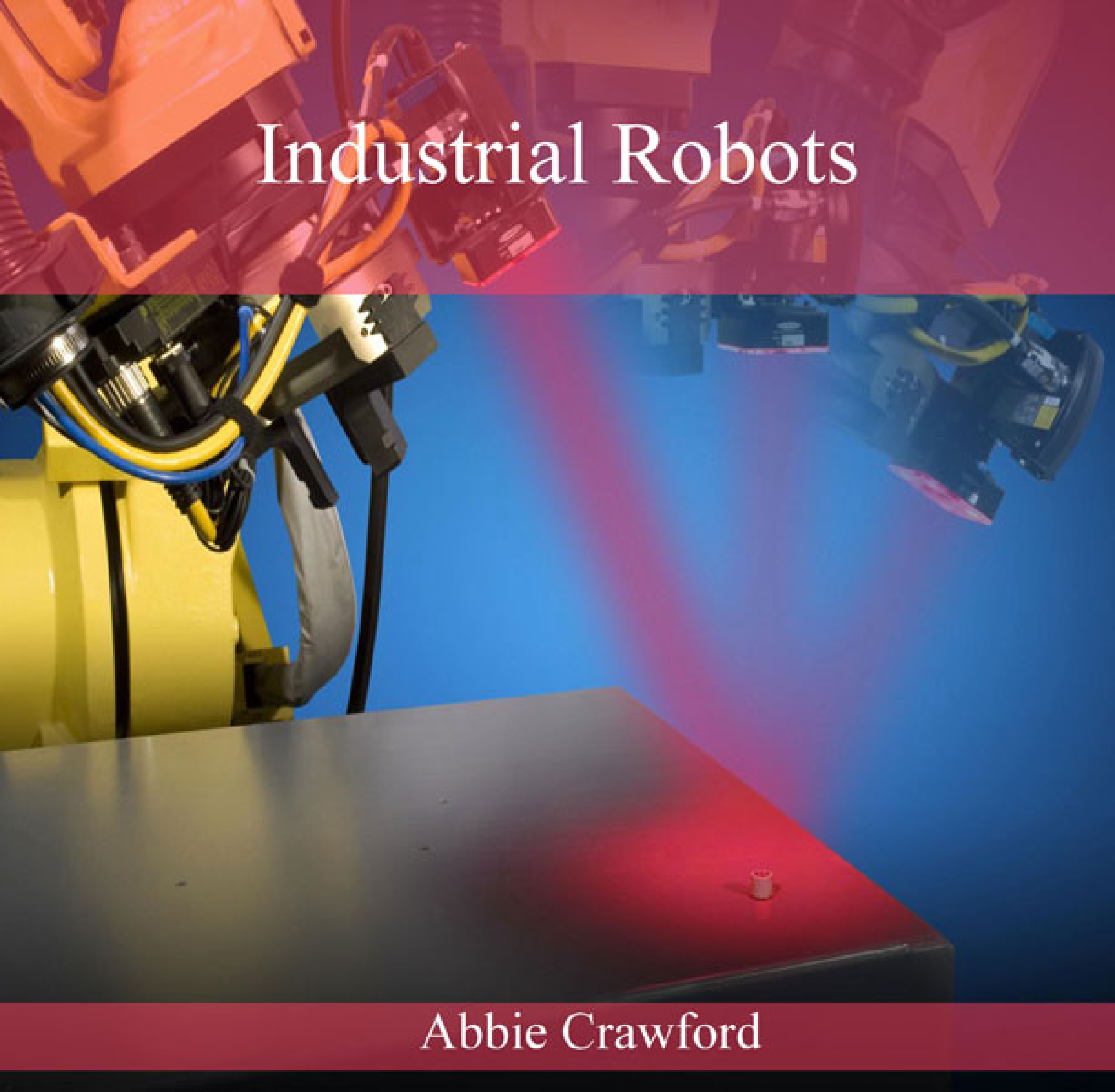
Industrial Robots



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Industrial Robots

Articulated industrial robot operating in a foundry.

A set of six-axis robots used for welding.

An **industrial robot** is officially defined by ISO as an *automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes*. The field of **robotics** may be more practically defined as the study, design and use of robot systems for manufacturing (a top-level definition relying on the prior definition of *robot*).

Typical applications of robots include welding, painting, assembly, pick and place, packaging and palletizing, product inspection, and testing, all accomplished with high endurance, speed, and precision.

Robot types, features

The most commonly used robot configurations are articulated robots, SCARA robots and Cartesian coordinate robots, (aka gantry robots or x-y-z robots). In the context of general robotics, most types of robots would fall into the category of robotic arms (inherent in the use of the word *manipulator* in the above-mentioned ISO standard). Robots exhibit varying degrees of autonomy:

Loading Tooling machine

- Some robots are programmed to faithfully carry out specific actions over and over again (repetitive actions) without variation and with a high degree of accuracy. These actions are determined by programmed routines that specify the direction, acceleration, velocity, deceleration, and distance of a series of coordinated motions.

Robots palletizing food (Bakery)

- Other robots are much more flexible as to the orientation of the object on which they are operating or even the task that has to be performed on the object itself, which the robot may even need to identify. For example, for more precise guidance, robots often contain machine vision sub-systems acting as their "eyes", linked to powerful computers or controllers. Artificial intelligence, or what passes for it, is becoming an increasingly important factor in the modern industrial robot.

History of industrial robotics

George Devol, c. 1982

George Devol applied for the first robotics patents in 1954 (granted in 1961). The first company to produce a robot was Unimation, founded by Devol and Joseph F. Engelberger in 1956, and was based on Devol's original patents. Unimation robots were also called *programmable transfer machines* since their main use at first was to transfer objects from one point to another, less than a dozen feet or so apart. They used hydraulic actuators and were programmed in *joint coordinates*, i.e. the angles of the various joints were stored during a teaching phase and replayed in operation. They were accurate to within 1/10,000 of an inch. Unimation later licensed their technology to Kawasaki Heavy Industries and Guest-Nettlefolds, manufacturing Unimates in Japan and England respectively. For some time Unimation's only competitor was Cincinnati Milacron Inc. of Ohio. This changed radically in the late 1970s when several big Japanese conglomerates began producing similar industrial robots.

Manufacturing of steel bridges, cutting steel

In 1969 Victor Scheinman at Stanford University invented the Stanford arm, an all-electric, 6-axis articulated robot designed to permit an arm solution. This allowed it accurately to follow arbitrary paths in space and widened the potential use of the robot to more sophisticated applications such as assembly and welding. Scheinman then designed a second arm for the MIT AI Lab, called the "MIT arm." Scheinman, after receiving a fellowship from Unimation to develop his designs, sold those designs to Unimation who further developed them with support from General Motors and later marketed it as the Programmable Universal Machine for Assembly (PUMA).

Industrial robotics took off quite quickly in Europe, with both ABB Robotics and KUKA Robotics bringing robots to the market in 1973. ABB Robotics (formerly ASEA) introduced IRB 6, among the world's first *commercially available* all electric micro-processor controlled robot. The first two IRB 6 robots were sold to Magnusson in Sweden for grinding and polishing pipe bends and were installed in production in January 1974. Also in 1973 KUKA Robotics built its first robot, known as FAMULUS, also one of the first articulated robot to have six electromechanically driven axes.

Automation in foundry industry, heat resistant robot

Interest in robotics increased in the late 1970s and many US companies entered the field, including large firms like General Electric, and General Motors (which formed joint venture FANUC Robotics with FANUC LTD of Japan). U.S. startup companies included Automatix and Adept Technology, Inc. At the height of the robot boom in 1984, Unimation was acquired by Westinghouse Electric Corporation for 107 million U.S. dollars. Westinghouse sold Unimation to Stäubli Faverges SCA of France in 1988, which is still making articulated robots for general industrial and cleanroom applications and even bought the robotic division of Bosch in late 2004.

Flat-glas handling, heavy duty robot with 500 kg payload

Only a few non-Japanese companies ultimately managed to survive in this market, the major ones being Adept Technology, Stäubli-Unimation, the Swedish-Swiss company ABB Asea Brown Boveri and the German company KUKA Robotics.

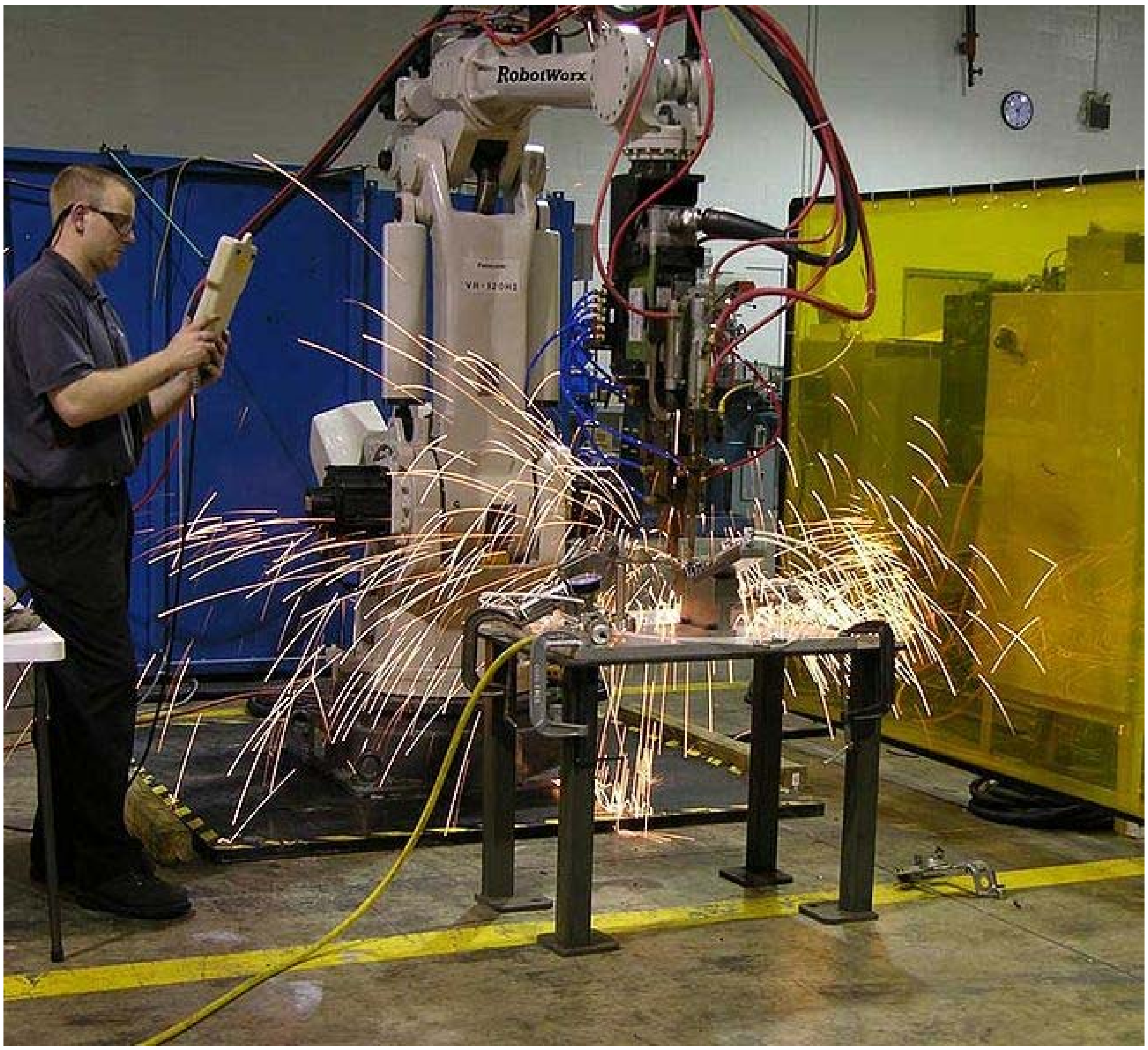
Technical description

Defining parameters

- *Number of axes* – two axes are required to reach any point in a plane; three axes are required to reach any point in space. To fully control the orientation of the end of the arm (i.e. the *wrist*) three more axes (yaw, pitch, and roll) are required. Some designs (e.g. the SCARA robot) trade limitations in motion possibilities for cost, speed, and accuracy.
- *Degrees of freedom* which is usually the same as the number of axes.
- *Working envelope* – the region of space a robot can reach.
- *Kinematics* – the actual arrangement of rigid members and joints in the robot, which determines the robot's possible motions. Classes of robot kinematics include articulated, cartesian, parallel and SCARA.
- *Carrying capacity or payload* – how much weight a robot can lift.
- *Speed* – how fast the robot can position the end of its arm. This may be defined in terms of the angular or linear speed of each axis or as a compound speed i.e. the speed of the end of the arm when all axes are moving.
- *Acceleration* - how quickly an axis can accelerate. Since this is a limiting factor a robot may not be able to reach its specified maximum speed for movements over a short distance or a complex path requiring frequent changes of direction.
- *Accuracy* – how closely a robot can reach a commanded position. When the absolute position of the robot is measured and compared to the commanded position the error is a measure of accuracy. Accuracy can be improved with

external sensing for example a vision system or IR. Accuracy can vary with speed and position within the working envelope and with payload.

- *Repeatability* - how well the robot will return to a programmed position. This is not the same as accuracy. It may be that when told to go to a certain X-Y-Z position that it gets only to within 1 mm of that position. This would be its accuracy which may be improved by calibration. But if that position is taught into controller memory and each time it is sent there it returns to within 0.1mm of the taught position then the repeatability will be within 0.1mm.

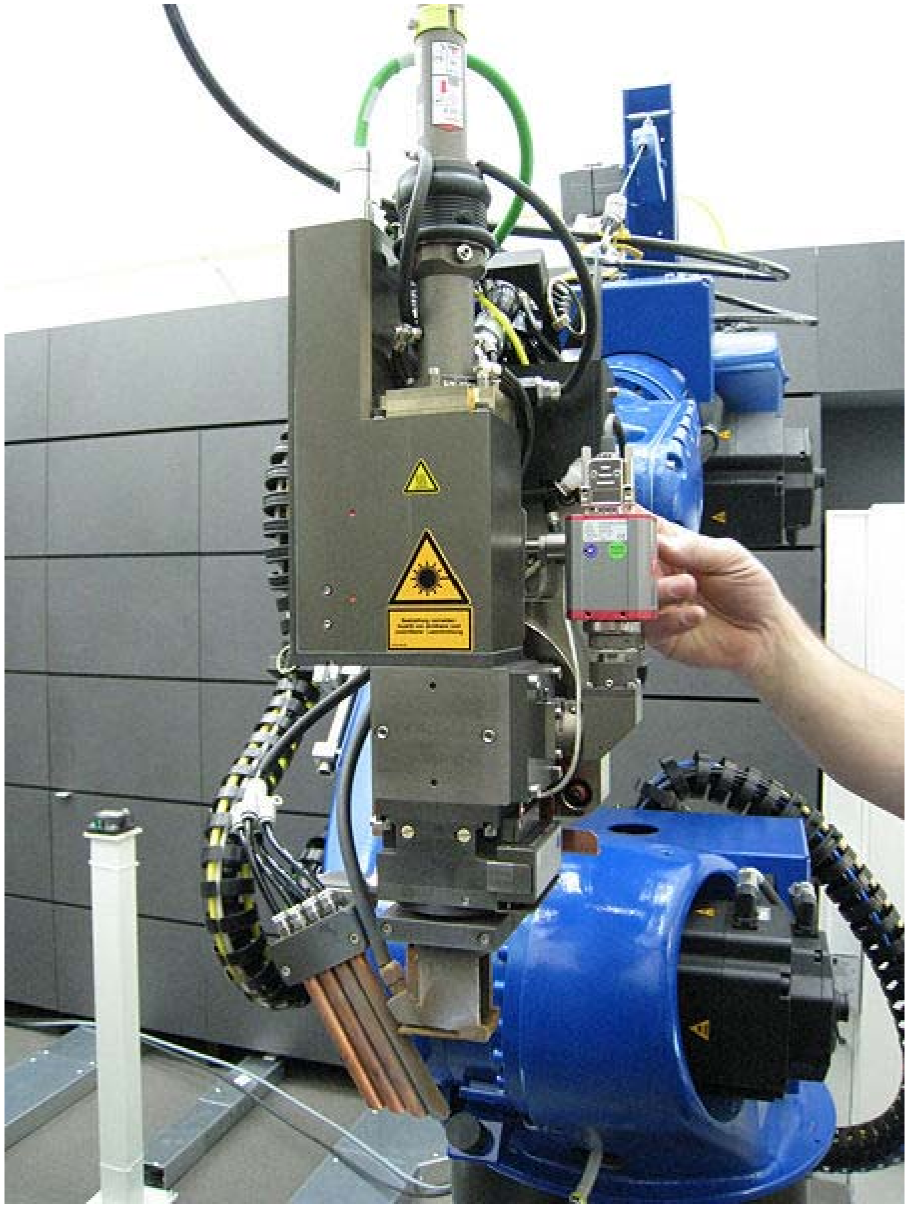


Spot Welding Robot

Accuracy and repeatability are different measures. Repeatability is usually the most important criterion for a robot. ISO 9283 sets out a method whereby both accuracy and repeatability can be measured. Typically a robot is sent to a taught position a number of times and the error is measured at each return to the position after visiting 4 other positions. Repeatability is then quantified using the standard deviation of those samples in all three dimensions. A typical robot can, of course make a positional error exceeding that and that could be a problem for the process. Moreover the repeatability is different in different parts of the working envelope and also changes with speed and payload. ISO 9283 specifies that accuracy and repeatability should be measured at maximum speed and at maximum payload. But this results in pessimistic values whereas the robot could be much more accurate and repeatable at light loads and speeds. Repeatability in an industrial process is also subject to the accuracy of the end effector, for example a gripper, and even to the design of the 'fingers' that match the gripper to the object being grasped. For example if a robot picks a screw by its head the screw could be at a random angle. A subsequent attempt to insert the screw into a hole could easily fail. These and similar scenarios can be improved with 'lead-ins' e.g. by making the entrance to the hole tapered.

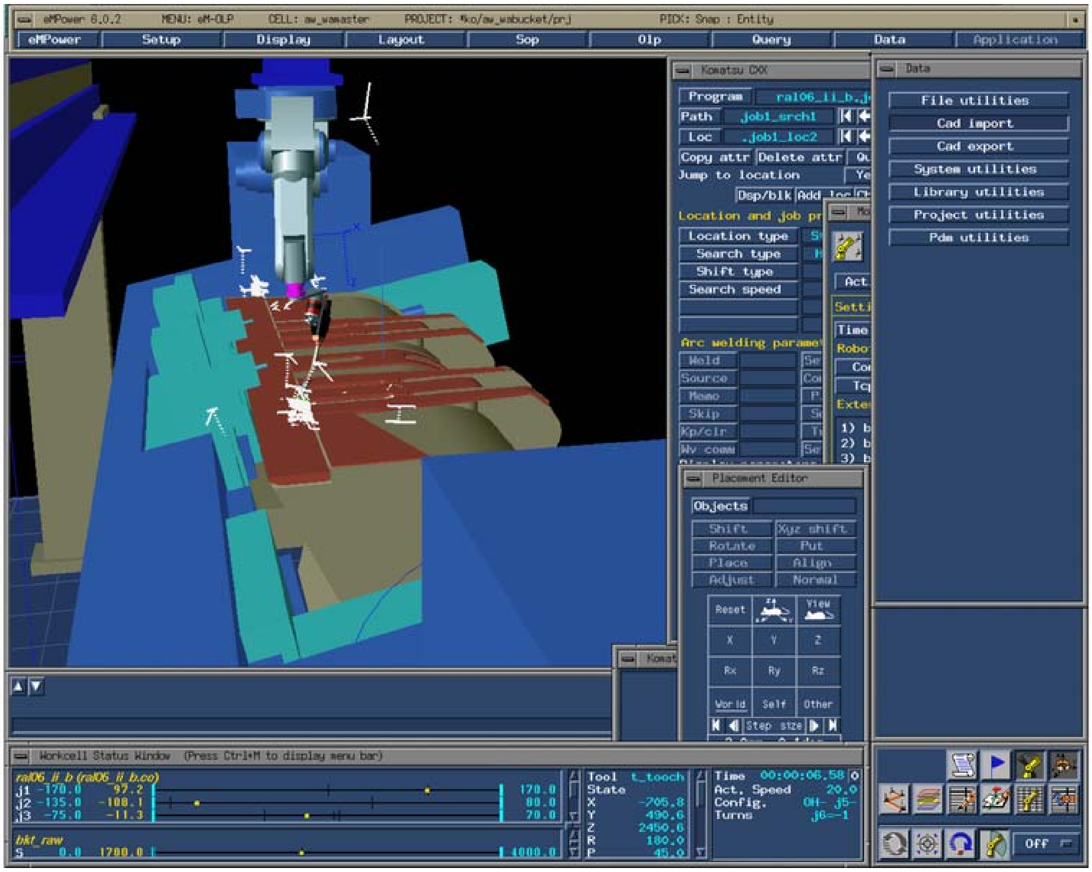
Stone processing: waterjet cutting of quartz kitchen countertops

- *Motion control* – for some applications, such as simple pick-and-place assembly, the robot need merely return repeatably to a limited number of pre-taught positions. For more sophisticated applications, such as welding and finishing (spray painting), motion must be continuously controlled to follow a path in space, with controlled orientation and velocity.
- *Power source* – some robots use electric motors, others use hydraulic actuators. The former are faster, the latter are stronger and advantageous in applications such as spray painting, where a spark could set off an explosion; however, low internal air-pressurisation of the arm can prevent ingress of flammable vapours as well as other contaminants.
- *Drive* – some robots connect electric motors to the joints via gears; others connect the motor to the joint directly (*direct drive*). Using gears results in measurable 'backlash' which is free movement in an axis. Smaller robot arms frequently employ high speed, low torque DC motors, which generally require high gearing ratios; this has the disadvantage of backlash. In such cases the harmonic drive is often used.
- *Compliance* - this is a measure of the amount in angle or distance that a robot axis will move when a force is applied to it. Because of compliance when a robot goes to a position carrying its maximum payload it will be at a position slightly lower than when it is carrying no payload. Compliance can also be responsible for overshoot when carrying high payloads in which case acceleration would need to be reduced.



Metal processing: YAG-laser-cutting

Robot programming and interfaces



Offline programming by ROBCAD

A typical well-used teach pendant with optional mouse

The setup or programming of motions and sequences for an industrial robot is typically taught by linking the robot controller to a laptop, desktop computer or (internal or Internet) network.

A robot and a collection of machines or peripherals is referred to as a workcell, or cell. A typical cell might contain a parts feeder, a molding machine and a robot. The various machines are 'integrated' and controlled by a single computer or PLC. How the robot interacts with other machines in the cell must be programmed, both with regard to their positions in the cell and synchronizing with them.

Software: The computer is installed with corresponding interface software. The use of a computer greatly simplifies the programming process. Specialized robot software is run either in the robot controller or in the computer or both depending on the system design.

There are two basic entities that need to be taught (or programmed): positional data and procedure. For example in a task to move a screw from a feeder to a hole the positions of the feeder and the hole must first be taught or programmed. Secondly the procedure to get the screw from the feeder to the hole must be programmed along with any I/O involved, for example a signal to indicate when the screw is in the feeder ready to be picked up. The purpose of the robot software is to facilitate both these programming tasks.

Teaching the robot positions may be achieved a number of ways:

Wood processing: CNC milling and cutting

Positional commands The robot can be directed to the required position using a GUI or text based commands in which the required X-Y-Z position may be specified and edited.

Teach pendant: Robot positions can be taught via a teach pendant. This is a handheld control and programming unit. The common features of such units are the ability to manually send the robot to a desired position, or "inch" or "jog" to adjust a position. They also have a means to change the speed since a low speed is usually required for careful positioning, or while test-running through a new or modified routine. A large emergency stop button is usually included as well. Typically once the robot has been programmed there is no more use for the teach pendant.

Lead-by-the-nose is a technique offered by many robot manufacturers. In this method, one user holds the robot's manipulator, while another person enters a command which de-energizes the robot causing it to go limp. The user then moves the robot by hand to the required positions and/or along a required path while the software logs these positions into memory. The program can later run the robot to these positions or along the taught path. This technique is popular for tasks such as paint spraying.

Offline programming is where the entire cell, the robot and all the machines or instruments in the workspace are mapped graphically. The robot can then be moved on screen and the process simulated. The technique has limited value because it relies on accurate measurement of the positions of the associated equipment and also relies on the positional accuracy the robot which may or may not conform to what is programmed.

Others In addition, machine operators often use user interface devices, typically touchscreen units, which serve as the operator control panel. The operator can switch from program to program, make adjustments within a program and also operate a host of peripheral devices that may be integrated within the same robotic system. These include end effectors, feeders that supply components to the robot, conveyor belts, emergency stop controls, machine vision systems, safety interlock systems, bar code printers and an almost infinite array of other industrial devices which are accessed and controlled via the operator control panel.

The teach pendant or PC is usually disconnected after programming and the robot then runs on the program that has been installed in its controller. However a computer is often used to 'supervise' the robot and any peripherals, or to provide additional storage for access to numerous complex paths and routines.

End effectors

Factory Automation with industrial robots for palletizing food products like bread and toast at a bakery in Germany

The most essential robot peripheral is the end effector, or end-of-arm-tooling. Common examples of end effectors include welding devices (such as MIG-welding guns, spot-welders, etc.), spray guns and also grinding and deburring devices (such as pneumatic disk or belt grinders, burrs, etc.), and grippers (devices that can grasp an object, usually electromechanical or pneumatic). Another common means of picking up an object is by vacuum. End effectors are frequently highly complex, made to match the handled product and often capable of picking up an array of products at one time. They may utilize various sensors to aid the robot system in locating, handling, and positioning products.

Movement and singularities

Most articulated robots perform by storing a series of positions in memory, and moving to them at various times in their programming sequence. For example, a robot which is moving items from one place to another might have a simple 'pick and place' program similar to the following:

Define points P1–P5:

1. Safely above workpiece (defined as P1)
2. 10 cm Above bin A (defined as P2)
3. At position to take part from bin A (defined as P3)
4. 10 cm Above bin B (defined as P4)
5. At position to take part from bin B. (defined as p5)

Define program:

1. Move to P1
2. Move to P2
3. Move to P3
4. Close gripper
5. Move to P2
6. Move to P4
7. Move to P5
8. Open gripper
9. Move to P4
10. Move to P1 and finish

For examples of how this would look in popular robot languages see robot software.

For a given robot the only parameters necessary to completely locate the end effector (gripper, welding torch, etc.) of the robot are the angles of each of the joints or displacements of the linear axes (or combinations of the two for robot formats such as SCARA). However there are many different ways to define the points. The most common and most convenient way of defining a point is to specify a Cartesian coordinate for it, i.e. the position of the 'end effector' in mm in the X, Y and Z directions relative to the robot's origin. In addition, depending on the types of joints a particular robot may have, the orientation of the end effector in yaw, pitch, and roll and the location of the tool point relative to the robot's faceplate must also be specified. For a jointed arm these coordinates must be converted to joint angles by the robot controller and such conversions are known as Cartesian Transformations which may need to be performed iteratively or recursively for a multiple axis robot. The mathematics of the relationship between joint angles and actual spatial coordinates is called kinematics.

Automation in foundry industry, heat resistant robot

Positioning by Cartesian coordinates may be done by entering the coordinates into the system or by using a teach pendant which moves the robot in X-Y-Z directions. It is much easier for a human operator to visualize motions up/down, left/right, etc. than to move each joint one at a time. When the desired position is reached it is then defined in some way particular to the robot software in use, e.g. P1 - P5 above.

The American National Standard for Industrial Robots and Robot Systems — Safety Requirements (ANSI/RIA R15.06-1999) defines a singularity as “a condition caused by the collinear alignment of two or more robot axes resulting in unpredictable robot motion and velocities.” It is most common in robot arms that utilize a “triple-roll wrist”. This is a wrist about which the three axes of the wrist, controlling yaw, pitch, and roll, all pass through a common point. An example of a wrist singularity is when the path through which the robot is traveling causes the first and third axes of the robot’s wrist to line up. The second wrist axis then attempts to spin 360° in zero time to maintain the orientation of the end effector. Another common term for this singularity is a “wrist flip”. The result of a singularity can be quite dramatic and can have adverse effects on the robot arm, the end effector, and the process. Some industrial robot manufacturers have attempted to side-step the situation by slightly altering the robot’s path to prevent this condition. Another method is to slow the robot’s travel speed, thus reducing the speed required for the wrist to make the transition. The ANSI/RIA has mandated that robot manufacturers shall make the user aware of singularities if they occur while the system is being manually manipulated.

Flat-glas handling, heavy duty robot with 1,000 kg payload

Recent and future developments

As of 2005, the robotic arm business is approaching a mature state, where they can provide enough speed, accuracy and ease of use for most of the applications. Vision guidance (aka machine vision) is bringing a lot of flexibility to robotic cells. However, the end effector attached to a robot is often a simple pneumatic, 2-position chuck. This does not allow the robotic cell to easily handle different parts, in different orientations.

Manufacturing of steel bridges, cutting steel

Hand-in-hand with increasing off-line programmed applications, robot calibration is becoming more and more important in order to guarantee a good positioning accuracy.

Other developments include downsizing industrial arms for light industrial use such as production of small products, sealing and dispensing, quality control, handling samples in the laboratory. Such robots are usually classified as "bench top" robots. Robots are used in pharmaceutical research in a technique called High-throughput screening. Bench top robots are also used in consumer applications (micro-robotic arms). Industrial arms may be used in combination with or even mounted on automated guided vehicles (AGVs) to make the automation chain more flexible between pick-up and drop-off.

Loading milling machine

Prices of robots will vary with the features, but are usually from 7,500 USD for a bench-top model such as the ST Robotics R12 or the Fisnar dispensing robot and as much as 100,000 USD or more for a heavy-duty, long-reach robot such as the Kuka KR1000.

Market structure

The 2006 report (pdf) from the International Federation of Robotics shows that Japanese companies lead the world in both stock and sales of multi-purpose industrial robots. About 60 per cent of the installations were articulated robots, 22 per cent were gantry robots, and 13 per cent were SCARA robots and 4 per cent were cylindrical robots. The majority of installations are in the automobile sector. There are increasing sales into non automotive sectors such as metals and plastics.

Robots palletizing food (Bakery)

In 2007 the world market grew by 3% with approximately 114,000 new installed industrial robots. At the end of 2007 there were around one million industrial robots in use, compared with an estimated 50,000 service robots for industrial use.

Chapter- 2

Various Industrial Robots

Automated guided vehicle

An **automated guided vehicle** or **automatic guided vehicle** (AGV) is a mobile robot that follows markers or wires in the floor, or uses vision or lasers. They are most often used in industrial applications to move materials around a manufacturing facility or a warehouse. Application of the automatic guided vehicle has broadened during the late 20th century and they are no longer restricted to industrial environments.

Heavy-duty AGV

Tow Type AGV

Light-duty assembly AGV

Inertial-guided automatic trailer loading vehicle

Laser Guided Unitload AGV

Introduction

Automated guided vehicles (AGVs) increase efficiency and reduce costs by helping to automate a manufacturing facility or warehouse. The AGV can tow objects behind them in trailers to which they can autonomously attach. The trailers can be used to move raw materials or finished product. The AGV can also store objects on a bed. The objects can be placed on a set of motorized rollers (conveyor) and then pushed off by reversing them. Some AGVs use fork lifts to lift objects for storage. AGVs are employed in nearly every industry, including, pulp, paper, metals, newspaper, and general manufacturing. Transporting materials such as food, linen or medicine in hospitals is also done.

An AGV can also be called a laser guided vehicle (LGV) or self-guided vehicle (SGV). In Germany the technology is also called *Fahrerlose Transportsysteme* (FTS) and in Sweden *förarlösa truckar*. Lower cost versions of AGVs are often called Automated Guided Carts (AGCs) and are usually guided by magnetic tape. AGCs are available in a variety of models and can be used to move products on an assembly line, transport goods throughout a plant or warehouse, and deliver loads to and from stretch wrappers and roller conveyors.

The first AGV was brought to market in the 1950s, by Barrett Electronics of Northbrook, Illinois, and at the time it was simply a tow truck that followed a wire in the floor instead of a rail. Over the years the technology has become more sophisticated and today automated vehicles are mainly Laser navigated e.g. LGV (Laser Guided Vehicle). In an automated process, LGVs are programmed to communicate (via an offboard server) with other robots to ensure product is moved smoothly through the warehouse, whether it is being stored for future use or sent directly to shipping areas. Today, the AGV plays an important role in the design of new factories and warehouses, safely moving goods to their rightful destinations.

In the late 20th century AGVs took on new roles as ports began turning to this technology to move ISO shipping containers. The Port of Rotterdam employs well over 100 AGVs.

AGV applications are seemingly endless as capacities can range from just a few pounds to hundreds of tons.

Flexible manufacturing system

To begin to understand AGV it is necessary to understand the fundamentals of flexible manufacturing systems (FMS). FMS is a means by which to manufacture a product. FMS is more of a philosophy rather than a tangible item. FMS is the idea that faster is better and uses machines to produce their products. Rather than using humans to perform repetitive tasks a machine is used to perform that task 24 hours a day. FMS uses computer numerical controlled machines (CNC) to form a work cell. Each cell performs a specific task to assist in the manufacturing of a product. Although FMS is fast and efficient it is not cheap as it requires a lot of expensive machines in order to work. Typically, it costs millions of dollars to introduce an FMS into a factory. Rather than using a complete FMS, most companies use part of an FMS called a flexible manufacturing cell. This is used to produce part of a product by machine and maybe part by other methods. Often one or more AGV’s are used in FMS to connect work cells together.

Laser-guided AGV to transport unit loads or skids. Courtesy Transbotics, Corp.

Navigation

Wired

The wired sensor is placed on the bottom of the robot and is placed facing the ground. A slot is cut in the ground and a wire is placed approximately 1 inch below the ground. The sensor detects the radio frequency being transmitted from the wire and follows it.

Guide Tape

Many light duty AGVs (some known as automated guided carts or AGCs) use tape for the guide path. The tapes can be one of two styles: magnetic or colored. The AGC is fitted with the appropriate guide sensor to follow the path of the tape. One major advantage of tape over wired guidance is that it can be easily removed and relocated if the course needs to change. It also does not involve the expense of cutting the factory or warehouse floor for the entire travel route. Additionally, it is considered a "passive" system since it does not require the guide medium to be energized as wire does. Colored tape is initially less expensive, but lacks the advantage of being embedded in high traffic areas where the tape may become damaged or dirty. A flexible magnetic bar can also be embedded in the floor like wire but works under the same provision as magnetic tape and so remains unpowered or passive.

Laser Target Navigation

The wireless navigation is done by mounting retroreflective tape on walls, poles or machines. The AGV carrys a laser transmitter and receiver on a rotating turret. The laser is sent off then received again the angle and (sometimes) distance are automatically calculated and stored into the AGV's memory. The AGV has reflector map stored in memory and can correct its position based on errors between the expected and received measurements. It can then navigate to a destination target using the constantly updating position.

- **Modulated Lasers** The use of modulated laser light gives greater range and accuracy over pulsed laser systems. By emitting a continuous fan of modulated laser light a system can obtain an uninterrupted reflection as soon as the scanner achieves line of sight with a reflector. The reflection ceases at the trailing edge of the reflector which ensures an accurate and consistent measurement from every reflector on every scan. The LS9 Scanner is manufactured by Guidance Navigation Ltd and, by using a modulated laser; this system achieves an angular resolution of ~ 0.1 mrad (0.006°) at 8 scanner revolutions per second.
- **Pulsed Lasers** A typical pulsed laser scanner emits pulsed laser light at a rate of 14,400 Hz which gives a maximum possible resolution of ~ 3.5 mrad (0.2°) at 8 scanner revolutions per second. To achieve a workable navigation, the readings must be interpolated based on the intensity of the reflected laser light, to identify the centre of the reflector.

Outdoor laser-guided AGV to carry pallets or skids.

Gyroscopic Navigation

Another form of an AGV guidance is inertial navigation. With inertial guidance, a computer control system directs and assigns tasks to the vehicles. Transponders are embedded in the floor of the work place. The AGV uses these transponders to verify that the vehicle is on course. A gyroscope is able to detect the slightest change in the direction of the vehicle and corrects it in order to keep the AGV on its path. The margin of error for the inertial method is ±1 inch.

Inertial can operate in nearly any environment including tight aisles or extreme temperatures.

Unit-load AGV using natural-features navigation to carry steel to quality assurance lab

Natural Features Navigation

Navigation without retrofitting of the workspace is called Natural Features Navigation. One method uses one or more range-finding sensors, such as a laser range-finder, as well as gyroscopes and/or inertial measurement units with Monte-Carlo/Markov localization techniques to understand where it is as it dynamically plans the shortest permitted path to its goal. The advantage of such systems is that they are highly flexible for on-demand delivery to any location. They can handle failure without bringing down the entire manufacturing operation, since AGVs can plan paths around the failed device. They also are quick to install, with less down-time for the factory.

Steering control

To help an AGV navigate it can use two different steer control systems. The differential speed control is the most common. In this method there are two sets of wheels being driven. Each set is connected to a common drive train. These drive trains are driven at different speeds in order to turn or the same speed to allow the AGV to go forwards and/or backwards. The AGV turns in a similar fashion to a tank. This method of steering is good in the sense that it is easy to maneuver in small spaces. More often than not, this is seen on an AGV that is used to transport and turn in tight spaces or when the AGV is working near machines. This setup for the wheels is not used in towing applications because the AGV would cause the trailer to jackknife when it turned.

The other type of steering used is steered wheel control AGV. This type of steering is similar to a cars steering. It is more precise in following the wire program than the differential speed controlled method. This type of AGV has smoother turning but cannot make sharp turns in tight spots. Steered wheel control AGV can be used in all applications; unlike the differential controlled. Steered wheel control is used for towing and can also at times have an operator control it.

Path Decision

AGVs have to make decisions on path selection. This is done through different methods: frequency select mode (wired navigation only), and path select mode (wireless navigation only) or via a magnetic tape on the floor not only to guide the AGV but also to issue steering commands and speed commands.

Frequency select mode

Frequency select mode bases its decision on the frequencies being emitted from the floor. When an AGV approaches a point on the wire which splits the AGV detects the two frequencies and through a table stored in its memory decides on the best path. The different frequencies are required only at the decision point for the AGV. The frequencies can change back to one set signal after this point. This method is not easily expandable and requires extra guide cutting meaning more money.

Path select mode

An AGV using the path select mode chooses a path based on preprogrammed paths. It uses the measurements taken from the sensors and compares them to values given to them by programmers. When an AGV approaches a decision point it only has to decide whether to follow path 1, 2, 3, etc. This decision is rather simple since it already knows its path from its programming. This method can increase the cost of an AGV because it is required to have a team of programmers to program the AGV with the correct paths and change the paths when necessary. This method is easy to change and set up.

Magnetic Tape mode

The magnetic tape is laid on the surface of the floor or buried in a 10 mm channel, not only does it provide the path for the AGV to follow but also sort strips of the tape in different combos of the strip tell the AGV to change lane and also speed up slow down and stop with north and south magnetic combos, this is used by TOYOTA USA and TOYOTA JAPAN.

Traffic Control

Flexible manufacturing systems containing more than one AGV may require it to have traffic control so the AGV’s will not run into one another. Methods include zone control, forward sensing control, and combination control each method has its advantages and disadvantages.

Zone control

Zone control is the favorite of most environments because it is simple to install and easy to expand. Zone control uses a wireless transmitter to transmit a signal in a fixed area.

Each AGV contains a sensing device to receive this signal and transmit back to the transmitter. If the area is clear the signal is set at “clear” allowing any AGV to enter and pass through the area. When an AGV is in the area the “stop” signal is sent and all AGV attempting to enter the area stop and wait for their turn. Once the AGV in the zone has moved out beyond the zone the “clear” signal is sent to one of the waiting AGVs. Another way to set up zone control traffic management is to equip each individual robot with its own small transmitter/receiver. The individual AGV then sends its own “do not enter” message to all the AGVs getting to close to its zone in the area. A problem with this method is if one zone goes down all the AGV’s are at risk to collide with any other AGV. Zone control is a cost efficient way to control the AGV in an area.

Forward sensing control

Forward sensing control uses collision avoidance sensors to avoid collisions with other AGV in the area. These sensors include: sonic, which work like radar; optical, which uses an infrared sensor; and bumper, physical contact sensor. Most AGVs are equipped with a bumper sensor of some sort as a fail safe. Sonic sensors send a “chirp” or high frequency signal out and then wait for a reply from the outline of the reply the AGV can determine if an object is ahead of it and take the necessary actions to avoid collision. The optical uses an infrared transmitter/receiver and sends an infrared signal which then gets reflected back; working on a similar concept as the sonic sensor. The problems with these are they can only protect the AGV from so many sides. They are relatively hard to install and work with as well.

Combination control

Combination control sensing is using collision avoidance sensors as well as the zone control sensors. The combination of the two helps to prevent collisions in any situation. For normal operation the zone control is used with the collision avoidance as a fail safe. For example, if the zone control system is down, the collision avoidance system would prevent the AGV from colliding.

System Management

Industries with AGVs need to have some sort of control over the AGVs. There are three main ways to control the AGV: locator panel, CRT color graphics display, and central logging and report.

A locator panel is a simple panel used to see which area the AGV is in. If the AGV is in one area for too long, it could mean it is stuck or broken down. CRT color graphics display shows real time where each vehicle is. It also gives a status of the AGV, its battery voltage, unique identifier, and can show blocked spots. Central logging used to keep track of the history of all the AGVs in the system. Central logging stores all the data and history from these vehicles which can be printed out for technical support or logged to check for up time.

AGV is a system often used in FMS to keep up, transport, and connect smaller subsystems into one large production unit. AGVs employ a lot of technology to ensure they do not hit one another and make sure they get to their destination. Loading and transportation of materials from one area to another is the main task of the AGV. AGV require a lot of money to get started with, but they do their jobs with high efficiency. In places such as Japan automation has increased and is now considered to be twice as efficient as factories in America. For a huge initial cost the total cost over time decreases

Vehicle Types

- *AGVS Towing Vehicles* were the first type introduced and are still a very popular type today. Towing vehicles can pull a multitude of trailer types and have capacities ranging from 8,000 pounds to 60,000 pounds.
- *AGVS Unit Load Vehicles* are equipped with decks, which permit unit load transportation and often automatic load transfer. The decks can either be lift and lower type, powered or non-powered roller, chain or belt decks or custom decks with multiple compartments.
- *AGVS Pallet Trucks* are designed to transport palletized loads to and from floor level; eliminating the need for fixed load stands.
- *AGVS Fork Truck* has the ability to service loads both at floor level and on stands. In some cases these vehicles can also stack loads in rack.
- *Light Load AGVS* are vehicles which have capacities in the neighborhood of 500 pounds or less and are used to transport small parts, baskets, or other light loads though a light manufacturing environment. They are designed to operate in areas with limited space.
- *AGVS Assembly Line Vehicles* are an adaptation of the light load AGVS for applications involving serial assembly processes.

Common AGV Applications

Automated Guided Vehicles can be used in a wide variety of applications to transport many different types of material including pallets, rolls, racks, carts, and containers. AGVs excel in applications with the following characteristics:

- Repetitive movement of materials over a distance
- Regular delivery of stable loads
- Medium throughput/volume
- When on-time delivery is critical and late deliveries are causing inefficiency
- Operations with at least two shifts
- Processes where tracking material is important

Raw Material Handling

AGVs are commonly used to transport raw materials such as paper, steel, rubber, metal, and plastic. This includes transporting materials from receiving to the warehouse, and delivering materials directly to production lines.

Work-in-Process Movement

Work-in-Process movement is one of the first applications where automated guided vehicles were used, and includes the repetitive movement of materials throughout the manufacturing process. AGVs can be used to move material from the warehouse to production/processing lines or from one process to another.

Pallet Handling

Pallet handling is an extremely popular application for AGVs as repetitive movement of pallets is very common in manufacturing and distribution facilities. AGVs can move pallets from the palletizer to stretch wrapping to the warehouse/storage and/or to the outbound shipping docks.

Finished Product Handling

Moving finished goods from manufacturing to storage or shipping is the final movement of materials before they are delivered to customers. These movements often require the gentlest material handling because the products are complete and subject to damage from rough handling. Because AGVs operate with precisely controlled navigation and acceleration and deceleration this minimizes the potential for damage making them an excellent choice for this type of application.

Trailer Loading

Automatic loading of trailers is a relatively new application for automated guided vehicles and becoming increasingly popular. AGVs are used to transport and load pallets of finished goods directly into standard, over-the-road trailers without any special dock equipment. AGVs can pick up pallets from conveyors, racking, or staging lanes and deliver them into the trailer in the specified loading pattern.

Roll Handling

AGVs are used to transport rolls in many types of plants including paper mills, converters, printers, newspapers, steel producers, and plastics manufacturers. AGVs can store and stack rolls on the floor, in racking, and can even automatically load printing presses with rolls of paper.

Primary Application Industries

Efficient, cost effective movement of materials is an important, and common element in improving operations in many manufacturing plants and warehouses. Because automatic guided vehicles (AGVs) can delivery efficient, cost effective movement of materials, AGVs can be applied to various industries in standard or customized designs to best suit an industry's requirements. Industry's currently utilizing AGVs include (but are not limited to):

A forktruck vehicle delivering a pallet of finished goods

A unitload vehicle for delivering steel plates (blanks)

Pharmaceutical

AGVs are a preferred method of moving materials in the pharmaceutical industry. Because an AGV system tracks all movement provided by the AGVs, it supports process validation and cGMP (current Good Manufacturing Practice).

Chemical

AGVs deliver raw materials, move materials to curing storage warehouses, and provide transportation to other processing cells and stations. Common industries include rubber, plastics, and specialty chemicals.

Manufacturing

AGVs are often used in general manufacturing of products. AGVs can typically be found delivering raw materials, transporting work-in process, moving finished goods, removing scrap materials, and supplying packaging materials.

Automotive

AGV installations are found in Stamping Plants, Power Train (Engine and Transmission) Plants, and Assembly Plants delivering raw materials, transporting work-in process, and moving finished goods. AGVs are also used to supply specialized tooling which must be changed.

A Tugger AGV pulling wheeled carts containing automotive body panels

Supplying a bin of parts for assembly onto cars

Paper and Print

AGVs can move paper rolls, pallets, and waste bins to provide all routine material movement in the production and warehousing (storage/retrieval) of paper, newspaper, printing, corrugating, converting, and plastic film.

Food and Beverage

AGVs can be applied to move materials in food processing (such as the loading of food and/or trays into sterilizers) and at the “end of line,” linking the palletizer, stretch wrapper, and the warehouse. AGVs can load standard, over-the-road trailers with finished goods, and unload trailers to supply raw materials or packaging materials to the plant. AGVs can also store and retrieve pallets in the warehouse.

Hospital

AGVs are becoming increasingly popular in the healthcare industry for efficient transport, and are programmed to be fully integrated to automatically operate doors, elevators/lifts, cart washers, trash dumpers, etc. AGVs typically move linens, trash, regulated medical waste, patient meals, soiled food trays, and surgical case carts.

Warehousing

Battery Charging

AGVs utilize a number of battery charging options. Each option is dependent on the users preference. The most commonly used battery charging technologies are *Battery Swap*, *Automatic/Opportunity Charging*, and *Automatic Battery Swap*.

Battery Swap

"Battery swap technology" requires an operator to manually remove the discharged battery from the AGV and place a fully charged battery in its place approximately 8 – 12 hours (about one shift) of AGVs operation. 5 – 10 minutes is required to perform this with each AGV in the fleet.

Automatic / Opportunity Charging

"Automatic and opportunity battery charging" allows for continuous operation. On average an AGV charges for 12 minutes every hour for automatic charging and no manual intervention is required. If opportunity is being utilized the AGV will receive a charge whenever the opportunity arises. When a battery pack gets to a predetermined level the AGV will finish the current job that it has been assigned before it goes to the charging station.

Automatic Battery Swap

"Automatic battery swap" is an alternative to manual battery swap. It requires an additional piece of automation machinery, an automatic battery changer, to the overall AGV system. AGVs will pull up to the battery swap station and have their batteries automatically replaced with fully charged batteries. The automatic battery changer then places the removed batteries into a charging slot for automatic recharging. The automatic battery changer keeps track of the batteries in the system and pulls them only when they are fully charged.

While a battery swap system reduces the manpower required to swap batteries, recent developments in battery charging technology allow batteries to be charged more quickly and efficiently potentially eliminating the need to swap batteries.

RoboLogix

RoboLogix	
Developer(s)	Logic Design Inc.
Stable release	V2.0 / January 2009
Operating system	Windows (2000, XP, Vista, or Windows 7)
Type	Robotics circuit simulation
License	Proprietary

Overview

RoboLogix is a robotics simulator which uses a physics engine to emulate real-world robotics applications. The advantages of using robotics simulation tools are that they save time in the design of robotics applications and they can also greatly increase the level of safety associated with robotic equipment since various "what if" scenarios can be tried and tested before the system is activated. By using RoboLogix, it is possible to teach, test, run, and debug programs that have been written using a five-axis industrial robot in a wide range of practical applications. These simulated applications include pick-and-place, palletizing, welding, and painting. RoboLogix allows for the execution of robot software programs to test and visually examine the operation of robot programs and control algorithms, while plotting instantaneous joint accelerations, velocities and positions.

RoboLogix was developed by Colin Simpson and John (Bud) Skinner. It is primarily intended as an educational resource, and is used by high schools, colleges, and universities to provide laboratory simulation of industrial robots. Some institutions, such as George Brown College use RoboLogix as part of an online robotics distance education program. The simulation software allows for verification of the robot's reaching ability, travel ranges and collisions. This type of simulation software provides an increased level of reliability in the planning process and program development as well as reducing the overall completion/commissioning time.

RoboLogix work envelope.

The ability to preview the behavior of a robotic system in a virtual world allows for a variety of mechanisms, devices, configurations and controllers to be tried and tested before being applied to a "real world" system. RoboLogix receives control signals, determines if contact or collision between objects in the system has occurred, and returns simulated sensor information as feedback. This system has the capacity of real-time simulation of the motion of an industrial robot through 3D animation. The principles of 3D motion simulation and both geometric modeling and kinematics modeling are presented in the RoboLogix virtual environment.

RoboLogix enables programmers to write their own robot programs, modify the environment and use the available sensors. These sensors include video cameras which are used for obtaining the desired position of the robot end effector. In addition, a teach pendant control panel is included with the simulator that allows the user to command the robot to pick up a tracked object and return it to a home location through jogged commands or pre-programmed positions.

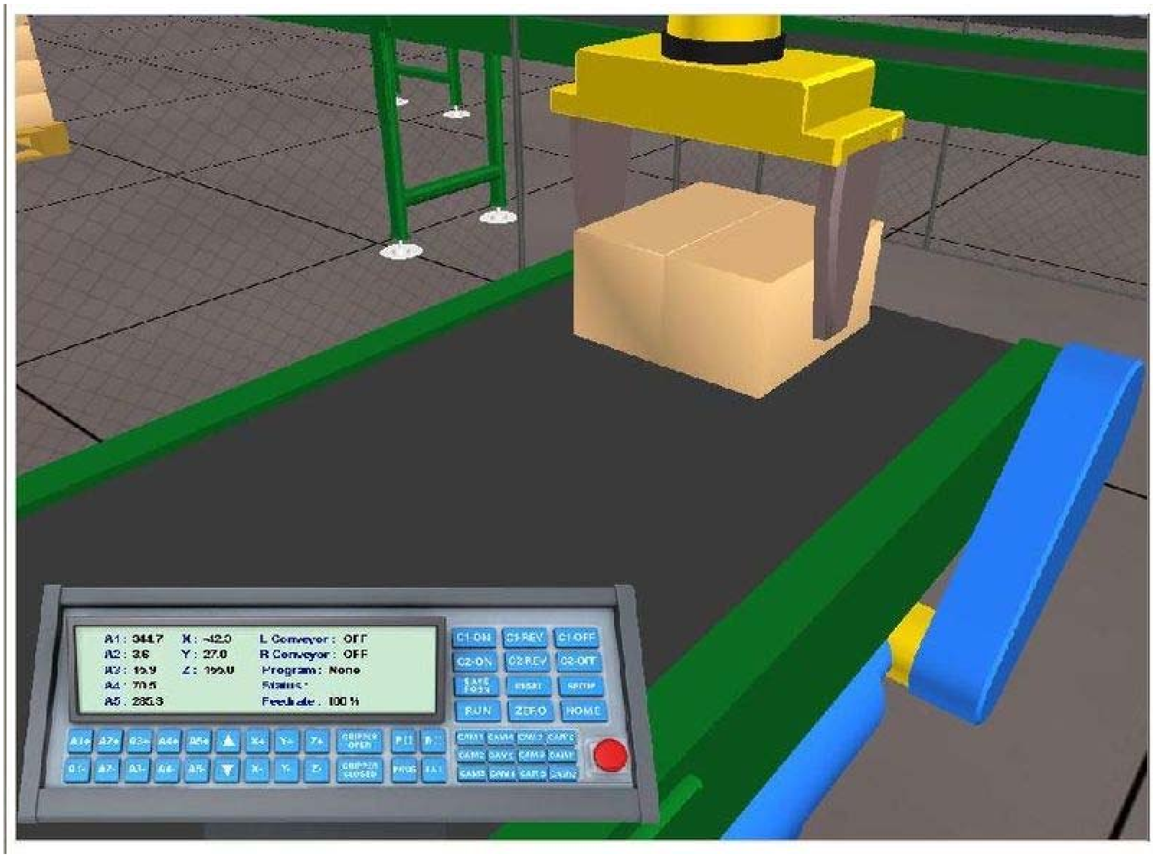
Control Panel

The RoboLogix control panel consists of both robot control functions as well as environment control functions such as conveyor system controls, on-off hard-wired control, etc. The conveyor controls can move either conveyor in the forward or reverse direction. Motion control of the robot accomplished by moving the robot from one location position to another. This movement is achieved by setting the angular (A1 -A5) coordinates and the linear (X, Y, Z) coordinates. With robotic systems in general, angular position movements are commonly used for large (course) motion and linear position movements are often used for smaller (fine) increments.

RoboLogix control panel.

There are several command instructions on the control panel such as Reset, Home, Setup and Zero which are used to automatically set the robot to a specific position for calibration or realignment. The Reset instruction is used to clear program errors and reset the system. The Home instruction will return the robot to its home base position, and the Zero instruction will reset the robot arm coordinates to zero. The Setup key provides access to a dialog box with setting adjustments for conveyor speed, as well as feed rates for angular (deg/sec) and linear (cm/sec) jog instructions. In addition, the Setup dialog box also allows for independent adjustment of the A5 rotary tool feedrate.

Vision System



One of the 12 camera views.

RoboLogix provides 12 viewpoints, or camera angles for a given robot work envelope. These viewpoints are accessed by the twelve CAM keys and allow for the viewing from a variety of angles and perspectives. By using these camera viewpoints, the user can move around in a 3D animated environment in much the same way they would in the real-world. When programming the robot, the camera views allow you to make fine adjustments to the arm and gripper position, or to view the entire work envelope and surrounding area. One of the camera views is from the robot's end effector. This viewpoint allows for the real-time visualization and positioning of the end effector (gripper) as it approaches the workpiece.

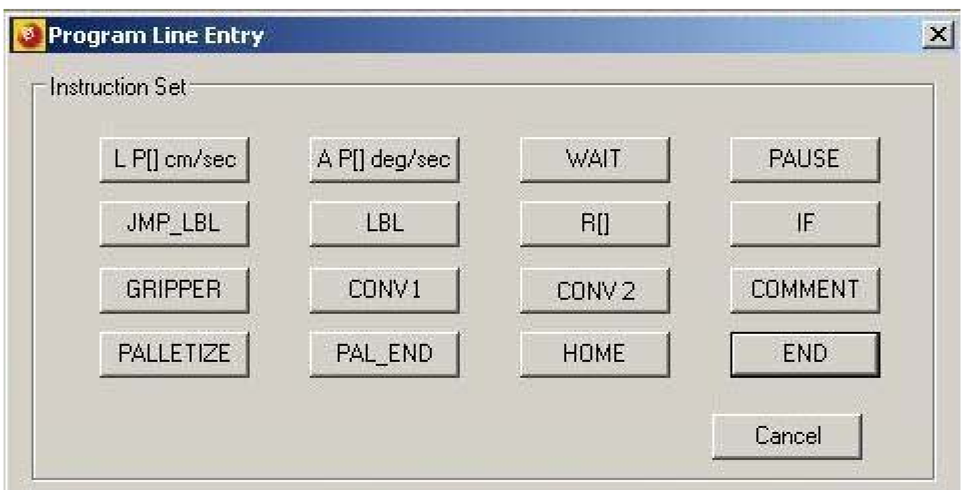
Programming Language

Like most robot programming languages, RoboLogix programs consist of data objects and program flow. The data objects reside in registers and the program flow represents the list of instructions, or instruction set, that is used to program the robot. RoboLogix program language is a type of scripting language that is used to control the software application.

Programming languages are generally designed for building data structures and algorithms from scratch, while scripting languages are intended more for connecting, or gluing, components and instructions together. Consequently, the RoboLogix instruction set is a streamlined list of program commands that are used to simplify the programming process and provide rapid application development.

Instruction Set

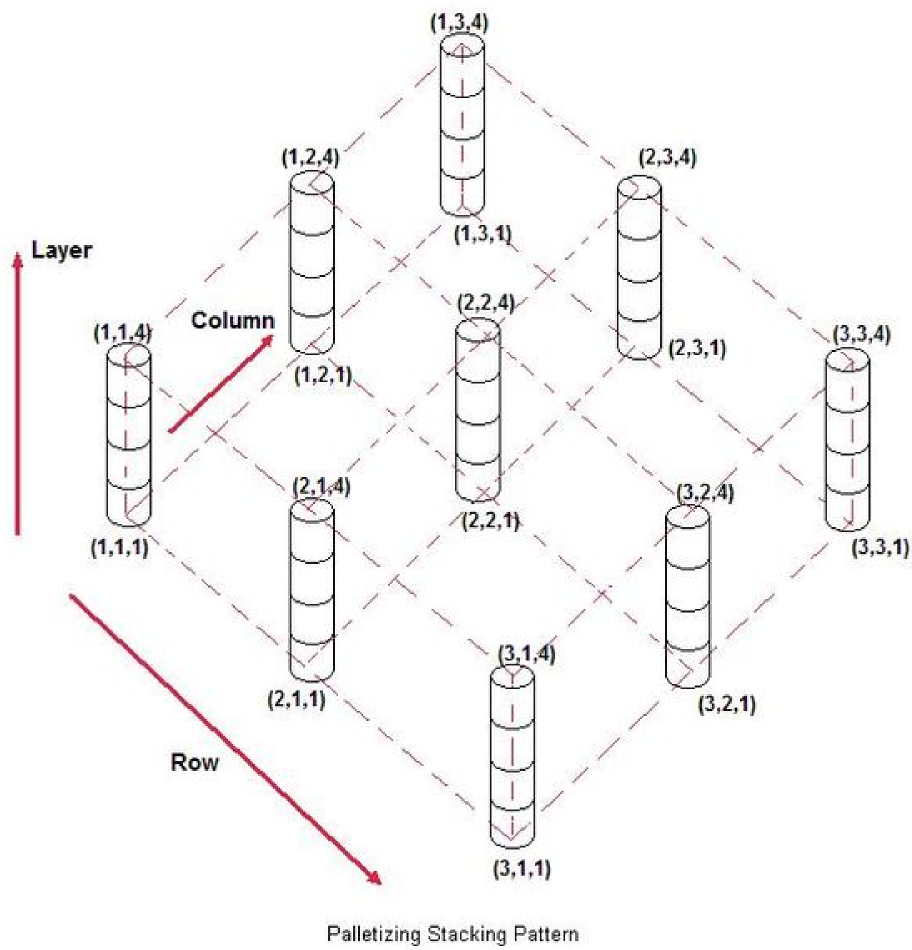
The RoboLogix instruction set contains 16 commands, which are usually written as a program on a line-by-line basis. These commands are used to instruct the robot to perform tasks such as moving to a specific location, picking up an object, executing a subroutine, waiting, etc. One of the more popular commands in the instruction set is the IF instruction, which compares numerical values located in two registers. If a register has a value that is greater than (>), less than (<), greater than/equal to (>=), less than/equal to (<=), equal to (=), or not equal to (<>) another register, it will execute the next line in the program if the condition is true. The IF command is often used with the JMP LBL instruction to control program execution.



RoboLogix Instruction Set.

All instruction set information is stored in registers, which are data locations capable of holding variable numeric values. There are two main types of registers used by RoboLogix: position registers and variable registers. Position registers contain both the linear and angular data point coordinates and include axis (joint) information for A1, A2, A3, etc. and for X, Y, Z linear, or Cartesian coordinates. There are also 32 variable registers which can be used for holding instruction set data such as position comparisons and time-delay information. In addition to position registers and variable registers, some robot software programs also have palletizing registers, which are used to manage the position of the stack point in palletizing applications.

Palletizing



Palletizing Stacking Pattern.

Palletizing is one of the more popular applications for robots, and is accomplished by combining a series of commands into a palletizing routine. A RoboLogix palletizing routine consists of five program instructions, or lines. The first instruction is the Palletize instruction, which is followed by a linear motion instruction to move to the stack point. The stack point is the top-center of the workpiece, and a group of stack points forms a stacking pattern, as shown in the image to the right. The first stack point in a stacking pattern is located at (1,1,1) (row,column, layer) and is incremented each time the palletizing routine is executed.

ST Robotics

ST Robotics is a twin company based in Cambridge, England, and Princeton, New Jersey, USA. The company designs and manufactures low-cost bench-top industrial robot arms and purpose built Cartesian robots. The company has no sales force and sells their robotic arm products purely through the Internet as "boxed robots".

History

In 1982, David Sands formed the company Intelligent Artefacts which was based in Cambridge, England. One of its products was educational robot arms. The arms were programmed in the programming language BASIC and would run on any of the popular makes of computers of the time such as Apple (Apple II series), Acorn Electron, Atari, BBC Micro or the Commodore Pet. The robot competed with others in that market like the Armdroid. As the language Forth became available on these computers, Sands wrote the first version of RoboForth which enabled the robots to run and respond far faster. A version of RoboForth was also written for Armdroid.

In 1984, Intelligent Artefacts was closed down and a new company formed, also in Cambridge, called Cyber Robotics who sold a redesigned arm known as the Cyber 310. The Cyber 310 had a 5 degrees of freedom (DOF) ability. Hundreds of them were sold around the world between 1981 and 1987. The robot arm was adopted in 1987 by Mike Topping as the basis for the *Handy 1*, a robotic helper for the severely disabled. Cyber Robotics was bought by the Bibby Corporation in 1982 and it was eventually closed due to lack of sales.

During the period that Intelligent Artifacts was in operation, many inquiries were received for more serious and professional uses of robot arms for which the Cyber 310 was not suitable. This alerted Sands to the potential for manufacturing a bench–top robot arm series, some of which already existed, notably the Zymark.

Sands Technology was formed in 1985 and in 1986 a shell company was created, Imagecroft Ltd. The company began to manufacture robot arms, such as the R12 Mk1, R15 and R16, which were used in applications from laboratory work in DNA processing to decommissioning nuclear reactors. In 1989, David Sands met Mathew Monforte in New Jersey and the pair decided to expand the company for the American market in 1991 and Sands Technology International was incorporated in New Jersey in 1992. The less personal pseudonym of ST Robotics was coined in 1995 under which both companies now trade.

Technology

ST Robotics uses technology which is based on stepping motors as opposed to the more usual DC servo motors. For some years the technology had problems from lack of power and motor resonance. These problems were solved with the advent of rare–earth hybrid motors, high voltage micro-stepping drives and incremental encoder feedback. The robots calibrate themselves by driving each axis slowly to a target sensed by a proximity detector. Incremental optical encoders then track along with the motors to check for errors. This is called *closed loop control* which differs from servo control in that the stepping motors run essentially an open loop — the loop is only closed at the end of each movement of the arm. ST's latest arm, the R12 Mk2, has the encoders only as an option.

The ST robot controller uses two processors: one to run the RoboForth programming language and a digital signal processor (DSP) to control the motors. The DSP is able to control all axes collectively with individual axes ramping up or down as necessary for a compound motion. At the same time it reads back the encoders data and passes this information to the CPU which also uses the DSP's timers.

Universal Robotics

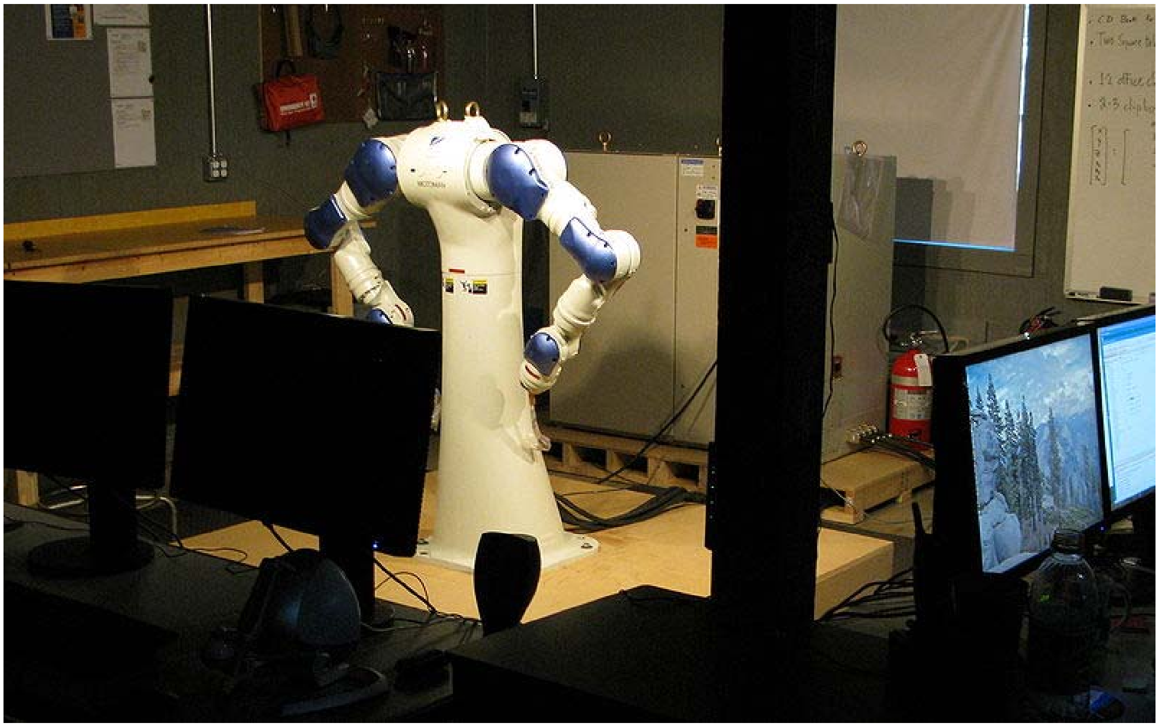
Universal Robotics, Inc, is a software engineering company that develops, manufactures, and supports an operating system for machine intelligence. Headquartered at Smith Springs in Nashville, Tennessee, Universal Robotics was co-founded by professor Dr. Alan Peters, of the Center for Intelligent Systems in the School of Engineering at Vanderbilt University and his brothers David Peters, a businessman, and Jonathan Peters, an IT consultant. The company was incorporated as a holding company on August 29, 2001. In June 2007 a securities offering commenced to raise early stage financing with the round successfully closing in March 2008.

NASA Robonaut

Product

The Company's signature software product is designed to automate intelligence and is called **Neocortex** after the cerebral cortex in mammal brains. The technology is based on the pattern of learning in nature which is common to all creatures. It mimics the capability to apply understanding from physical experience. Neocortex differs from Artificial Intelligence (AI) in that the machine develops its own understanding from sensing and acting in the physical world, rather than being programmed. It will serve as the intelligence for different types of machines including industrial robots, forklifts, and mining equipment. Selling is planned to begin in 2009 to the materials handling industry where Neocortex will palletize and de-palletize mix sized boxes using industrial robots. The company developed tagline for marketing is *Software with an IQ*. The invention is patent protected and was developed at Vanderbilt University and NASA, where it has been the "brain" of their humanoid robot for four years.

Efforts to apply Machine intelligence to industry, have met with only limited success. The problem stemmed from the belief that if enough facts where loaded into a sophisticated data base, a machine would become intelligent (i.e. the Artificial Intelligence approach). Since this approach was not working, a number of roboticists in academia came to believe that a machine could exhibit intelligent behavior only through physically manipulating the world and, through its own sensors, learn the immediate effects of its actions. Intelligence would emerge as the machine developed skills through its interactions with people and the world.



Motoman SDA10 at Smith Springs Lab, 2008.

Neocortex does not rely on classical artificial intelligence (AI), and though it organizes sensory-motor data in vector space, it is not simply an artificial neural network. It is modeled after hypotheses on the acquisition of natural intelligence by animals, integrating concepts from a number of disciplines concerned with behavior, biology, and engineering.

Operations

Universal is a hybrid of functional and product organizational structures. There six task areas: 1) strategic planning, 2) sales and service of customers, 3) engineering and programming, 4) quality control, 5) research and development, and 6) security. Layers of management are reduced and the interconnectedness of individual tasks is paramount.

Chapter- 3

Significant Industrial Robots

Vision Guided Robotic Systems

Introduction

A Vision Guided Robot System comprises three core systems including robotic system, vision system, and component bulk handling system (hopper or conveyor system).

The vision system determines the position of randomly fed products onto a recycling conveyor system. The vision system and control software gives the robot exact coordinates of the components, which are spread out randomly beneath the camera field of vision, enabling the robot arm(s) to move to a selected component and pick from the conveyor belt. The conveyor, normally, stops under the camera where the position of the parts is determined. If the cycle time is short it is also possible to pick a component without stopping the conveyor. This is achieved by fitting an encoder to the conveyor and tracking the component through the vision software.

This functionality is usually referred to as vision guided robotics (VGR). It is a fast growing technology and a way to reduce manpower and retain production, especially in countries with high manufacturing overheads and labour costs.

Vision systems for robot guidance

Camera lens for machine vision

A vision system comprises a camera and microprocessor or computer, with associated software. This is a very wide definition that can be used to cover many different types of systems which aim to solve a large variety of different tasks. Vision systems can be implemented in virtually any industry for any purpose. It can be used for quality control to check dimensions, angles, colour or surface structure-or for the recognition of an object as used in VGR systems.

A camera can be anything from a standard compact camera system with integrated vision processor to more complex laser sensors and high resolution high speed cameras. Combinations of several cameras to build up 3D images of an object are also available.

Limitations of a vision system

There are always difficulties of integrated vision system to match the camera with the set expectations of the system, in most cases this is caused by lack of knowledge on behalf of the integrator or machine builder. Many vision systems can be applied successfully to virtually any production activity, as long as the user knows exactly how to set up system parameters. This set-up, however, requires a large amount of knowledge by the integrator and the number of possibilities can make the solution complex. Lighting in industrial environments can be another major downfall of many vision systems.

VGR systems Benefits

Traditional automation means serial production with large batch sizes and limited flexibility. Complete automation lines are usually built up around a single product or possibly a small family of similar products that can run in the same production line. If a component is changed or if a complete new product is introduced, this usually causes large changes in the automation process-in most cases new component fixtures are required with time consuming set up procedures. If components are delivered to the process by traditional hoppers and vibratory feeders, new bowl feeder tooling or additional bowl feeder tops are required. It may be that different product must be manufactured on the same process line, the cost for pallets, fixtures and bowl feeders can often be a large part of the investment. Other areas to be considered are space constraints, storage of change parts, spare components, and changeover time between products.

VGR systems can run side-by-side with very little mechanical set up, in the most extreme cases a gripper change is the only requirement, and the need to position components to set pick-up position is eliminated. With its vision system and control software, it is possible for the VGR system to handle different types of components. Parts with various geometry, can be fed in any random orientation to the system and be picked and placed without any mechanical changes to the machine, resulting in quick changeover times. Other features and benefits of VGR system are:

- Switching between products and batch runs is software controlled and very fast, with no mechanical adjustments.
- High residual value, even if production is changed.
- Short lead times, and short payback periods
- High machinery efficiency, reliability, and flexibility
- Possibility to integrate a majority of secondary operations such as deburring, clean blowing, washing, measuring and so on.
- Reduces manual work

UWA Telerobot

Development

The **UWA telerobot** is a historic landmark on the Internet. It was the first teleoperable industrial robot made available for general use on the Internet in 1994. The UWA telerobot was originally developed as part of a PhD thesis by Dr Kenneth Taylor and was the subject of a later PhD by Dr Barney Dalton.

The first robot on the Internet, a plastic toy robot with only 2 degrees of freedom, was placed online by a team under Ken Goldberg at the University of Southern California only three weeks before the UWA team released their website. The USC robot only lasted for seven months. The UWA robot is still online today, although the original robot was replaced in 1996 and the robot is no longer available for unrestricted public access, though interested parties can request permission.

Implementation

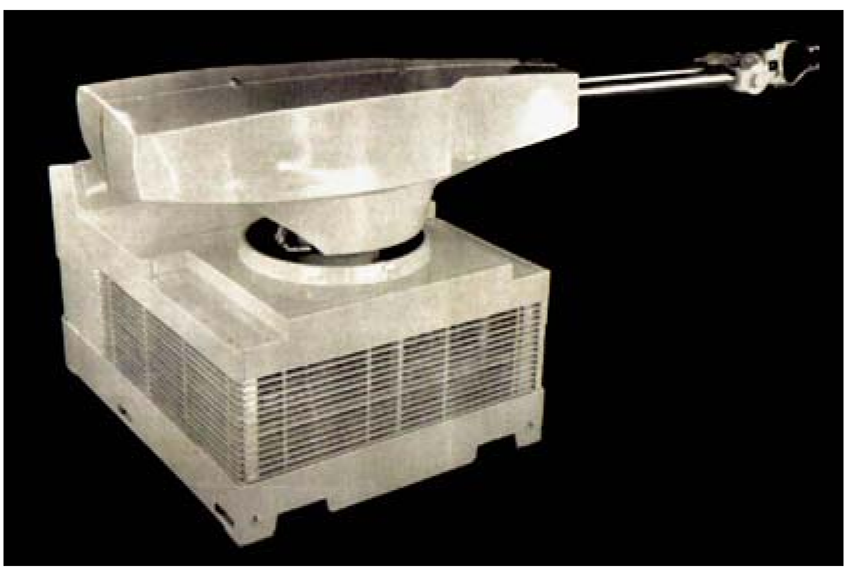
The current UWA telerobot is an ABB IRB1400 model 6 DOF serial chain robot fitted with a pneumatic gripper attachment. The robot runs on a standard ABB S4 Robot Controller linked to a Linux server and which in turn communicates with a second server running ABB's RobComm software and a National Instruments Labview application that was custom written for the task by Professor James Trevelyan with assistance from Perth-based Icon Technologies and students. The robot forms part of the UWA telelabs project.

The Telerobot has undergone many changes to its control structure over time. Originally controlled via static html web pages using CGI, work by Dalton saw the introduction of an augmented reality Java-based interface that met with limited success. Control is currently by way of a downloadable LabVIEW client application that incorporates real-time video streaming, with access control provided by the Telelabs system.

Current status

The robot continues to be the basis for research and group projects undertaken by Mechatronics Engineering students and staff at UWA, Primarily involving the addition of new features or capabilities to the system. The robot is also used as a teaching aid for a course in mechanisms and multibody systems run by Dr Karol Miller.

Unimate



The original Unimate

Unimate was the first industrial robot, which worked on a General Motors assembly line in New Jersey, in 1961. It was created by George Devol in the 1950s using his original patents. Devol, together with Joseph Engelberger, started Unimation the world's first robot manufacturing company.

The machine undertook the job of transporting die castings from an assembly line and welding these parts on auto bodies—a dangerous task for workers, who might be poisoned by exhaust gas or lose a limb if they were not careful.

The original Unimate consisted of a large computer-like box, joined to another box and was connected to an arm, with systematic tasks stored in a drum memory. Modern versions feature up to six degrees of freedom and are designed for high speed handling of car parts, but can be programmed for other tasks.

In 2003 the Unimate was inducted into the Robot Hall of Fame.

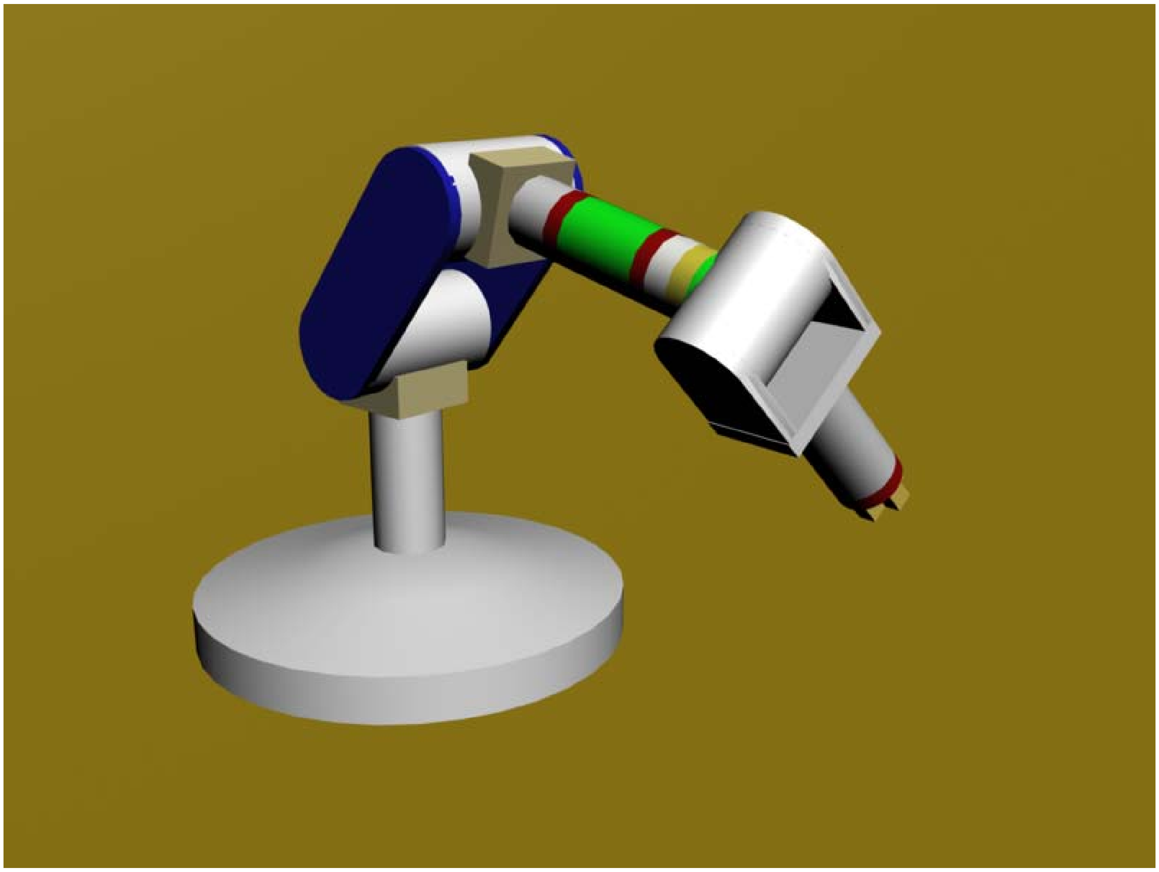
Serial manipulator

Serial manipulators are by far the most common industrial robots. Often they have an anthropomorphic mechanical arm structure, i.e. a serial chain of rigid links, connected by (mostly revolute) joints, forming a "shoulder", an "elbow", and a "wrist".
Their main advantage is their large workspace with respect to their own volume and occupied floor space.
Their main disadvantages are

- the low stiffness inherent to an open kinematic structure
- errors are accumulated and amplified from link to link
- the fact that they have to carry and move the large weight of most of the actuators
- the relatively low effective load that they can manipulate

From rigid body motion it is known that it requires at least six degrees of freedom to place a manipulated object in an arbitrary position and orientation in the workspace of the robot. Hence, many serial robots have six joints. However the most popular application for serial robots in today's industry is pick-and-place assembly. Since this only requires four degrees of freedom, special assembly robots of the so called SCARA type are built.

Structure



An example of a serial manipulator with 7 DOF in a kinematic chain.

In its most general form, a serial robot consists of a number of rigid links connected with joints. Simplicity considerations in manufacturing and control have led to robots with only revolute or prismatic joints and orthogonal, parallel and/or intersecting joint axes (instead of arbitrarily placed joint axes).
Donald L. Pieper derived the first practically relevant result in this context, referred to as 321 kinematic structure: *The inverse kinematics of serial manipulators with six revolute joints, and with three consecutive joints intersecting, can be solved in closed-form, i.e. analytically* This result had a tremendous influence on the design of industrial robots.

Kinematics

The position and orientation of a robot's end effector are derived from the joint positions by means of a geometric model of the robot arm. For serial robots, the mapping from joint positions to end-effector pose is easy, the inverse mapping is more difficult. Therefore, most industrial robots have special designs that reduce the complexity of the inverse mapping.

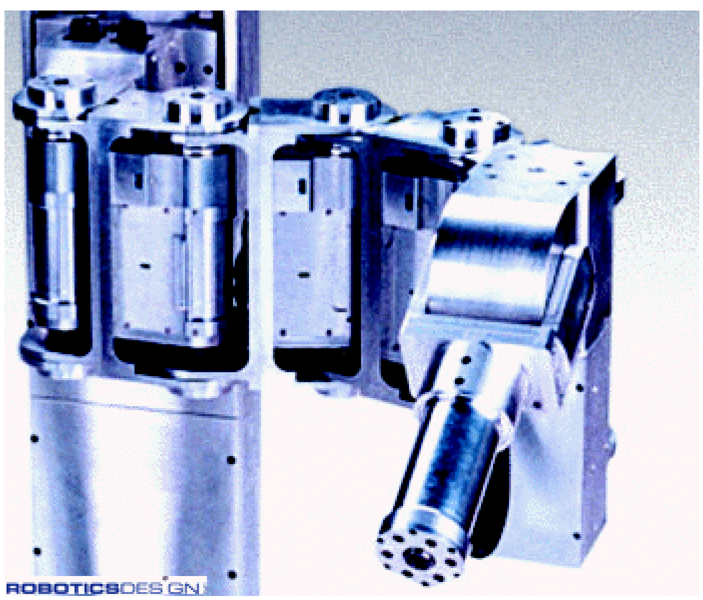
Workspace

The reachable workspace of a robot's end-effector is the manifold of reachable frames. The dextrous workspace consists of the points of the reachable workspace where the robot can generate velocities that span the complete tangent space at that point, i.e., it can translate the manipulated object with three degrees of freedom, and rotate the object with three degrees of rotation freedom.
The relationships between joint space and Cartesian space coordinates of the object held by the robot are in general multiple-valued: the same pose can be reached by the serial arm in different ways, each with a different set of joint coordinates. Hence the reachable workspace of the robot is divided in configurations (also called assembly modes), in which the kinematic relationships are locally one-to-one.

Singularities

At a singularity the end-effector loses one or more degrees of twist freedom (instantaneously, the end-effector cannot move in these directions).
Serial robots with less than six independent joints are always singular in the sense that they can never span a six-dimensional twist space. This is often called an architectural singularity. A singularity is usually not an isolated point in the workspace of the robot, but a sub-manifold.

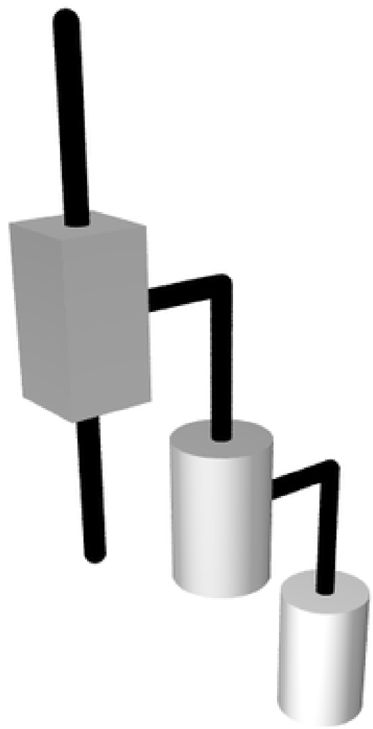
Redundancies



An example of a serial manipulator with 8 DOF that can be configured to n degrees of freedom in mono and dual arm configurations

A manipulator with 7 joints is called redundant if it exceeds this number up to n joints, it is called hyper-redundant. An example of such a robot is Robotics Design's ANAT AMI-100, an arm with a combined SCARA-articulated configuration.

SCARA



Kinematic diagram of SCARA configuration

The **SCARA** acronym stands for **Selective Compliant Assembly Robot Arm** or **Selective Compliant Articulated Robot Arm**.

In 1981, Sankyo Seiki, Pentel and NEC presented a completely new concept for assembly robots. The robot was developed under the guidance of Hiroshi Makino, a professor at the University of Yamanashi. The robot was called Selective Compliance Assembly Robot Arm, SCARA. Its arm was rigid in the Z-axis and pliable in the XY-axes, which allowed it to adapt to holes in the XY-axes.

By virtue of the SCARA's parallel-axis joint layout, the arm is slightly compliant in the X-Y direction but rigid in the 'Z' direction, hence the term: Selective Compliant. This is advantageous for many types of assembly operations, i.e., inserting a round pin in a round hole without binding.

The second attribute of the SCARA is the jointed two-link arm layout similar to our human arms, hence the often-used term, Articulated. This feature allows the arm to extend into confined areas and then retract or "fold up" out of the way. This is advantageous for transferring parts from one cell to another or for loading/ unloading process stations that are enclosed.

SCARA's are generally faster and cleaner than comparable Cartesian systems. Their single pedestal mount requires a small footprint and provides an easy, unhindered form of mounting. On the other hand, SCARA's can be more expensive than comparable Cartesian systems and the controlling software requires inverse kinematics for linear interpolated moves. This software typically comes with the SCARA though and is usually transparent to the end-user.

RoboTurb

RoboTurb is a welding robot used to repair turbine blades developed at Universidade Federal de Santa Catarina. It is a redundant robot with a flexible rail.

Robocrane

Robocrane Project.

The **Robocrane** is a kind of manipulator resembling a Stewart platform but using an octahedral assembly of cables instead of struts. Like the Stewart platform, the Robocrane has six degrees of freedom (x, y, z, pitch, roll, & yaw).

It was developed by James S. Albus of the National Institute of Standards and Technology (NIST), using the Real-Time Control System which is a hierarchical control system. Given its unusual ability to "fly" tools around a work site, it has many possible applications, including stone carving, ship building, bridge construction, inspection, pipe or beam fitting and welding.

Dr. Albus invented and developed a new generation of robot cranes based on six cables and six winches configured as a Stewart platform. The NIST RoboCraneTM has the capacity to lift and precisely manipulate heavy loads over large volumes with fine control in all six degrees of freedom. Laboratory RoboCranes have demonstrated the ability to manipulate tools such as saws, grinders, and welding torches, and to lift and precisely position heavy objects such as steel beams and cast iron pipe. In 1992, the RoboCrane was selected by Construction Equipment magazine as one of the 100 most significant new products of the year for construction and related industries. It was also selected by Popular Science magazine for the "Best of What's New" award as one of the 100 top products, technologies, and scientific achievements of 1992.

A version of the RoboCrane has been commercially developed for the Air Force to enable rapid paint stripping, inspection, and repainting of very large military aircraft such as the C-5 Galaxy. RoboCrane is expected to save the Air Force $8 million annually at each of its maintenance facilities. This project was recognized in 2008 by a National Laboratories Award for technology transfer. Potential future applications of the RoboCrane include ship building, construction of high rise buildings, highways, bridges, tunnels, and port facilities; cargo handling, ship-to-ship cargo transfer on the high seas, radioactive and toxic waste clean-up; and underwater applications such as salvage, drilling, cable maintenance, and undersea waste site management.

Paint robot

Industrial paint robots have been used for decades in automotive paint applications from the first hydraulic versions - which are still in use today but are of inferior quality and safety - to the latest electronic offerings. The newest robots are accurate and deliver results with uniform film builds and exact thicknesses.

Originally industrial paint robots were large and expensive, but today the price of the robots have come down to the point that general industry can now afford to have the same level of automation that only the big automotive manufacturers could once afford.

The selection of today's paint robot is much greater varying in size and payload to allow many configuration for painting items of all sizes. The prices vary as well as the new robot market becomes more competitive and the used market continues to expand.

Painting robots are generally equipped with five or six axis, three for the base motions and up to three for applicator orientation. These robots can be used in any explosion hazard Class 1 Division 1 environment.

Delta robot

Delta robot

A **delta robot** is a type of parallel robot. It consists of three arms connected to universal joints at the base. The key design feature is the use of parallelograms in the arms, which maintains the orientation of the end effector. The delta robots have popular usage in picking and packaging in factories because they can be quite fast, some executing up to 300 picks per minute.

History

The Delta robot (a parallel arm robot) was invented in the early 1980s by Reymond Clavel at the École Polytechnique Fédérale de Lausanne (EPFL, Switzerland). The purpose of this new type of robot was to manipulate light and small objects at a very high speed, an industrial need at that time. In 1987, the company Demaurex purchased a license for the Delta robot and started the production of Delta robots for the packaging industry. In 1991 Reymond Clavel presents his doctoral thesis 'Conception d'un robot parallèle rapide à 4 degrés de liberté' and receives the golden robot award in 1999 for his work and development of the Delta robot. Also in 1999, ABB Flexible Automation starts selling its Delta robot, the FlexPicker. By the end of 1999 the Delta robots are also sold by Sigpack Systems.

Design

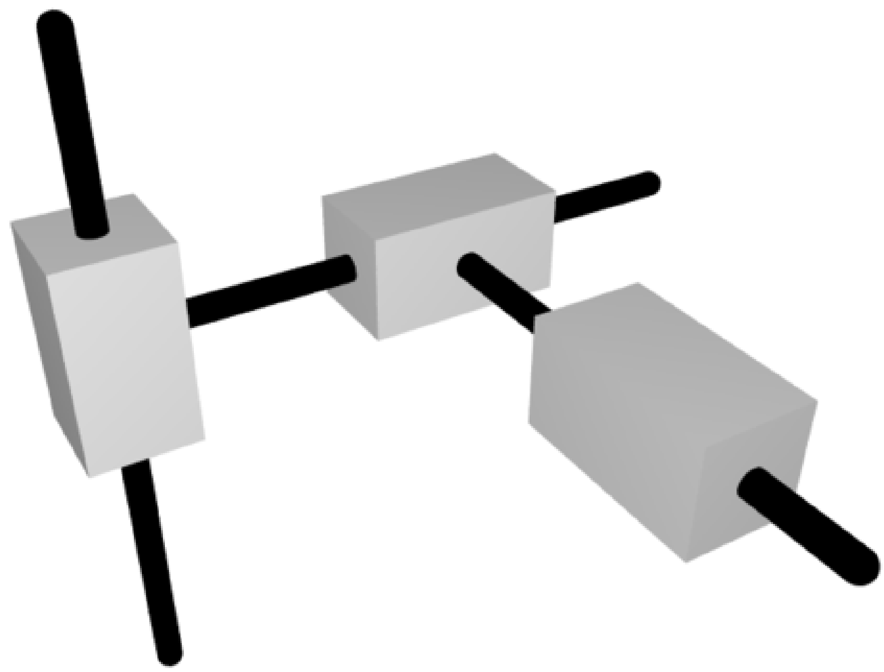
The Delta robot is a parallel robot, which means there's more than one kinematic chain from the base to the end effector. The robot can also be seen as a spatial generalisation of a four-bar linkage. It has four degrees of freedom; three translational and one rotational. The key concept of the Delta robot is the use of parallelograms. These parallelograms restrict the movement of the end platform to pure translation (only movement in the X, Y or Z direction). The robot's base is mounted above the workspace. All the actuators are located in this base. From the base, three middle jointed arms extend. The arms are made of lightweight composite material. The ends of the three arms are connected to a small triangular platform. Actuation of the input links will move the triangular platform in the X, Y or Z direction. Actuation can be done with linear or rotational actuators. From the base, a fourth leg extends to the middle of the triangular platform to give the end effector a fourth, rotational degree of freedom.

Because the actuators are all located in the base, and the arms are made of a composite material the moving parts of the Delta robot have a small inertia. This allows for very high accelerations. Accelerations can be up to 30 g and speeds of 10 m/s can be reached.

Applications

Industries that take advantage of the high speed of the Delta robot are the packaging industry, medical and pharmaceutical industry. Other possible applications include assembly tasks or operation in a clean room for electronic components. The structure of the Delta robot can also be used to create haptic controllers, such as the Force Dimension omega.x, delta.x and sigma.x devices, or the Novint Falcon game controller.

Cartesian coordinate robot



Kinematic diagram of cartesian coordinate robot

A **cartesian coordinate robot** (also called **linear robot**) is an industrial robot whose three principal axes of control are linear (i.e. they move in a straight line rather than rotate) and are at right angles to each other. Among other advantages, this mechanical arrangement simplifies the Robot control arm solution. Cartesian coordinate robots with the horizontal member supported at both ends are sometimes called **Gantry robots**. They are often quite large.

A popular application for this type of robot is a computer numerical control machine (CNC machine). The simplest application is used in milling and drawing machines where a pen or router translates across an x-y plane while a tool is raised and lowered onto a surface to create a precise design.

Articulated robot

A six-axis articulated welding robot reaching into a fixture to weld.

An **articulated robot** is a robot with rotary joints (e.g. a legged robot or an industrial robot). Articulated robots can range from simple two-jointed structures to systems with 10 or more interacting joints. They are powered by a variety of means, including electric motors.

Some types of robots, such as robotic arms, can be articulated or non-articulated.

ASEA IRB

The **ASEA IRB** is an industrial robot series for material handling, packing, transportation, polishing, welding, and grading. Built in 1975, the robot allowed movement in 5 axes with a lift capacity of 6 kg. It was the world's first fully electrically driven and microprocessor-controlled robot, using Intel's first chipset.

The ASEA IRB was constructed by Björn Weichbrodt, Ove Kullborg, Bengt Nilsson and Herbert Kaufmann and was manufactured by ASEA in Sweden/Västerås. The first model, IRB 6, was developed in 1972-1973 on assignment by the ASEA CEO Curt Nicolin and was shown for the first time at the end of August 1973. The example shown in the technical museum is the first robot that was sold. It was bought by Magnussons in Genarp to wax and polish rust-free tubes bent at 90° angles. This robot was donated to the museum during ASEA's 100-year anniversary in 1983.

The IRB 6 sold 1900 copies during the next 17 years (1975-1992). It became the Swedish symbol for a new Labour market, shared between man and robot.

5DX

The **5DX** is an automated x-ray inspection robot, which belongs to the set of automated test equipment robots and industrial robots utilizing machine vision. The 5DX is manufactured by Agilent Technologies. The 5DX is a non-destructive structural test x-ray machine, using laminography (tomography) to take 3D slices of an assembled printed circuit board. It is used in the assembled printed circuit board (PCB) electronics manufacturing industry to provide process feedback to a surface mount technology assembly line, as well as defect capture.

The 5DX is one of several tools used by many companies in the electronics manufacturing services sector to provide a means of structurally testing both the visible and hidden joints of components on assembled printed circuit boards for defects. These joints are referred to as integrated circuit to PCB interconnects.

Structural defects

- Bridging (causing electrical shorts)
- Opens
- Missing/damaged components
- Non-wetting
- Billboards
- Tombstones
- Lifted leads
- Solderballs
- Voids (found in ball grid arrays and paste)
- Insufficient solder
- Excess solder
- Misalignment

5DX technology

The 5DX uses a gantry robot to move the assembled printed circuit board underneath an x-ray source to be able to see the components' joints that require inspection. The positioning of board is guided with the use of CAD data, which represents the outer layers of a printed circuit board's electrical design.

A predefined laser surface map is used to bring the PCB into the plane of focus (depth of field) so that a slice of the component's joints can be taken. A slice will remove obstructions above or below the plane of focus so that only the regions of interest remain (which would otherwise be visible in a 2D x-ray image).

History of the 5DX

Agilent Technologies the OEM of the 5DX and x6000 has announced its plan to exit the x-ray business and focus resources in other areas of automated manufacturing test.

Product Revision History

- 3DX (end of life) originally developed by Four Pi Systems which was acquired by Hewlett Packard.
- 5DX Series I (end of life)
- 5DX Series 2/II/2L (end of life)
- 5DX Series 3
- 5DX Series 5000
- x6000 or x6k (next generation)

Chapter- 4

Global Robotics Headquarters

ABB Group

ABB Ltd.

Type	Public (SIX: ABBN, NYSE: ABB, OMX: ABB)
Industry	Power technology, Industrial automation
Founded	1988 through merger of ASEA (1883) of Sweden and Brown, Boveri & Cie (1891) of Switzerland
Headquarters	Zürich, Switzerland
Area served	Worldwide
Key people	Joe Hogan (CEO), Hubertus von Grünberg (Chairman of the board)
Revenue	▼US $31.80 billion (2009)
Operating income	▼US $4.126 billion (2009)
Profit	▼US $2.901 billion (2009)

Total assets	▲US $34.73 billion (2009)
Total equity	▲US $14.47 billion (2009)
Employees	▼117,000 (2009)

ABB is a Swiss-Swedish multinational corporation headquartered in Zürich, Switzerland, operating mainly in the power and automation technology areas.

ABB is one of the largest engineering companies as well as one of the largest conglomerates in the world. ABB has operations in around 100 countries, with approximately 117,000 employees, and reported global revenue of $31.8 billion for 2009.

ABB is traded on the SIX Swiss Exchange in Zürich and the Stockholm Stock Exchange in Sweden since 1999, and the New York Stock Exchange in the United States since 2001.

History

ABB resulted from the 1988 merger of the corporations ASEA (Allmänna Svenska Elektriska Aktiebolaget, Swedish) and Brown, Boveri & Cie (Swiss); the latter had absorbed the Maschinenfabrik Oerlikon in 1967. CEO at the time of the merger was the former CEO of ASEA, Percy Barnevik, who ran the company until 1996.

ABB's history goes back to the late nineteenth century. ASEA was incorporated by Ludwig Fredholm in 1883 and Brown, Boveri & Cie (BBC) was formed in 1891 in Baden, Switzerland, by Charles Eugene Lancelot Brown and Walter Boveri as a Swiss group of electrical companies producing AC and DC motors, generators, steam turbines and transformers.

Organizational structure

ABB is the world's largest builder of electricity grids and is active in many sectors, its core businesses being in power and automation technologies. The company has one corporate division and five production divisions since reorganisation in January 2010.

Power Products

Power products are the key components for the transmission and distribution of electricity. The division incorporates ABB's manufacturing network for transformers, switchgear, circuit breakers, cables, and associated high voltage and medium voltage equipment such as digital protective relays. It also offers maintenance services. The division is subdivided into three business units - High Voltage Products, Medium Voltage Products and Transformers.

Power Systems

Power Systems offers turnkey systems and service for power transmission and distribution grids, and for power plants. Electrical substations and substation automation systems are key areas. Additional highlights include flexible alternating current transmission systems (FACTS), high-voltage direct current (HVDC) systems and network management systems. In power generation, Power Systems offers the instrumentation, control and electrification of power plants. The division is subdivided into four business units - Grid Systems, Substations, Network Management, and Power Generation.

Discrete Automation and Motion

The division "Discrete Automation and Motion" provides products and services for industrial production. It includes electric motors, generators, drives, programmable logic controllers (PLCs), analytical, power electronics and industrial robots. ABB has installed over 175,000 industrial robots. In 2006 ABB's global robotics headquarters moved to Shanghai, China. Also, Wind generators and solar energy are in this division.

Low Voltage Products

The Low Voltage Products division manufactures low-voltage circuit breakers, switches, control products, wiring accessories, enclosures and cable systems to protect people, installations and electronic equipment from electrical overload. The division further makes KNX systems that integrate and automate a building's electrical installations, ventilation systems, and security and data communication networks. Customers include a wide range of industry and utility operations, plus commercial and residential buildings.

Process Automation

The main focus of this ABB business is to provide customers with systems for control, plant optimization, and industry-specific application knowledge. The industries served include oil and gas, power, chemicals and pharmaceuticals, pulp and paper, metals and minerals, marine and turbocharging.

Corporate and Other

The Corporate and Other department of ABB deals with the overall management and functioning of the company as well as asset management and investment.

Corporate affairs

In the early 1990s, ABB purchased Combustion Engineering (C-E) headquartered in Stamford and Norwalk, Connecticut, a leading U.S. firm in the development of conventional fossil fuel power and nuclear power supply systems to break into the North American market. Continuing with its expansion plans, ABB purchased Elsag Bailey, a process automation group, in 1997, which included Bailey Controls, Hartmann & Braun, and Fischer & Porter. This was the largest acquisition to date in ABB's history.

ABB bought International Combustion Ltd from Rolls-Royce in 1997.

ABB's boiler and fossil fuel businesses were purchased by Alstom in 2000, and its nuclear business was purchased by Westinghouse Electric Company also in 2000.

In 2000, ABB signed a contract for the delivery of equipment and services for two North Korean nuclear powerplants to be supplied under an agreement with the Korean Peninsula Energy Development Organization (KEDO), a consortium formed in 1995 by the governments of the United States, Japan, South Korea and the European Union. Also in 2000, ABB formally divested from a joint venture named ABB-Alstom Power and sold its interest in conventional power generation systems to Alstom Power. ABB's nuclear business was sold to BNFL and merged into Westinghouse Electric Company.

In 2001, ABB was ranked as number one on the Dow Jones corporate sustainability index for the third year in a row.

In 2002 ABB asked Lindahl, the company's former chief executive, to return some of his $50 million retirement pay, which its board called excessive. ABB also asked its former chairman Percy Barnevik to pay back part of his $87 million pension package. The size of the pensions was disclosed at the same time as ABB's $691 million net loss for 2001 made headlines and drew sharp criticism in Switzerland and Sweden.

ABB's Building Systems business unit was sold off in 2004 to Capvis, a Swiss private equity company, as part of ABB's strategy to focus on power and automation technologies. ABB's building systems businesses in Australia and Hong Kong were sold off the year before in May 2003 to Downer EDI Limited. Building Systems provided services for building facilities encompassing indoor air quality, building automation as well as power distribution and management.

Financial debt and lingering asbestos liability brought ABB to the brink of bankruptcy in the early 2000s. In 2006, ABB returned to financial health by settling its asbestos liability regarding claims that were filed against ABB's U.S. subsidiaries, Combustion Engineering and Lummus Global. In August 2007, Lummus Global was sold to CB&I.

In 2009, ABB realigned its automation divisions to enhance growth opportunities. As of January 1, 2010, the business units in the Automation Products and Robotics divisions were regrouped into two new divisions – Discrete Automation and Motion, and Low Voltage Products. The Process Automation division remained unchanged except for the addition of the instrumentation business from the Automation Products division.

Adept Technology

An *Adept Cobra* SCARA Robot in a pick and place application using vision guidance and the *AnyFeeder* for flexible feeding applications. All robot guidance and vision calculations are done in the base of the robot.

Adept Technology, Inc. is a multinational corporation with headquarters in Pleasanton, California (San Francisco Bay Area). The company focuses on industrial automation and robotics, including software and vision guidance. Adept has offices throughout the United States as well as in Dortmund, Germany, Paris, France, and Singapore. Adept is publicly traded on the U.S. NASDAQ under the sticker symbol (NASDAQ: ADEP).

Company history

Adept was founded in 1983, and was formerly the West Coast Division of Unimation, which became part of Westinghouse after being a division of Consolidated Diesel Electronic (Condec) for many years. However, its roots go back almost 10 years earlier, when company founders Bruce Shimano and Brian Carlisle, both Stanford graduate students, started to work with Victor Scheinman at Standford's AI lab.

Today, the company is active in a variety of industries requiring high speed, precision part handling including food handling, consumer product and electronics, packaging, medical and lab automation, automotive, as well as emerging markets like solar manufacturing.

Robots

In 1984, the company introduced its first product, the *AdeptOne* SCARA robot. The simplicity of the mechanism, based on direct-drive motors, made *AdeptOne* robots very robust in continuous industrial automation applications, while maintaining high accuracy. *AdeptOne* robots continue to be in use worldwide in 2009.

Around 2004, Adept introduced table-top SCARA robots called the *Adept Cobra i600/i800*, with the system and servo controls, and the power amplifiers, embedded in the base of the robot. The related *Adept Cobra s600/s800* models employ an external controller (with the servo controls and amplifiers still in the robot base) to achieve greater system functionality. These robots are claimed to be the fastest robots in their class.

In 2006, Adept released its new delta-4 robot, the *Adept Quattro*. It is based on a new concept of delta-style robot mechanism that has four arms versus the traditional three-arm design. The rotation is achieved through a parallel platform.

Adept also offers *Adept Python* linear-module robots with one to four axes in various configurations, and six-axis *Adept Viper* articulated robots.

Software & Vision

On the software side, Adept continues to develop its powerful robotic language, *V+*. Even though *V+* does not have the full capabilities of a general-purpose OS, it does offer a variety of tools aimed at manipulating robot arms. For example, functions relating to transformation and frames: one can command the robot to move to a position relative to a conveyor belt, and track the position as the belt moves, with a single instruction: *MOVES %belt:pos*

Vision guidance, first introduced with the *AdeptOne* robot, was further developed and now contains a powerful object finder, vision inspection, blob finder, etc. enabling vision-to-robot calibration.

In 2008, Adept released its new software platform called *Adept ACE*. *Adept ACE* is an application development software environment that allows a user to program a robotic application.

Hardware and Software History

Adept has its own robot control operating system, *V+*, which has come to version 17 by 2009. The history of *V+* dates back to the days of Unimation. At the time it was called *VAL* (Victor's Assembly Language), which evolved into *VAL-II* and *VAL-III* later. After the formation of Adept, the rights to parts of the OS were granted to Adept.

The Adept OS at that time was called *V*, and it ran on the refrigerator-sized controllers that were based on the MultiBus technology. Around 1986 the *Adept MC* controller was introduced; while still based on the MultiBus, it was smaller than the original controller. After the *Adept MC* controller (around 1990), came the *Adept MV* controller, which was based on the VME backplane technology. Then around 2000 the *SmartController CS/CX* controllers were introduced, which are current production as of 2009.

Along with the changes of the controller itself, the servo controls also saw major improvements over the years. Around 200x, with the *V+* version reaching ver. 14, the servo amplifier and controls were part of the robot, and hence separated from the main robot controller itself. This is when distributed controls were introduced by the company. The idea of having the amplifier and servo controls in the base of the robot was named AIB (Amplifier in Base). Adept still follows the AIB mantra, and has an AIB in the latest robot, *Adept Quattro*, reducing the footprint of the robot/manipulator/controller system.

Controls

The Adept core business continues to be motion control. Its *SmartController CX* integrates motion controller, vision guidance, and interfaces to factory networks.

Denso

DENSO Corporation

DENSO

Industry	automotive components
Founded	1949
Headquarters	Kariya, Aichi, Japan
Revenue	▲$32.28 billion
Net income	▼$860 million
Total assets	$29.34 billion
Total equity	$24.05 billion
Website	DENSO Global

DENSO Corporation (株式会社デンソー *Kabushiki-gaisha Densō*?) (TYO: 6902) is a global automotive components manufacturer headquartered in the city of Kariya, Aichi Prefecture, Japan. Established December 16, 1949 as Nippondenso Co. Ltd. (日本電装株式会社 *Nippon Densō Kabushiki-gaisha*?), DENSO is a member of the Toyota Group of companies.

The company is known for creating the QR Code, a two-dimensional barcoding system which is particularly prevalent in Japan.

As of March 31, 2005 DENSO Corporation consisted of 171 subsidiaries (64 in Japan, 33 in the Americas, 31 in Europe and 43 in Asia/Oceania) with a total of 104,183 employees. In 2006, DENSO was listed at #207 on the Fortune 500 list with a total revenue of US$ 28.2 billion and a profit of US$ 1.5 billion. In 2009, DENSO was listed at #271 on the Fortune 500 list with a total revenue of US$ 31,282 million.

Sales

In 2004, DENSO's global sales were distributed as follows:

- Thermal Systems 34.9%
- Powertrain Control Systems 22.7%
- Electronic Systems 14.8%
- Electric Systems 11.4%
- Small Motors 7.1%
- ITS (Intelligent Transportation Systems) 3.6%
- Industrial Systems, Consumer Products 2.1%
- Other Automotive 1.4%

Denso International America

Denso International America is the American subsidiary of DENSO Corporation.

In 1970, DENSO Corporation decided to expand overseas from Kariya, Japan to North America. In March 1971 DENSO Sales California, Inc. was founded in Hawthorne, California. The company was staffed with only 12 associates, four of them were Americans. The objective of DENSO Sales California was to promote their air conditioner systems to be options in Japanese-made vehicles.

In May 1975 DENSO Corporation opened a sales division, DENSO Sales, in Southfield, Michigan.

In September 1975 DENSO International America opened a service center in Cedar Falls, Iowa. This was opened due to an agricultural parts contract with John Deere including starter motors and meters.

DENSO International America employs over 17,000 people at 38 locations between North, Central, and South America. At year end, on March 31, 2008, combined sales totaled $8.3 billion for all American locations.

Epson Robots

EPSON Robots is the robotics design and manufacturing department of Japanese corporation Seiko Epson, the brand-name watch and computer printer producer.

EPSON manufacture Cartesian, SCARA and 6-axis industrial robots for factory automation. Cleanroom and ESD compliant models are available.

They offer PC-based controllers and vision systems based on Matrox Imaging technology.

EPSON have a 21 year heritage and there are more than 18,000 EPSON robots installed in manufacturing industries around the world. EPSON used a standardized PC-based controller for 6-axis robots, SCARA, and Linear Module needs. A move that simplifies support and reduces learning time.

FANUC

FANUC LTD.

FANUC

Type	Public KK (TYO: 6954)
Industry	Manufacturing, Robotics
Founded	1972, spin-off from Fujitsu
Headquarters	Oshino-mura, Minamitsuru-gun, Yamanashi Prefecture, Japan
Area served	Worldwide
Key people	Dr. Eng. Seiuemon Inaba (Honorary Chairman) Dr. Eng. Yoshiharu Inaba (President & CEO)
Revenue	▼¥253,393 million JPY (2009)
Operating income	▼¥55,024 million JPY (2009)
Profit	▼¥37,511 million JPY(2009)
Employees	4,872 consolidated (2007)

FANUC or **FANUC LTD** (ファナック株式会社 *Fanukku Kabushikigaisha*?) (TYO: 6954) is a Japanese electromechanical manufacturer specializing in robotics. It is one of the largest maker of industrial robots in the world. It is part of the Furukawa Group. FANUC had its beginnings as part of Fujitsu developing numerical control (NC) and servo systems. The company name is an acronym for **F**actory **A**utomatic **Nu**merical **C**ontrol.

In 1972, the Computing Control Division became independent and FANUC Ltd was established.

FANUC is listed on the Tokyo Stock Exchange, Section 1, 6954. It is headquartered in Yamanashi Prefecture.

Among FANUC's biggest clients are many US and Japanese automobile and electronics manufacturers. FANUC probably more than any other Japanese company has been instrumental in developing Japan's image as a producer of precision and quality equipment. Use of industrial robots has allowed companies like Panasonic in Amagasaki to run factories which produce 2 million television sets *a month* (mostly high end plasma LCD screens including the world's largest at 103 inches), with just 15 people.

FANUC has joint ventures, subsidiaries, and sales offices on 5 continents and over 22 countries. It is one of the largest makers of CNC controls by market share.

Subsidiaries and joint ventures

FANUC Robotics America, Inc. is the leading supplier of robotic automation in North and South America with over 210,000 robots installed. It offers over 200 robot model variations to meet the needs of a wide range of applications. It also produces software, controls, and vision products that aid in the development of state-of-the-art robotic systems. Headquartered in Rochester Hills, Michigan, FANUC Robotics America has ten regional locations in the U.S., Canada, Mexico and Brazil. The company provides these systems for a variety of industries - from automotive and fabricated metals to medical devices and plastics. The company began in 1982 as a joint venture between FANUC Ltd and General Motors Corporation, named GMFanuc Robotics Corporation. A staff of 70 began work at the GM Technical Center in Warren, Michigan. In 1992, the company became a wholly owned subsidiary of FANUC Ltd of Oshino-mura, Japan.

FANUC Robotics Europe S.A., a sister company, is headquartered in Luxembourg, and serves customers throughout Europe. Sales, service and support are provided worldwide.

FANUC America Corporation is responsible for CNC operations in North and South America. It offers CNC and laser technical services, training, replacement parts, PCB and motor repair and return, field support, and after hours support. Headquartered in the Chicago suburb of Hoffman Estates, Illinois, FANUC AMERICA has over 30 locations in the U.S., Canada, Mexico, Brazil and Argentina. The company provides these services to machine tool builders, machine tool dealers, and small mom and pop tool shops across a variety of industries. In 1977, the company was established as a wholly owned subsidiary of FANUC Ltd of Oshino-mura, Japan.

GE Fanuc Intelligent Platforms was a joint venture between General Electric and FANUC Ltd. that began in 1986. In 2009, GE and FANUC Ltd. agreed to split, with FANUC Ltd. retaining the CNC business. GE will rename the company **GE Intelligent Platforms**.

On January 1, 2010, **Fanuc America Corporation** and the prior CNC business unit from **GE Fanuc Intelligent Platforms** in the US were combined into a new company by the name of **FANUC CNC America**. This new business unit is a wholly owned subsidiary of FANUC Ltd, Japan and now offers CNC systems, Lasers, Manufacturing Intelligence software products, field repairs and advanced technical services, expanded training classes, a vast inventory of CNC replacement parts, PCB motor repair and return, field support, and CS-24 after hours support. This new company will be headquartered in the Chicago suburb of Hoffman Estates, Illinois,

Intelligent Actuator

Intelligent Actuator, also called **IAI**, is a robotics design company. It was founded in Japan in 1976. The company designs, manufactures, and markets a complete line of motion control systems. IAI is the world's largest manufacturer of cartesian coordinate robots and is an established leader in low cost, high performance SCARA robots.

IAI (International Automation Industry)

Type	Public KK
Industry	Manufacturing, Robotics, Automation
Founded	1976
Headquarters	Shizuoka Prefecture, Japan
Area served	Worldwide

With the introduction in 2001 of a full range of "ROBO Cylinders", IAI is also leading a transition away from pneumatics to cost-effective, low-maintenance, and fully-programmable electric cylinders.

IAI Industrieroboter GmbH is the European subsidiary of IAI, founded in 1995.

IAI America, Inc. was established in 1989. IAI products are distributed in North America through a network of authorized representatives supported by regional centers in Los Angeles, CA, Chicago, IL, and Atlanta, GA.

KUKA

KUKA Robotics Corp.

Type	private (Subsidiary of KUKA Roboter GmbH)
Industry	Automation
Founded	1896 in Germany,
Headquarters	Augsburg, Bavaria, Germany
Products	Industrial robots
Parent	KUKA Roboter GmbH, Germany

KUKA Robotics is a leading German producer of industrial robots for a variety of industries - from automotive and fabricated metals to food and plastics. The KUKA Robotics Corporation has over 20 subsidiaries worldwide, including: the United States, Canada, Mexico, Brazil, Japan, Korea, Taiwan, India and almost all European countries.

The company name, KUKA, is an acronym for Keller und Knappich Augsburg, and at the same time is the registered trademark found on the industrial robots and other products they produce. The company was founded in 1898 and in 1995 was split into KUKA Robotics Corporation and KUKA Schweißanlagen GmbH (now KUKA Systems GmbH). The company headquarters are located in Augsburg, Germany. The company belongs to the publicly traded KUKA AG (earlier IWKA Group).

In 1973 KUKA created the world's first industrial robot with six electromechanically driven axes, known as FAMULUS. Today the company's 4 and 6 axis robots range from 3 kg to 1300 kg payloads, and 350 mm to 3700 mm reach, SCARAs, palletizers, gantry and articulated robots, all controlled from a common PC based controller platform.

By 2006, the KUKA Robotics Corporation and its subsidiaries have installed close to 80,000 robots and the company has become one of the worldwide market leaders in industrial robots. KUKA industrial robots are used in a number of industries – from automotive and metal working to foodstuffs and plastics.

KUKA industrial robots are used in production by companies like: GM, Chrysler, Ford, Porsche, BMW, Audi, Mercedes-Benz, Volkswagen, Ferrari, Harley-Davidson, Boeing, Siemens, IKEA, Swarovski, Wal-Mart, Budweiser, BSN Medical as well as Coca-Cola and others.

The KUKA Chair of Robotics (Prof. Henrik Christensen) at the Georgia Institute of Technology is one source of KUKA's future robotics developments.

System information

Robots come with a control panel that has a display resolution of 640 x 480 pixels and an integrated mouse, with which the manipulator is moved, positions are saved (TouchUp), or where modules, functions, data lists, etc. are created and modified. To manually control the axles the enabling switch on the back of the control panel (the KCP, or KUKAControlPanel) must be activated (today only with a panic function). The connection to the controller is a VGA interface and a CAN-bus.

A rugged computer located in the control cabinet communicates with the robot system via an MFC card. Control signals between the manipulator and the controls are transferred using the so-called DSE-RDW connection. The DSE card is in the control cabinet, the RDW card in the robot socket.

Controls for the old KRC1 types used Windows 95 to run VxWorks-based software. Peripheral equipment includes a CD-ROM and a disk drive; Ethernet, Profibus, Interbus, Devicenet and ASI sockets are also available.

Controls for the newer KRC2 type use the Windows XP operating system. Systems contain a CD-ROM drive and USB ports, Ethernet connection and feature optional connections for Profibus, Interbus, DeviceNet and Profinet.

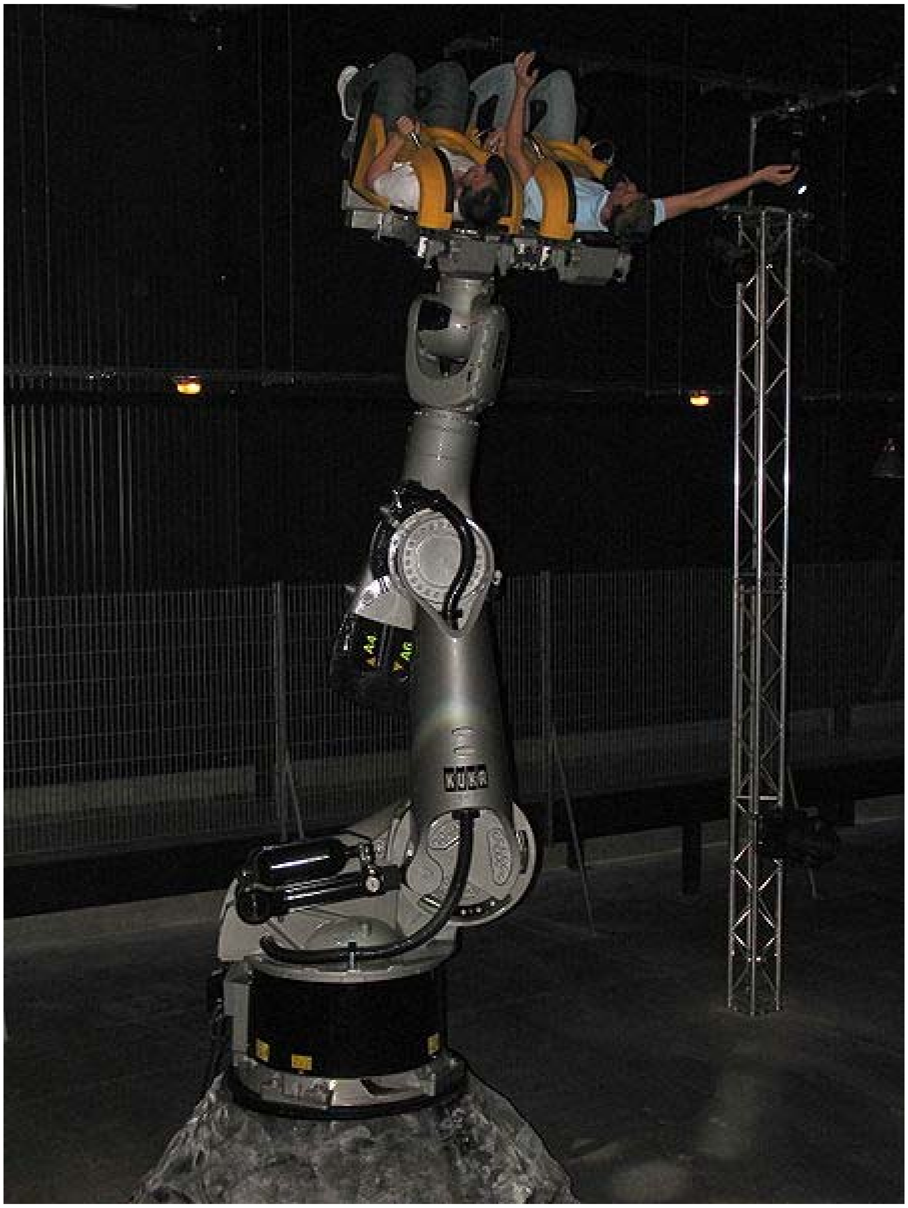
Most robots come in the orange or black, the former featuring prominently as a corporate color.

KUKA's industrial robots product range:

KUKA´s industrial robots

Kinematic Type	Number of Axes	Significance	Payload Range
articulated robot	6 axis	handling robots	5 to 1000 kg
articulated robot	6 axis	arc welding robots	5 to 16 kg
articulated robot	6 axis	spot welding robots	100 to 240 kg
articulated robot	6 axis	shelf-mounted robots, top loader robots for machine loading and unloading	6 to 210 kg
articulated robot	6 axis	stainless steel robot for food processing, IP67	15 kg
articulated robot	6 axis	cleanroom robots	16 to 500 kg
articulated robot	6 axis	heat resistant robots for foundry industry	16 to 500 kg
articulated robot	6 axis	painting robots, ATEX-compliant robots for operating in explosive atmospheres	16 kg
articulated robot	6 axis	heat resistant robots for foundry industry	16 to 500 kg
articulated robot	4 axis	palletizers for bag and box palletizing and depalletizing	40 to 1300 kg
SCARA robot	4 axis	handling robots for pick and place, handling and packaging operations	5 to 10 kg
gantry robot	6 axis	portal robot for machine tending and material handling tasks for distances of up to 20 m	30 to 60 kg

KUKA Robot application examples



KUKA´s Robocoaster is an amusement ride based on industrial robotics technology.

KUKA industrial robots are used in material handling, loading and unloading of machines, palletizing, spot and arc welding. KUKA Robots have also appeared in various Hollywood Films. In the James Bond film Die Another Day, in a scene depicting an ice palace in Iceland, the NSA agent Jinx (Halle Berry) is threatened by laser-wielding robots. In the Ron Howard directed film The Da Vinci Code, a KUKA robot hands Tom Hanks’ character Robert Langdon a container containing a cryptex. In 2001 KUKA developed the Robocoaster, which is the world’s first passenger-carrying industrial robot. The ride uses roller-coaster-style seats attached to robotic arms and provides a roller coaster-like motion sequence to its two passengers through a series of programmable maneuvers. There is also the possibility that riders themselves can program the motions of their ride. In 2007 KUKA introduced a simulator, based on the Robocoaster. Since

2010 Universal's Islands of Adventure theme park in Orlando, Florida utilises KUKA robotic arm technology in the Harry Potter and the Forbidden Journey ride. This was revolutionary, as the robotic arm is mounted on a track, allowing the robotic arm to laterally move on a pathway through a warehouse while performing its movements.

Motoman

Motoman Inc.

Type	Private sector
Industry	Robotics, Automation
Founded	August 1989
Headquarters	West Carrollton, Ohio, USA
Key people	Steve Barhorst, President/COO
Products	Industrial Robots
Employees	450 (2007)

Motoman Inc. is an American subsidiary of the Japanese company Yaskawa Electric Corporation.

Motoman produces robotic automation for industry and robotic applications, including arc welding, assembly, clean room, coating, dispensing, material cutting (laser, plasma, waterjet), materials handling, materials removal, and spot welding. Motoman's official website claims that they are the second largest robotics company in the Americas. In June 2010 Motoman announced that they would move their corporate headquarters to neighboring Miamisburg in 2011

Reis Robotics

Reis Robotics Inc.

Type	private (Subsidiary of Reis Robotics GmbH&Co.KG)
Industry	Automation
Founded	1957 in Germany
Headquarters	Obernburg, Bavaria, Germany
Products	Industrial robots and software solutions
Divisions	Sales Offices USA Elgin, IL & Valencia, CA

Reis Robotics is a leading technology company for robotics and system integration. Their robotic automation solutions are used by all major application fields such as solar energy, foundry and welding. The Reis Robotics group comprises three German subsidiaries and eight international subsidiaries as well as representative agencies in many countries. Reis Robotics USA has two locations, the headquarters in Elgin, IL and the west coast technical center in Valencia, CA.

Reis Robotics was founded in 1957 in Obernburg, Bavaria, Germany by Walter Reis as a tool maker. Today they are the market leader for robotic automation systems.