equipped with safety systems, and possibly sets of 'laws' akin to Asimov's Three Laws of Robotics. An official report was issued in 2009 by the Japanese government's Robot Industry Policy Committee. Chinese officials and researchers have issued a report suggesting a set of ethical rules, as well as a set of new legal guidelines referred to as "Robot Legal Studies." Some concern has been expressed over a possible occurrence of robots telling apparent falsehoods.

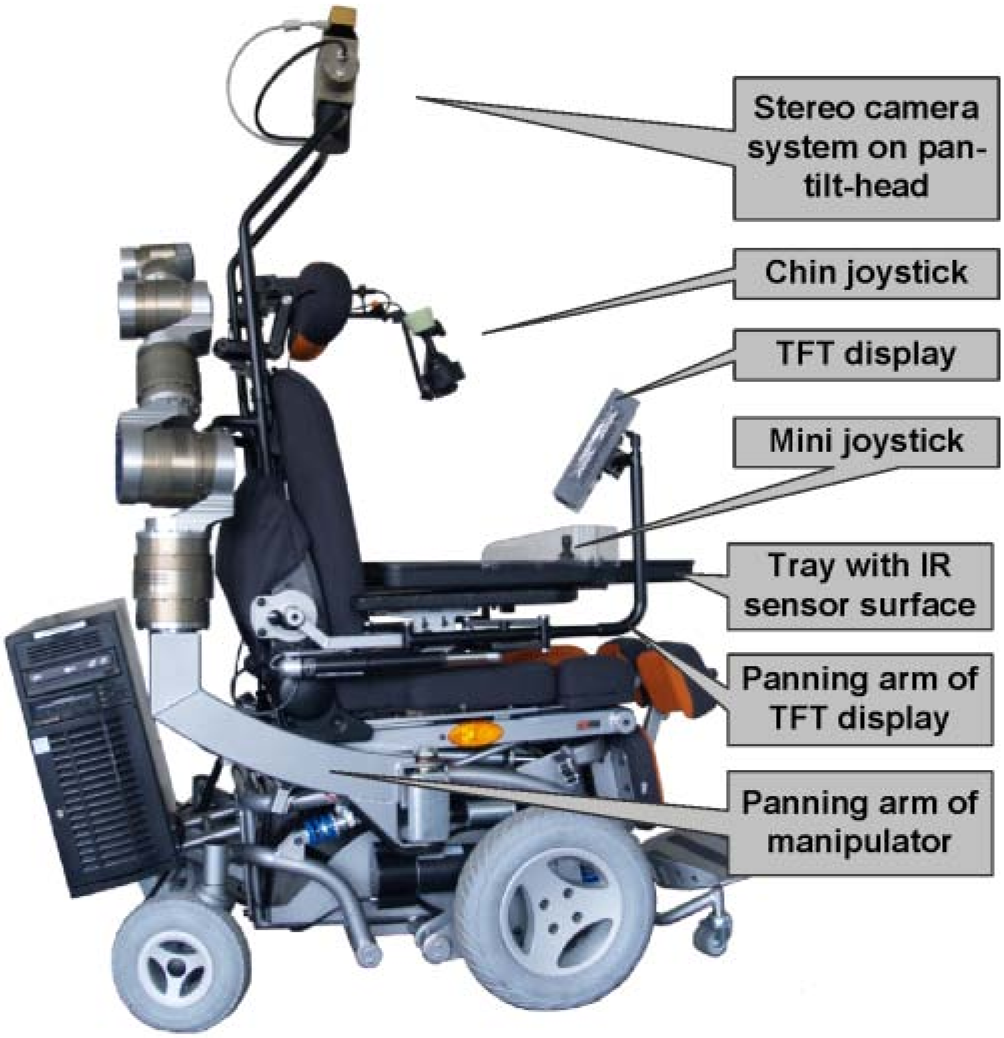
Schools

Robotics have also been introduced into the lives of elementary and high school students with the company FIRST (For Inspiration and Recognition of Science and Technology). The organization is the foundation for the FIRST Robotics Competition, FIRST LEGO League, Junior FIRST LEGO League, and FIRST Tech Challenge competitions.

Healthcare

Robots in healthcare have two main functions. Those which assist an individual, such as a sufferer of a disease like Multiple Sclerosis, and those which aid in the overall systems such as pharmacies and hospitals.

Home automation for the elderly and disabled



The Care-Providing robot FRIEND. (Photo: IAT)

Robots have developed over time from simple basic robotic assistants, such as the Handy 1, through to semi-autonomous robots, such as FRIEND which can assist the elderly and disabled with common tasks.

The population is aging in many countries, especially Japan, meaning that there are increasing numbers of elderly people to care for, but relatively fewer young people to care for them. Humans make the best carers, but where they are unavailable, robots are gradually being introduced.

FRIEND is a semi-autonomous robot designed to support disabled and elderly people in their daily life activities, like preparing and serving a meal. FRIEND make it possible for patients who are paraplegic, have muscle diseases or serious paralysis (due to strokes etc.), to perform tasks without help from other people like therapists or nursing staff.

Pharmacies

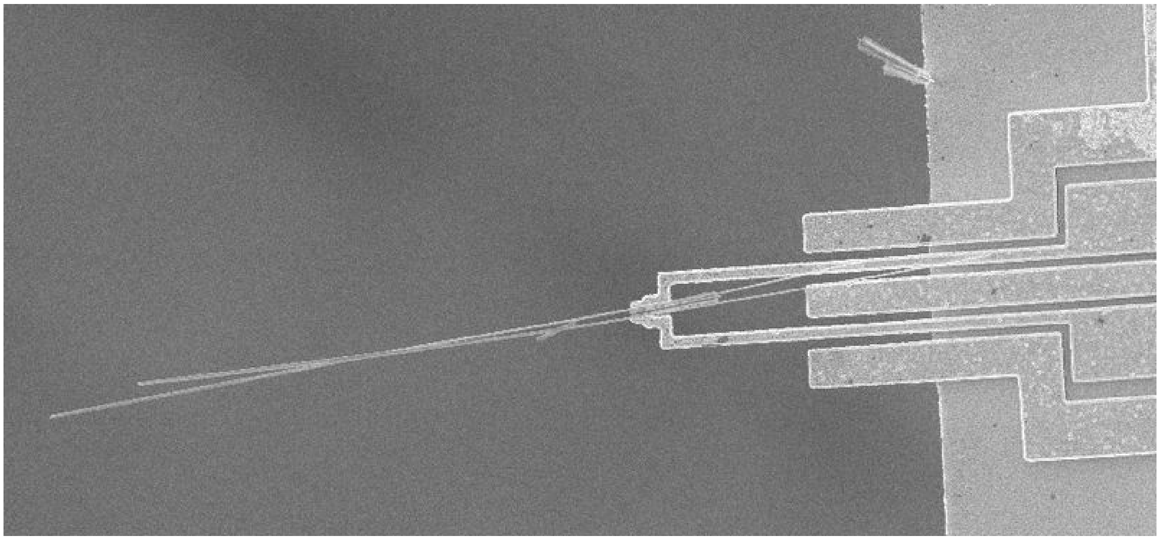
Script Pro manufactures a robot designed to help pharmacies fill prescriptions that consist of oral solids or medications in pill form. The pharmacist or pharmacy technician enters the prescription information into its information system. The system, upon determining whether or not the drug is in the robot, will send the information to the robot for filling. The robot has 3 different size vials to fill determined by the size of the pill. The robot technician, user, or pharmacist determines the needed size of the vial based on the tablet when the robot is stocked. Once the vial is filled it is brought up to a conveyor belt that delivers it to a holder that spins the vial and attaches the patient label. Afterwards it is set on another conveyor that delivers the patient's medication vial to a slot labeled with the patient's name on an LED read out. The pharmacist or technician then checks the contents of the vial to ensure it's the correct drug for the correct patient and then seals the vials and sends it out front to be picked up. The robot is a very time efficient device that the pharmacy depends on to fill prescriptions.

McKesson's Robot RX is another healthcare robotics product that helps pharmacies dispense thousands of medications daily with little or no errors. The robot can be ten feet wide and thirty feet long and can hold hundreds of different kinds of medications and thousands of doses. The pharmacy saves many resources like staff members that are otherwise unavailable in a resource scarce industry. It uses an electromechanical head coupled with a pneumatic system to capture each dose and deliver it to its either stocked or dispensed location. The head moves along a single axis while it rotates 180 degrees to pull the medications. During this process it uses barcode technology to verify its pulling the correct drug. It then delivers the drug to a patient specific bin on a conveyor belt. Once the bin is filled with all of the drugs that a particular patient needs and that the robot stocks, the bin is then released and returned out on the conveyor belt to a technician waiting to load it into a cart for delivery to the floor.

Research robots

While most robots today are installed in factories or homes, performing labour or life saving jobs, many new types of robot are being developed in laboratories around the world. Much of the research in robotics focuses not on specific industrial tasks, but on investigations into new types of robot, alternative ways to think about or design robots, and new ways to manufacture them. It is expected that these new types of robot will be able to solve real world problems when they are finally realized.

Nanorobots



A microfabricated electrostatic gripper holding some silicon nanowires.

Nanorobotics is the still largely hypothetical technology of creating machines or robots at or close to the scale of a nanometer (10^{-9} meters). Also known as "nanobots" or "nanites", they would be constructed from molecular machines. So far, researchers have mostly produced only parts of these complex systems, such as bearings, sensors, and Synthetic molecular motors, but functioning robots have also been made such as the entrants to the Nanobot Robocup contest. Researchers also hope to be able to create entire robots as small as viruses or bacteria, which could perform tasks on a tiny scale. Possible applications include micro surgery (on the level of individual cells), utility fog, manufacturing, weaponry and cleaning. Some people have suggested that if there were nanobots which could reproduce, the earth would turn into "grey goo", while others argue that this hypothetical outcome is nonsense.

Reconfigurable Robots

A few researchers have investigated the possibility of creating robots which can alter their physical form to suit a particular task, like the fictional T-1000. Real robots are nowhere near that sophisticated however, and mostly consist of a small number of cube shaped units, which can move relative to their neighbours. Algorithms have been designed in case any such robots become a reality.

Soft Robots

Robots with silicone bodies and flexible actuators (air muscles, electroactive polymers, and ferrofluids), controlled using fuzzy logic and neural networks, look and feel different from robots with rigid skeletons, and are capable of different behaviors.

Swarm robots

A swarm of robots from the Open-source Micro-robotic Project

Inspired by colonies of insects such as ants and bees, researchers are modeling the behavior of swarms of thousands of tiny robots which together perform a useful task, such as finding something hidden, cleaning, or spying. Each robot is quite simple, but the emergent behavior of the swarm is more complex. The whole set of robots can be considered as one single distributed system, in the same way an ant colony can be considered a superorganism, exhibiting swarm intelligence. The largest swarms so far created include the iRobot swarm, the SRI/MobileRobots CentiBots project and the Open-source Micro-robotic Project swarm, which are being used to research collective behaviors. Swarms are also more resistant to failure. Whereas one large robot may fail and ruin a mission, a swarm can continue even if several robots fail. This could make them attractive for space exploration missions, where failure is normally extremely costly.

Haptic interface robots

Robotics also has application in the design of virtual reality interfaces. Specialized robots are in widespread use in the haptic research community. These robots, called "haptic interfaces," allow touch-enabled user interaction with real and virtual environments.

Robotic forces allow simulating the mechanical properties of "virtual" objects, which users can experience through their sense of touch.

Future development

Technological trends

Various techniques have emerged to develop the science of robotics and robots. One method is Evolutionary robotics, in which a number of differing robots are submitted to tests. Those which perform best are used as a model to create a subsequent "generation" of robots. Another method is Developmental robotics, which tracks changes and development within a single in the areas of problem-solving and other functions.

Technological development

Overall trends

Japan hopes to have full-scale commercialization of service robots by 2025. Much technological research in Japan is led by Japanese government agencies, particularly the Trade Ministry.

As robots become more advanced, eventually there may be a standard computer operating system designed mainly for robots. Robot Operating System is an open-source set of programs being developed at Stanford University, the Massachusetts Institute of Technology and the Technical University of Munich, Germany, among others. ROS provides ways to program a robot's navigation and limbs regardless of the specific hardware involved. It also provides high-level commands for items like image recognition and even opening doors. When ROS boots up on a robot's computer, it would obtain data on attributes such as the length and movement of robots' limbs. It would relay this data to higher-level algorithms. Microsoft is also developing a "Windows for robots" system with its Robotics Developer Studio, which has been available since 2007.

New functions and abilities

The Caterpillar Company is making a dump truck which can drive itself without any human operator.

Many future applications of robotics seem obvious to people, even though they are well beyond the capabilities of robots available at the time of the prediction. As early as 1982 people were confident that someday robots would: 1. clean parts by removing molding flash 2. spray paint automobiles with absolutely no human presence 3. pack things in boxes—for example, orient and nest chocolate candies in candy boxes 4. make electrical cable harness 5. load trucks with boxes—a packing problem 6. handle soft goods, such as garments and shoes 7. shear sheep 8. prosthesis 9. cook fast food and work in other service industries 10. household robot.

Generally such predictions are overly optimistic in timescale.

Reading robot

A reading robot or 'robot literacy' calls Marge has intelligence comes from software. She can read newspapers, find and correct misspelled words and learn about bank like Barclays and the restaurants like Strada are good place to eat.

Timeline

Date	Significance	Robot name	Inventor
1st century AD and earlier	Descriptions of over a hundred machines and automata, including a fire engine, wind organ, coin-operated machine, and steam-powered aeliopile, in *Pneumatica* and *Automata* by Heron		Ctesibius, Philo, Heron, and others
1206	Early programmable automata	Robot band	Al-Jazari
c. 1495	Designs for a humanoid robot	Mechanical knight	Leonardo da Vinci
1738	Mechanical duck that was able to eat, flap its wings, and excrete	Digesting Duck	Jacques de Vaucanson
19th century	Japanese mechanical toys that served tea, fired arrows, and painted	*Karakuri* toys	Hisashige Tanaka
1921	First fictional automata called "robots" appear in the play *R.U.R.*	Rossum's Universal Robots	Karel Čapek
1928	Humanoid robot, based on a suit of armor with electrical actuators, exhibited at the annual exhibition of the Model Engineers Society in London	Eric	W. H. Richards
1930s	Humanoid robot exhibited at the 1939 and 1940 World's Fairs	Elektro	Westinghouse Electric Corporation
1948	Simple robots exhibiting biological behaviors	Elsie and Elmer	William Grey Walter
1956	First commercial robot, from the Unimation company founded by George Devol and Joseph Engelberger, based on Devol's patents	Unimate	George Devol
1961	First installed industrial robot	Unimate	George Devol
1963	First palletizing robot	Palletizer	Fuji Yusoki Kogyo
1973	First robot with six electromechanically driven axes	Famulus	KUKA Robot Group

1975	Programmable universal manipulation arm, a Unimation product	PUMA	Victor Scheinman