



Different Types of Robots & their Applications

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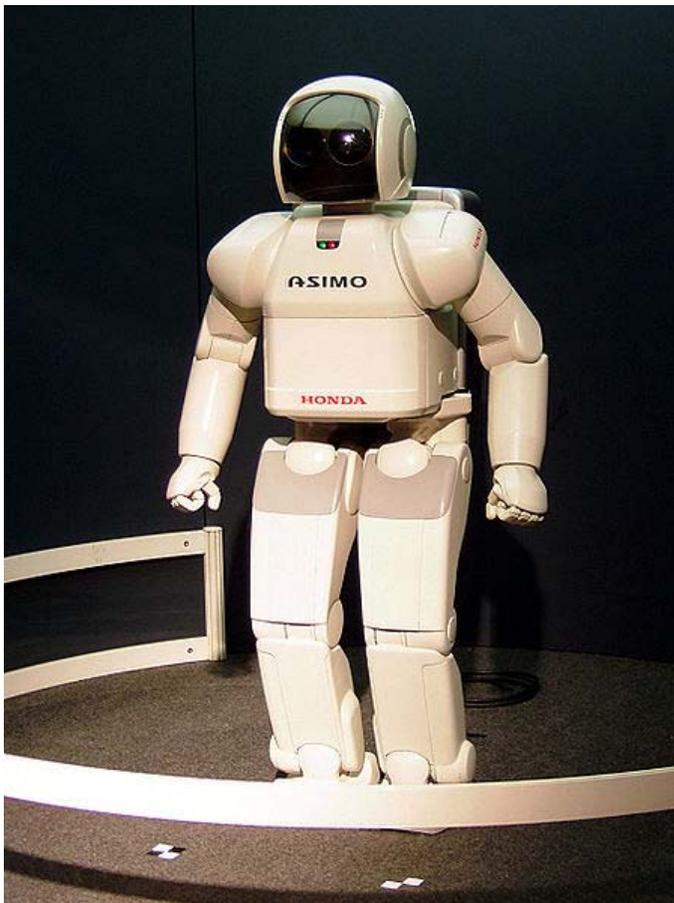
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Chapter-1

Introduction to Robot

Robot



ASIMO, a humanoid robot.

Industry	Automotive, Medical
Fuel Source	Electric
Powered	Yes
Self-Propelled	Yes

A **robot** is a virtual or mechanical artificial agent. In practice, it is usually an electro-mechanical machine which is guided by computer or electronic programming, and is thus able to do tasks on its own. Another common characteristic is that by its appearance or movements, a robot often conveys a sense that it has intent or agency of its own.

Origins



Building the robot of Leonardo da Vinci

Since the beginnings of civilisation man has had a fascination for a human-like creation that would assist him. Societies in the early part of the first millennium engaged in slavery and used those slaves to perform the tasks which were either dirty or menial

labours. Having slaves freed the enslavers to carry on their society and concentrate on what they perceived as more important tasks such as business and politics. Man had discovered mechanics and the means of creating complex mechanisms which would perform repetitive functions such as waterwheels and pumps. Technological advances were slow but there were more complex machines, generally limited to a very small number, which performed more grandiose functions such as those invented by Hero of Alexandria.

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

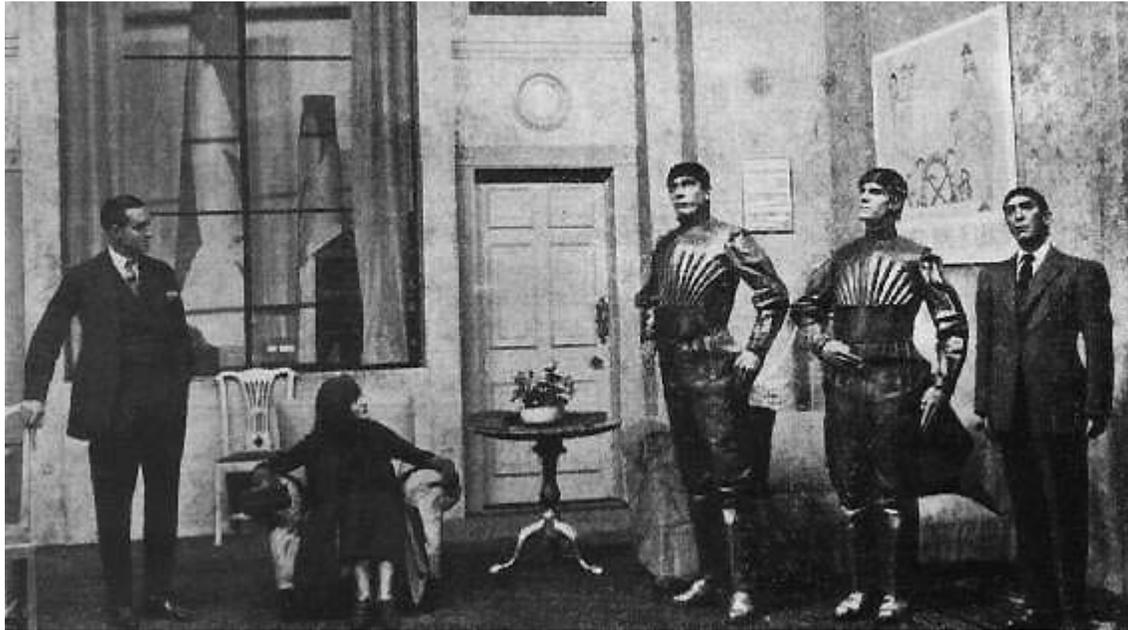
Electronics now became the driving force of development instead of mechanics with the advent of the first electronic autonomous robots created by William Grey Walter in Bristol, England in 1948. The first digital and programmable robot was invented by George Devol in 1954 and was ultimately called the Unimate. Devol sold the first Unimate to General Motors in 1960 where it was used to lift pieces of hot metal from die casting machines in a plant in Trenton, New Jersey.

Since then we have seen robots finally reach a more true assimilation of all technologies to produce robots such as ASIMO which can walk and move like a human. Robots have replaced slaves in the assistance of performing those repetitive and dangerous tasks which humans prefer not to do or unable to do due to size limitations or even those such as in outer space or at the bottom of the sea where humans could not survive the extreme environments.

Robots come in those two basic forms: Those which are used to make or move things, such as Industrial robots or mobile or servicing robots and those which are used for research into human-like robots such as ASIMO and TOPIO as well as those into more defined and specific roles such as Nano robots and Swarm robots.

Man has developed a fear of the autonomous robot and how it may react in society, such as Shelley's Frankenstein and the EATR, and yet we still use robots in a wide variety of tasks such as vacuuming floors, mowing lawns, cleaning drains, investigating other planets, building cars, entertainment and in warfare.

Etymology



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

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

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

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

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

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

Definitions

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

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



The various types of robots

KITT (a fictitious robot) is mentally anthropomorphic

ASIMO is physically anthropomorphic

Defining characteristics

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

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

Mental agency

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

- A clockwork car is never considered a robot.
- A mechanical device able to perform some preset motions but with no ability to adapt (an automaton) is rarely considered a robot.
- A remotely-operated vehicle is sometimes considered a robot (or telerobot).
- A car with an onboard computer, like Bigtrak, which could drive in a programmable sequence, might be called a robot.
- A self-controlled car which could sense its environment and make driving decisions based on this information, such as the 1990s driverless cars of Ernst Dickmanns or the entries in the DARPA Grand Challenge, would quite likely be called a robot.
- A sentient car, like the fictional KITT, which can make decisions, navigate freely and converse fluently with a human, is usually considered a robot.

Physical agency

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

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

- A zoomorphic mechanical toy, like Roboraptor, is usually characterized as a robot.
- A mechanical humanoid, like ASIMO, is almost always characterized as a robot, usually as a service robot.

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

Social impact

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

Regional perspectives

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

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

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

Autonomy and ethical questions

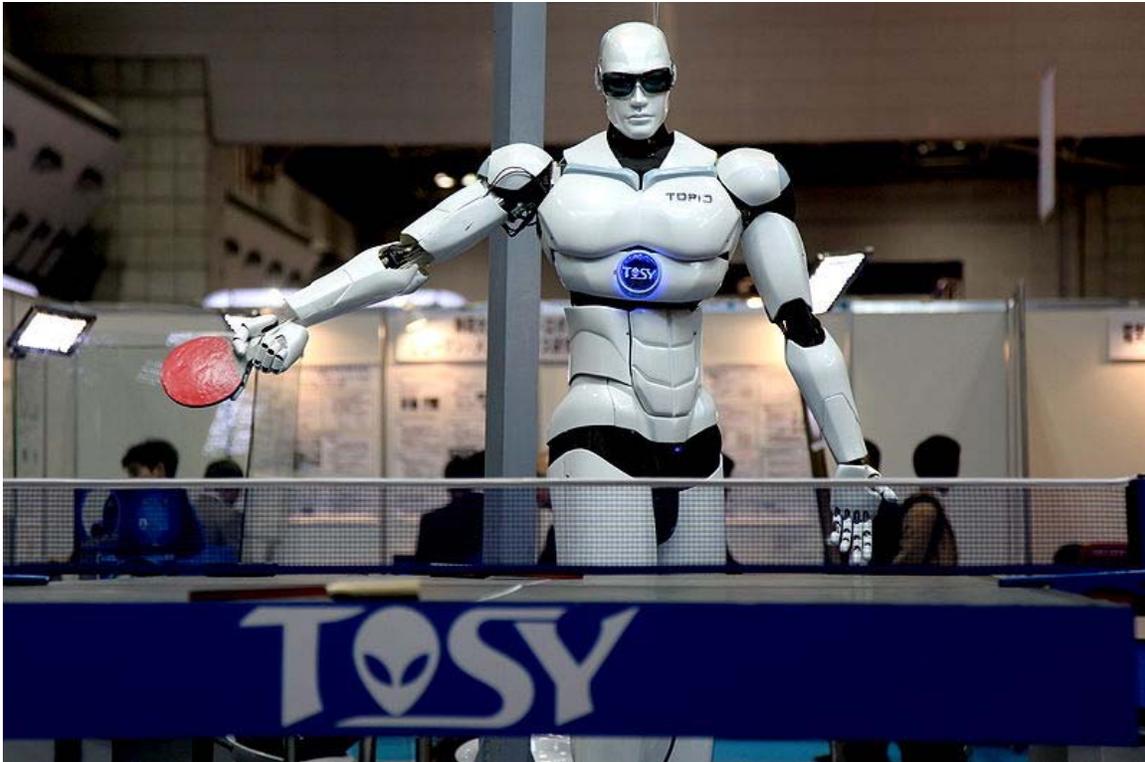
As robots have become more advanced and sophisticated, experts and academics have increasingly explored the questions of what ethics might govern robots' behavior, and whether robots might be able to claim any kind of social, cultural, ethical or legal rights. One scientific team has said that it is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

predict robot intelligence breakthroughs by 2050. Recent advances have made robotic behavior more sophisticated.

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

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

Contemporary uses



TOPIO, a humanoid robot that can play ping-pong.

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

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

General-purpose autonomous robots

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



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

Factory robots

Car production

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



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

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

Electronics

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

Automated guided vehicles (AGVs)

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

Early AGV-Style Robots

Limited to tasks that could be accurately defined and had to be performed the same way every time. Very little feedback or intelligence was required, and the robots needed only the most basic exteroceptors (sensors). The limitations of these AGVs are that their paths are not easily altered and they cannot alter their paths if obstacles block them. If one AGV breaks down, it may stop the entire operation.

Interim AGV-Technologies

Developed to deploy triangulation from beacons or bar code grids for scanning on the floor or ceiling. In most factories, triangulation systems tend to require moderate to high maintenance, such as daily cleaning of all beacons or bar codes. Also, if a tall pallet or large vehicle blocks beacons or a bar code is marred, AGVs may become lost. Often such AGVs are designed to be used in human-free environments.

Intelligent AGVs (i-AGVs)



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

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

Dirty, dangerous, dull or inaccessible tasks

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

Space probes

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

Telerobots

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

Automated fruit harvesting machines



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

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

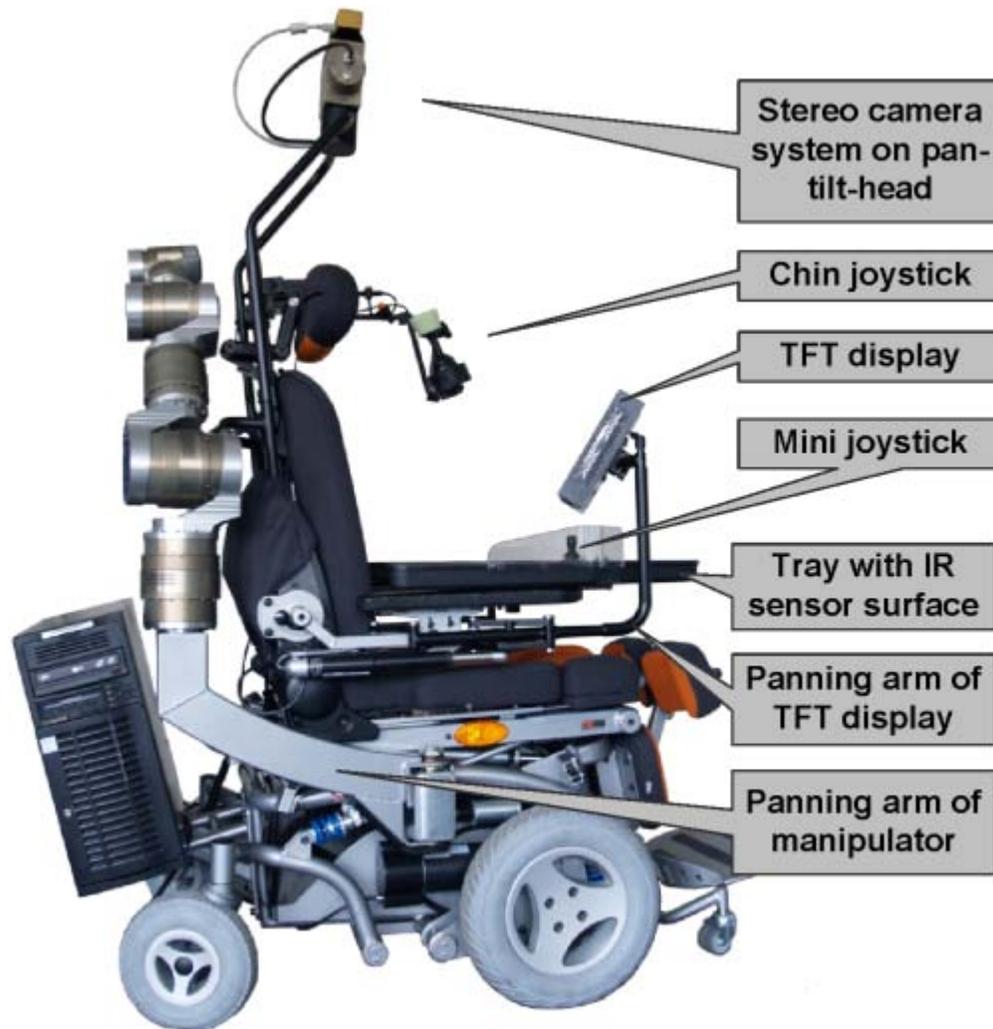
In the home

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

Home automation for the elderly and disabled

The population is aging in many countries, especially Japan, meaning that there are increasing numbers of elderly people to care for, but relatively fewer young people to

care for them. Humans make the best carers, but where they are unavailable, robots are gradually being introduced.



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

The Care-Providing robot FRIEND is a semi-autonomous robot designed to support disabled and elderly people in their daily life activities, like preparing and serving a meal, or reintegration in professional life. FRIEND make it possible for such people, e.g. patients which are paraplegic, have muscle diseases or serious paralysis, e.g. due to strokes, to perform special tasks in daily life self-determined and without help from other people like therapists or nursing staff. The robot FRIEND is the third generation of such robots developed at the Institute of Automation (IAT) of University of Bremen within different research projects. Within the last project, AMaRob (AMaRob web page), an interdisciplinary consortium, consisting of technicians, designers as well as therapists and further representatives of various interest groups, influences the development of FRIEND. Besides covering the various technical aspects, also design aspects were

included as well as requirements from daily practice given by therapists, in order to develop a care-providing robot that is suitable for daily life activities. The AMaRob project was founded by the German Federal Ministry of Education and Research (*BMBF* – *Bundesministerium für Bildung und Forschung*) within the “Leitinnovation Servicerobotik”.

Duct Cleaning



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

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

Military robots

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

Unmanned combat air vehicles (UCAVs), which are an upgraded form of UAVs, can do a wide variety of missions, including combat. UCAVs are being designed such as the Mantis UCAV which would have the ability to fly themselves, to pick their own course and target, and to make most decisions on their own.

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

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

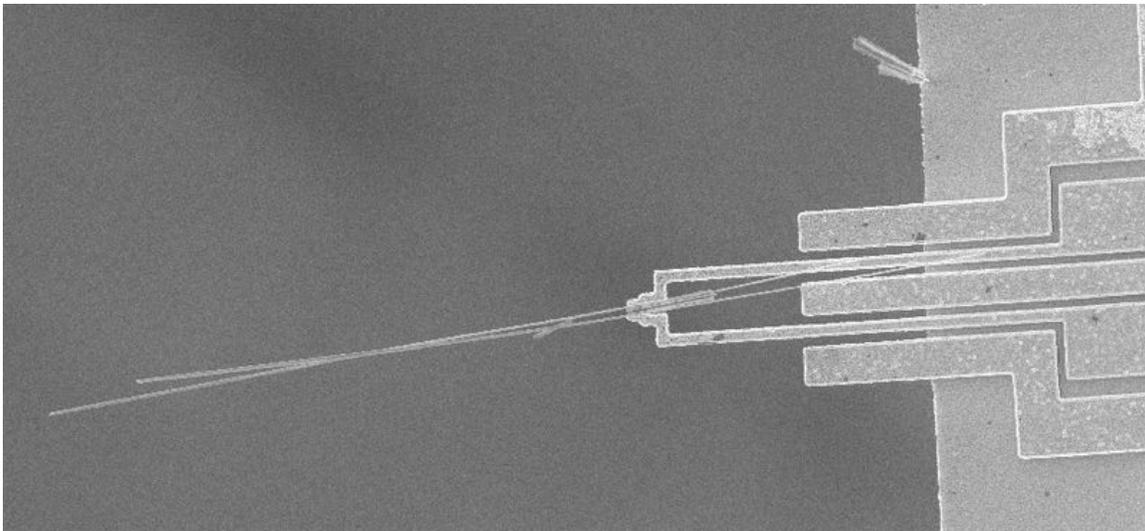
Schools

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

Research robots

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

Nanorobots



A microfabricated electrostatic gripper holding some silicon nanowires.

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

Reconfigurable Robots

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

Soft Robots

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

Swarm robots



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

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

Haptic interface robots

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

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

Future development

Technological trends

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

Technological development

Overall trends

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

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

New functions and abilities

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

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

Chapter-2

History of Robots

The **history of robots** date at least as far back as ancient myths and legends. Digitally controlled Industrial robots and robots making use of Artificial intelligence have been built since the 1960s.

Robotics in Antiquity

Likely fictional, the Iliad illustrates the concept of robotics by stating that the god Hephaestus made talking mechanical handmaidens out of gold. Around 400 BC, Archytas of Tarentum is reputed to have built a mechanical pigeon, possibly powered by steam, capable of flying. Not only representing one of the earliest works in the field of robotics, the wooden pigeon was also an early study of flight. Taking up the earlier reference in Homer's Iliad, Aristotle speculated in his *Politics* (ca. 322 BC) that automatons could someday bring about human equality by making possible the abolition of slavery:

— There is only one condition in which we can imagine managers not needing subordinates, and masters not needing slaves. This condition would be that each instrument could do its own work, at the word of command or by intelligent anticipation, like the statues of Daedalus or the tripods made by Hephaestus, of which Homer relates that

'Of their own motion they entered the conclave of Gods on Olympus'

as if a shuttle should weave of itself, and a plectrum should do its own harp playing.

In ancient China, a curious account on automata is found in the *Lie Zi* text, written in the 3rd century BC. Within it there is a description of a much earlier encounter between King Mu of Zhou (1023-957 BC) and a mechanical engineer known as Yan Shi, an 'artificer'. The latter proudly presented the king with a life-size, human-shaped figure of his mechanical handiwork.

Early water clocks, or clepsydra, are sometimes grouped in with the beginning of robotics. It was common to attempt to make such clocks automatic (such as a clepsydra by Ctesibius), or to decorate them with complicated astrological designs (popular in the Eastern world). Of particular interest in China, these astrological clocks led to extremely complex works such as Su Song's clock tower in 1088 AD, which featured moving mannequins, among other devices.

1400 to 1800

Interest in automata was either mostly non-existent in medieval Europe, or unrecorded. Oriental automata did, however, find their way into the imaginary worlds of medieval literature. For instance, the Middle Dutch tale *Roman van Walewein* ("The Romance of Walewein", early 13th century) describes mechanical birds and angels producing sound by means of systems of pipes.

In 1495, Leonardo Da Vinci designed a humanoid automaton in knight's armor to entertain, but it is not known if the design was ever built. Between 1500 and 1800, many automatons were built including ones capable of acting, drawing, flying, and playing music; several mechanical calculators were also built in this time period, some of the most famous ones are Wilhelm Schickard's "Calculating Clock", Blaise Pascal's "Pascaline", and the "Liebniz Stepped Drum", by Gottfried Wilhelm Leibniz. In 1533, Johannes Müller von Königsberg created an automaton eagle and fly made of iron; both could fly. John Dee is also famous for creating a wooden beetle, capable of flying.

Some of the most famous works of the period were created by Jacques de Vaucanson in 1737, including an automaton flute player, tambourine player, and his most famous work, "The Digesting Duck". Vaucanson's duck was capable of imitating a real duck by flapping its wings (over 400 parts were in each of the wings alone), eat grain, digest it, and defecate; the duck was powered by weights.

John Kay invented his "flying shuttle" in 1733, and the "Spinning Jenny" was invented in 1764 by James Hargreaves, each radically increasing the speed of production in the weaving and spinning industries respectively. The Spinning Jenny is hand-powered and requires a skilled operator; Samuel Crompton's Spinning Mule first developed in 1779 is a fully automated power driven spinning machine capable of spinning hundreds of threads at once.

Richard Arkwright built a water powered weaving machine, and factory around it in 1781, starting the Industrial Revolution. By 1800, cloth production was completely automated. With the advent of the Industrial Revolution, the idea of automata began to be applied to industry, as cost and time saving devices.

1801 to 1900

Improvements in the weaving industry had led to large amounts of automation, and the idea of programmable machines became popular with Charles Babbage's Analytical Engine Babbage conceived his Analytical Engine as a replacement for his uncompleted Difference Engine; this larger, more complex device would be able to perform multiple operations, and would be operated by punch cards. Construction of the Analytical Engine was never completed; work was begun in 1833. However, Ada Lovelace's work on the project has resulted in her being credited as the first computer programmer.

In 1837, the story of the Golem of Prague, a humanoid artificial intelligence activated by inscribing Hebrew letters on its forehead, based on Jewish folklore, was created by Jewish German writer Berthold Auerbach for his novel *Spinoza*.

George Boole invented a new type of symbolic logic in 1847 instrumental to the creation of computers and robots.

1901 to 1950

The word robot was popularized by Czech author Karel Capek in his 1921 play R.U.R. (Rossum's Universal Robots). According to Karel, his brother Josef was the actual inventor of the word "robot", creating the word from the Czech word "robota", meaning servitude. In 1927, Fritz Lang's *Metropolis* was released; the *Maschinenmensch* ("machine-human"), a gynoid humanoid robot, also called "Parody", "Futura", "Robotrix", or the "Maria impersonator" (played by German actress Brigitte Helm), was the first robot ever to be depicted on film. The world's first actual robot, a humanoid named Televox operated through the telephone system, was constructed in the United States in 1927. In 1928, Makoto Nishimura produced Japan's first robot, Gakutensoku.

In his 1936 paper "On Computable Numbers, with an Application to the *Entscheidungsproblem*" (submitted on 28 May 1936), Turing reformulated Kurt Gödel's 1931 results on the limits of proof and computation, replacing Gödel's universal arithmetic-based formal language with what are now called Turing machines, formal and simple devices. He proved that some such machine would be capable of performing any conceivable mathematical computation if it were representable as an algorithm, thus creating the basis for what is now called computer science.

Many robots were constructed before the dawn of computer-controlled servomechanisms, for the public relations purposes of major firms. Electro appeared in Westinghouse's pavilion at the 1939 New York World's Fair. Some were built in between such major public gatherings, such as Garco, made by Garrett AiResearch in the 1950s. These were essentially machines that could perform a few stunts, like the automatons of the 18th century.

Vannevar Bush created the first differential analyzer at the Massachusetts Institute Of Technology (MIT). Known as the Differential Analyzer, the computer could solve differential equations. 1940 brought about the creation of two electrical computers, John Vincent Atanasoff and Clifford Berry's Atanasoff-Berry Computer (ABC).

Ultimately, ideas from ABC were stolen for ENIAC.

In 1941 and 1942, Isaac Asimov formulated the Three Laws of Robotics, and in the process of doing so, coined the word "robotics".

In the UK, the Robinson machine was designed for the British war effort in cracking Enigma messages. This was done at the British code-breaking establishment at Bletchley

Park; Ultra is the name for the intelligence so received. Robinson was superseded by Colossus, which was built in 1943 to decode FISH messages by the British group Ultra; it was designed by Tommy Flowers and was 100 to 1000 times faster than Robinson, and was the first fully electronic computer. The Bletchley machines were kept secret for decades, and so do not appear in histories of computing written until recently. After the war, Tommy Flowers joined the team that built the early Manchester computers.

In Germany, Konrad Zuse built the first fully programmable digital computer in the world (the Z3) in 1941; it would later be destroyed in 1944. Zuse was also known for building the first binary computer from 1936 to 1938, called the Z1; he also built the Z4, his only machine to survive World War II.

The first American programmable computer was completed in 1944 by Howard Aiken and Grace Hopper. The Mark I (as it was called) ran computations for the US Navy until 1959. ENIAC was built in 1946 and gained fame because of its reliability, speed, and versatility. John Presper Eckert and John W. Mauchly spent 3 years building ENIAC, which weighed over 60,000 lbs.

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

The first Turtles (Elmo and Elsie) were created by pioneer roboticist William Grey Walter in 1949.

The first working digital computer to be sold was Zuse's Z4 in Germany; the fully electronic US BINAC was sold twelve months earlier in September 1949 but it never worked reliably at the customer's site due to mishandling in transit. Second was the UK's Ferranti Mark 1 delivered in February 1951, the first software programmable digital electronic computer to be sold that worked upon delivery. It was based on the world's first software programmable digital electronic computer, Manchester's SSME of 1948.

In 1950, UNIVAC I (also by Eckert and Mauchley) handled the US Census results; it was the third commercially marketed computer that worked on delivery (in December 1951).

The Turing test is proposed by Alan Turing in his 1950 paper *Computing Machinery and Intelligence*, which opens with the words: "I propose to consider the question, 'Can machines think?'"

1951 to 2000

After 1950, computers (and robotics), began to rapidly increase in both complexity and numbers as the technology needed to make the devices became easier to produce.

1951 to 1960

In 1951, William Shockley invented the junction transistor, which was announced at a press conference on July 4, 1951. Shockley obtained a patent for this invention on September 25, 1951. In 1951, LEO became operational in the UK. It was built by Lyons for its own use: this was the world's first software programmable digital electronic computer for commercial applications, exploiting the US development of mercury delay line memory, and built with the support of the Cambridge EDSAC project. LEO was used for commercial work running business application programs, the first of which was rolled out 17 November 1951.

Eckert and Mauchly completed EDVAC in 1951. An improvement on ENIAC and UNIVAC, EDVAC used mercury delay lines to store data, making it the USA's first software stored program computer. In 1952, the television network CBS correctly predicted the election of Dwight D. Eisenhower as president using UNIVAC. In 1952 IBM announced its 701 model computer, marketed towards scientific use, it was designed by Nathaniel Rochester. Stanislaw Ulam and physicist Paul Stein converted MANIAC I (used for solving calculations involved in creating the hydrogen bomb) to play a modified game of chess in 1956; it was the first computer to beat a human in a game of chess. The term "Artificial Intelligence" was created at a conference held at Dartmouth College in 1956. Alan Newell, J. C. Shaw, and Herbert Simon pioneered the newly created artificial intelligence field with the Logic Theory Machine (1956), and the General Problem Solver in 1957. In 1958, John McCarthy and Marvin Minsky started the MIT Artificial Intelligence lab with \$50,000. John McCarthy also created LISP in the summer of 1958, a programming language still important in artificial intelligence research. Jack Kilby and Robert Noyce invented the integrated circuit or "chip" in 1959; the inventors worked independent of each other. This development eventually revolutionized computers by affecting both the size and speed.

1961 to 1970

Unimate, the first industrial robot ever created began work on the General Motors assembly line in 1961; the machine was conceived in 1954 by George Devol. Unimate was manufactured by Unimation. Unimate is remembered as the first industrial robot. In 1962 John McCarthy founded the Stanford Artificial Intelligence Laboratory at Stanford University. The Rancho Arm was developed as a robotic arm to help handicapped patients at the Rancho Los Amigos Hospital in Downey, California; this computer controlled arm was bought by Stanford University in 1963. IBM announced its IBM System/360 in 1964. The system was heralded as being more powerful, faster, and more capable than its predecessors. In 1965, Gordon Moore, a co-founder of Intel in 1968, develops what will become known as Moore's Law; the idea that the number of components capable of being built onto a chip will double every two years. The same year, doctoral student Edward Feigenbaum, geneticist and biochemist Joshua Lederberg, and Bruce Buchanan (who held a degree in philosophy) begin work on the DENDRAL, an expert system designed to work in the field of organic chemistry. Feigenbaum also founded the Heuristic Programming Project in 1965, it later became the Stanford

Knowledge Systems Artificial Intelligence Laboratory. The program Mac Hack was also written in 1966; it beat artificial intelligence critic Hubert Dreyfus in a game of chess. The program was created by Richard Greenblatt. Seymour Papert created the Logo programming language in 1967. It was designed as an educational programming language. The film 2001: A Space Odyssey was released in 1968; the movie prominently features HAL 9000, a malevolent artificial intelligence unit which controls a spacecraft. Marvin Minsky created the Tentacle Arm in 1968; the arm was computer controlled and its 12 joints were powered by hydraulics. Mechanical Engineering student Victor Scheinman created the Stanford Arm in 1969; the Stanford Arm is recognized as the first electronic computer controlled robotic arm (Unimate's instructions were stored on a magnetic drum). The first floppy disc was released in 1970. It measured eight inches in diameter and read-only. The first mobile robot capable of reasoning about its surroundings, Shakey was built in 1970 by the Stanford Research Institute. Shakey combined multiple sensor inputs, including TV cameras, laser rangefinders, and "bump sensors" to navigate. In the winter of 1970, the Soviet Union explored the surface of the moon with the lunar vehicle Lunokhod 1, the first roving remote-controlled robot to land on another world.

1971 to 1980

The first microprocessor, called the 4004 was created by Ted Hoff at Intel in 1971. Measuring 1/8th of an inch by 1/16th of an inch, the chip itself was more powerful than ENIAC. Artificial intelligence critic Hubert Dreyfuss published his influential book "What Computers cannot Do" in 1972. Douglas Trumbull's "Silent Running" was released in 1972; the movie was notable for the three robot co-stars, named Huey, Dewey, and Louie. Released in 1973 was the logic based programming language PROLOG; this logic based language becomes important in the field of artificial intelligence. Freddy and Freddy II, both built in the United Kingdom, were robots capable of assembling wooden blocks in a period of several hours. German based company KUKA built the world's first industrial robot with six electromechanically driven axes, known as FAMULUS. In 1974, David Silver designed The Silver Arm; the Silver Arm was capable of fine movements replicating human hands. Feedback was provided by touch and pressure sensors and analyzed by a computer. MYCIN, an expert system developed to study decisions and prescriptions relating to blood infections. MYCIN was written in Lisp. Marvin Minsky published his landmark paper "A Framework for Representing Knowledge" on artificial intelligence. By 1975, four expert systems relating to medicine had been created; PIP, MYCIN, CASNET, and Internist. 1975: more than 5,000 computers were sold in the United States, and the first personal computer was introduced. The Kurzweil Reading Machine (invented by Raymond Kurzweil), intended to help the blind, was released in 1976. Capable of recognizing characters, the machine formulated pronunciation based on programmed rules. Based on studies of flexible objects in nature (such as elephant trunks and the vertebrae of snakes), Shigeo Hirose designed the Soft Gripper in 1976 the gripper was capable of conforming to the object it was grasping. The knowledge based system Automated Mathematician was presented by Douglas Lenat in 1976 as part of his doctoral dissertation. Automated Mathematician began with a knowledge of 110 concepts and rediscovered many

mathematical principles; Automated Mathematician was written in Lisp. Joseph Weizenbaum (creator of ELIZA, a program capable of simulating a Rogerian psychotherapist) published *Computer Power and Human Reason*, presenting an argument against the creation of artificial intelligence. Steven Jobs and Stephen Wozniak created the Apple Computer in 1977, and released the Apple II. George Lucas' movie *Star Wars* was also released in 1977. *Star Wars* featured two robots; an android named C-3PO and R2-D2, both of which become extremely iconic as robots. Voyagers 1 and 2 were launched in 1977 to explore the solar system. The 30 year old robotic space probes continue to transmit data back to earth and are approaching the heliopause and the interstellar medium. The SCARA, Selective Compliance Assembly Robot Arm, was created in 1978 as an efficient, 4-axis robotic arm. Best used for picking up parts and placing them in another location, the SCARA was introduced to assembly lines in 1981. XCON, an expert system designed to customize orders for industrial use, was released in 1979. The Stanford Cart successfully crossed a room full of chairs in 1979. The Stanford Cart relied primarily on stereo vision to navigate and determine distances. The Robotics Institute at Carnegie Mellon University was founded in 1979 by Raj Reddy.

1981 to 1990

Takeo Kanade created the first "direct drive arm" in 1981. The first of its kind, the arm's motors were contained within the robot itself, eliminating long transmissions. IBM released its first personal computer (PC) in 1981; the name of the computer was responsible for popularizing the term "personal computer". Prospector a "computer-based consultation program for mineral exploration", created in 1976, discovered an unknown deposit of molybdenum in Washington state. The expert system had been updated annually since its creation. The Fifth Generation Computer Systems Project (FGCS) was started in 1982. Its goals were knowledge based information processing and massive parallelism in a supercomputer, artificial intelligence like system. Cyc, a project to create a database of common sense for artificial intelligence, was started in 1984 by Douglas Leant. The program attempts to deal with ambiguity in language, and is still underway. The first program to publish a book, the expert system Racter, programmed by William Chamberlain and Thomas Etter, wrote the book "The Policeman's Beard is Half-Constructed" in 1983. It is now thought that a system of complex templates were used. In 1984 Wabot-2 was revealed; capable of playing the organ, Wabot-2 had 10 fingers and two feet. Wabot-2 was able to read a score of music and accompany a person. In 1985, Kawasaki Heavy Industries' license agreement with Unimation was terminated; Kawasaki began to produce its own robots. Their first robot was released one year later. By 1986, artificial intelligence revenue was about \$1 billion US dollars. Chess playing programs HiTech and Deep Thought defeated chess masters in 1989. Both were developed by Carnegie Mellon University; Deep Thought development paved the way for the Deep Blue. In 1986, Honda began its humanoid research and development program to create robots capable of interacting successfully with humans. Artificial intelligence related technologies, not including robots, now produce a revenue of \$1.4 billion US dollars. In 1988, Stäubli Group purchased Unimation. The Connection Machine was built in 1988 by Daniel Hillis; the supercomputer used 64,000 processors simultaneously. A hexapodal robot named Genghis was revealed by MIT in 1989. Genghis was famous for being made

quickly and cheaply due to construction methods; Genghis used 4 microprocessors, 22 sensors, and 12 servo motors. Rodney Brooks and Anita M. Flynn published "Fast, Cheap, and Out of Control: A Robot Invasion of The Solar System". The paper advocated creating smaller cheaper robots in greater numbers to increase production time and decrease the difficulty of launching robots into space.

1991 to 2000

While competing in a 1993 NASA sponsored competition, Carnegie Mellon University's eight legged robot Dante failed to collect gases from Mt. Erebus because of a broken fiber optic cable. Dante was designed to scale slopes and harvest gases near the surface of the magma; however, the failure in the cable did not permit the robot to enter the active volcano. In 1994, Dante II entered Mt. Spurr and successfully sampled the gases within the volcano. The biomimetic robot RoboTuna was built by doctoral student David Barrett at the Massachusetts Institute of Technology in 1996 to study how fish swim in water. RoboTuna is designed to swim and resemble a blue fin tuna. Invented by Dr. John Adler, in 1994, the Cyberknife (a stereotactic radiosurgery performing robot) represented a faster method of performing surgery with equivalent accuracy to one done by human doctors. Honda's P2 humanoid robot was first shown in 1996. Standing for "Prototype Model 2", P2 was an integral part of Honda's humanoid development project; over 6 feet tall, P2 was smaller than its predecessors and appeared to be more human-like in its motions. Expected to only operate for seven days, the Sojourner rover finally shuts down after 83 days of operation in 1997. This small robot (only weighing 23 lbs) performed semi-autonomous operations on the surface of Mars as part of the Mars Pathfinder mission; equipped with an obstacle avoidance program, Sojourner was capable of planning and navigating routes to study the surface of the planet. Sojourner's ability to navigate with little data about its environment and nearby surroundings allowed the robot to react to unplanned events and objects. Also in 1997, IBM's chess playing program Deep Blue beat the then current World Chess Champion Garry Kasparov playing at the "Grandmaster" level. The super computer was a specialized version of a framework produced by IBM, and was capable of processing twice as many moves per second as it had during the first match (which Deep Blue had lost), reportedly 200,000,000 moves per second. The event was broadcast live over the internet and received over 74 million hits. The P3 humanoid robot was revealed by Honda in 1998 as a part of the company's continuing humanoid project. In 1999, Sony introduced the AIBO, a robotic dog capable of interacting with humans, the first models released in Japan sold out in 20 minutes. Honda revealed the most advanced result of their humanoid project in 2000, named ASIMO. ASIMO is capable of running, walking, communication with humans, facial and environmental recognition, voice and posture recognition, and interacting with its environment. Sony also revealed its Sony Dream Robots, small humanoid robots in development for entertainment. In October 2000, the United Nations estimated that there were 742,500 industrial robots in the world, with more than half of the robots being used in Japan.



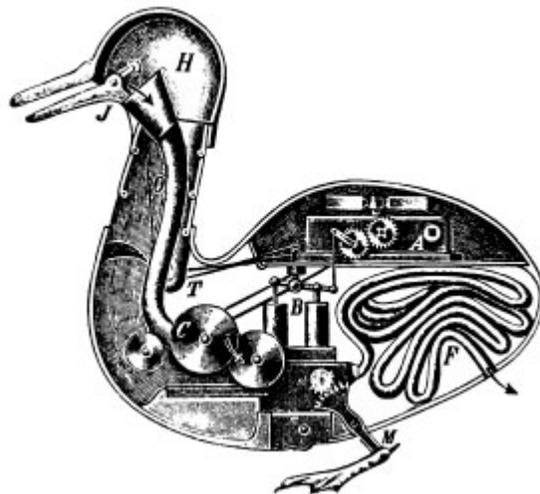
Tea-serving karakuri, with mechanism, 19th century. Tokyo National Science Museum.

2001 to the present

In April 2001, the Canadarm2 was launched into orbit and attached to the International Space Station. The Canadarm2 is a larger, more capable version of the arm used by the Space Shuttle and is hailed as being "smarter." Also in April, the Unmanned Aerial Vehicle Global Hawk made the first autonomous non-stop flight over the Pacific Ocean from Edwards Air Force Base in California to RAAF Base Edinburgh in Southern Australia. The flight was made in 22 hours. The popular Roomba, a robotic vacuum cleaner, was first released in 2002 by the company iRobot. In 2004, Cornell University revealed a robot capable of self-replication; a set of cubes capable of attaching and detaching, the first robot capable of building copies of itself. On January 3 and 24 the

Mars rovers Spirit and Opportunity land on the surface of Mars. Launched in 2003, the two robots will drive many times the distance originally expected, and are still operating. All 15 teams competing in the 2004 DARPA Grand Challenge failed to complete the course, with no robot successfully navigating more than five percent of the 150 mile off road course, leaving the \$1 million dollar prize unclaimed. In the 2005 DARPA Grand Challenge, five teams completed the off-road course; Stanford University's Stanley won first place and the \$2 million dollar prize. Also in 2005, Honda revealed a new version of its ASIMO robot, updated with new behaviors and capabilities. In 2006, Cornell University revealed its "Starfish" robot, a 4-legged robot capable of self modeling and learning to walk after having been damaged. In September 2007, Google announced its Lunar X Prize. The Lunar X Prize offers 30 million dollars to the first private company which lands a rover on the moon and sends images back to earth. In 2007, TOMY launched the entertainment robot, i-sobot, which is a humanoid bipedal robot that can walk like a human beings and performs kicks and punches and also some entertaining tricks and special actions under "Special Action Mode".

Automaton



The *Digesting Duck* by Jacques de Vaucanson, hailed in 1739 as the first automaton capable of digestion.

An **automaton** (plural: **automata** or **automatons**) is a self-operating machine. The word is sometimes used to describe a robot, more specifically an autonomous robot. An alternative spelling, now obsolete, is **automation**.

Etymology

The word *Automaton* is derived from the Greek *αὐτόματος*,... *automatos*, “acting of one’s own will”. It is more often used to describe non-electronic moving machines, especially

those that have been made to resemble human or animal actions, such as the *jacks* on old public striking clocks, or the cuckoo and any other animated figures on a cuckoo clock.

Ancient automata

The automata in the Hellenistic world were intended as toys, religious idols, or tools for demonstrating basic scientific principles, including those built by Greek mathematician Hero of Alexandria (sometimes known as Heron). When his writings on hydraulics, pneumatics, and mechanics were translated into Latin in the sixteenth century, Hero's readers initiated reconstruction of his machines, which included siphons, a fire engine, a water organ, the aeolipile, and a programmable cart.

Complex mechanical devices are known to have existed in ancient Greece, though the only surviving example is the Antikythera mechanism. It is thought to have come originally from Rhodes, where there was apparently a tradition of mechanical engineering; The island was renowned for its automata; to quote Pindar's seventh Olympic Ode:

The animated figures stand
Adorning every public street
And seem to breathe in stone, or
move their marble feet.

However, the information gleaned from recent scans of the fragments indicate that it may have come from the colonies of Corinth in Sicily and implies a connection with Archimedes.

There are also examples from myth: Daedalus used quicksilver to install a voice in his statues. Hephaestus created automata for his workshop: Talos, an artificial man of bronze, and, according to Hesiod, the woman Pandora.

According to Jewish tradition, Solomon used his wisdom to design a throne with mechanical animals which hailed him as king when he ascended it; upon sitting down an eagle would place a crown upon his head, and a dove would bring him a Torah scroll.

In ancient China, a curious account on automata is found in the *Lie Zi* text, written in the 3rd century BC. Within it there is a description of a much earlier encounter between King Mu of Zhou (1023-957 BC) and a mechanical engineer known as Yan Shi, an 'artificer'. The latter proudly presented the king with a life-size, human-shaped figure of his mechanical handiwork (Wade-Giles spelling):

The king stared at the figure in astonishment. It walked with rapid strides, moving its head up and down, so that anyone would have taken it for a live human being. The artificer touched its chin, and it began singing, perfectly in tune. He touched its hand, and it began posturing, keeping perfect time...As the performance was drawing to an end, the robot winked its eye and made advances to the ladies in attendance, whereupon the king

became incensed and would have had Yen Shih [Yan Shi] executed on the spot had not the latter, in mortal fear, instantly taken the robot to pieces to let him see what it really was. And, indeed, it turned out to be only a construction of leather, wood, glue and lacquer, variously coloured white, black, red and blue. Examining it closely, the king found all the internal organs complete—liver, gall, heart, lungs, spleen, kidneys, stomach and intestines; and over these again, muscles, bones and limbs with their joints, skin, teeth and hair, all of them artificial...The king tried the effect of taking away the heart, and found that the mouth could no longer speak; he took away the liver and the eyes could no longer see; he took away the kidneys and the legs lost their power of locomotion. The king was delighted.

In the mid-8th century, the first wind powered automata were built: "statues that turned with the wind over the domes of the four gates and the palace complex of the Round City of Baghdad". The "public spectacle of wind-powered statues had its private counterpart in the 'Abbasid palaces where automata of various types were predominantly displayed." Also in the 8th century, the Muslim alchemist, Jābir ibn Hayyān (Geber), included recipes for constructing artificial snakes, scorpions, and humans which would be subject to their creator's control in his coded *Book of Stones*. In 827, Caliph Al-Ma'mun had a silver and golden tree in his palace in Baghdad, which had the features of an automatic machine. There were metal birds that sang automatically on the swinging branches of this tree built by Muslim inventors and engineers at the time. The Abbasid Caliph Al-Muqtadir also had a golden tree in his palace in Baghdad in 915, with birds on it flapping their wings and singing. In the 9th century, the Banū Mūsā brothers invented a programmable automatic flute player and which they described in their *Book of Ingenious Devices*.

Automata from the 13th to 19th centuries



Automaton in the Swiss Museum CIMA

Al-Jazari described complex programmable humanoid automata amongst other machines he designed and constructed in the “Book of Knowledge of Ingenious Mechanical Devices” in 1206. His automaton was a boat with four automatic musicians that floated on a lake to entertain guests at royal drinking parties. His mechanism had a programmable drum machine with pegs (cams) that bump into little levers that operate the percussion. The drummer could be made to play different rhythms and different drum patterns if the pegs were moved around. According to Charles B. Fowler, the automata

were a "robot band" which performed "more than fifty facial and body actions during each musical selection."

Al-Jazari also invented a hand washing automaton first employing the flush mechanism now used in modern flush toilets. It features a female automaton standing by a basin filled with water. When the user pulls the lever, the water drains and the female automaton refills the basin. His "peacock fountain" was another more sophisticated hand washing device featuring humanoid automata as servants which offer soap and towels. Mark E. Rosheim describes it as follows: "Pulling a plug on the peacock's tail releases water out of the beak; as the dirty water from the basin fills the hollow base a float rises and actuates a linkage which makes a servant figure appear from behind a door under the peacock and offer soap. When more water is used, a second float at a higher level trips and causes the appearance of a second servant figure — with a towel!" Al-Jazari thus appears to have been the first inventor to display an interest in creating human-like machines for practical purposes such as manipulating the environment for human comfort.

Villard de Honnecourt, in his 1230s sketchbook, show plans for animal automata and an angel that perpetually turns to face the sun.

The Chinese author Xiao Xun wrote that when the Ming Dynasty founder Hongwu (r. 1368–1398) was destroying the palaces of Khanbaliq belonging to the previous Yuan Dynasty, there were—amongst many other mechanical devices—automatons found that were in the shape of tigers.

Leonardo da Vinci sketched a more complex automaton around the year 1495. The design of Leonardo's robot was not rediscovered until the 1950s. The robot, which appears in Leonardo's sketches, could, if built successfully, move its arms, twist its head, and sit up.

The Renaissance witnessed a considerable revival of interest in automata. Hero's treatises were edited and translated into Latin and Italian. Numerous clockwork automata were manufactured in the 16th century, principally by the goldsmiths of the Free Imperial Cities of central Europe. These wondrous devices found a home in the cabinet of curiosities or *Wunderkammern* of the princely courts of Europe. Hydraulic and pneumatic automata, similar to those described by Hero, were created for garden grottoes.

A new attitude towards automata is to be found in Descartes when he suggested that the bodies of animals are nothing more than complex machines - the bones, muscles and organs could be replaced with cogs, pistons and cams. Thus mechanism became the standard to which Nature and the organism was compared. France in the 17th century was the birthplace of those ingenious mechanical toys that were to become prototypes for the engines of the Industrial Revolution. Thus, in 1649, when Louis XIV was still a child, an artisan named Camus designed for him a miniature coach, and horses complete with footmen, page and a lady within the coach; all these figures exhibited a perfect movement. According to P. Labat, General de Gennes constructed, in 1688, in addition to

machines for gunnery and navigation, a peacock that walked and ate. The Jesuit Athanasius Kircher produced many automatons to create Jesuit shows, including a statue which spoke and listened via a speaking tube.



Tea-serving Japanese automaton, "karakuri ningyō", with mechanism (right), 19th century.

The world's first successfully-built biomechanical automaton is considered to be *The Flute Player*, invented by the French engineer Jacques de Vaucanson in 1737. He also constructed the Digesting Duck, a mechanical duck that gave the false illusion of eating and defecating, seeming to endorse Cartesian ideas that animals are no more than machines of flesh.

In 1769, a chess-playing machine called the Turk, created by Wolfgang von Kempelen, made the rounds of the courts of Europe purporting to be an automaton. The Turk was operated from inside by a hidden human director, and was not a true automaton.

Other 18th century automaton makers include the prolific Frenchman Pierre Jaquet-Droz and his contemporary Henri Maillardet. Maillardet, a Swiss mechanic, created an automaton capable of drawing four pictures and writing three poems. Maillardet's Automaton is now part of the collections at the Franklin Institute Science Museum in Philadelphia. Belgian-born John Joseph Merlin created the mechanism of the Silver Swan automaton, now at Bowes Museum.

According to philosopher Michel Foucault, Frederick the Great, king of Prussia from 1740 to 1786, was "obsessed" with automata. According to Manuel de Landa, "he put together his armies as a well-oiled clockwork mechanism whose components were robot-like warriors."

Japan adopted automata during the Edo period (1603–1867); they were known as *karakuri ningyō*.

The famous magician Jean Eugène Robert-Houdin (1805–1871) was known for creating automata for his stage shows.

The period 1860 to 1910 is known as "The Golden Age of Automata". During this period many small family based companies of Automata makers thrived in Paris. From their workshops they exported thousands of clockwork automata and mechanical singing birds around the world. It is these French automata that are collected today, although now rare and expensive they attract collectors worldwide. The main French makers were Vichy, Rouillet & Decamps, Lambert, Phalibois, Renou and Bontems.

Contemporary automata

Contemporary automata continue this tradition with an emphasis on art, rather than technological sophistication. Contemporary automata are represented by the works of Cabaret Mechanical Theatre in the United Kingdom, Dug North and Chomick+Meder, Thomas Kuntz, Arthur Ganson, Joe Jones in the United States, and Le Défenseur du Temps by French artist Jacques Monestier.

An evolution of the mechanized toys developed during the 18th and 19th centuries is represented by automata made with paper. Despite the relative simplicity of the material, paper automata intrinsically are objects with a high degree of technology, where the principles of mechanics meet the artistic creativity.

Other historic examples

Other notable examples of automata include Archytas's dove, mentioned by Aulus Gellius. Similar Chinese accounts of flying automata are written of the 5th century BC Mohist philosopher Mozi and his contemporary Lu Ban, who made artificial wooden birds (*ma yuan*) that could successfully fly according to the *Han Fei Zi* and other texts.

The Smithsonian Institution has in its collection a clockwork monk, about 15 in (380 mm) high, possibly dating as early as 1560. The monk is driven by a key-wound spring and walks the path of a square, striking his chest with his right arm, while raising and lowering a small wooden cross and rosary in his left hand, turning and nodding his head, rolling his eyes, and mouthing silent obsequies. From time to time, he brings the cross to his lips and kisses it. It is believed that the monk was manufactured by Juanelo Turriano, mechanician to the Holy Roman Emperor Charles V.

Chapter-3

Mobile Robot

A **mobile robot** is an automatic machine that is capable of movement in a given environment.

Overview

Mobile robots have the capability to move around in their environment and are not fixed to one physical location. In contrast, industrial robots usually consist of a jointed arm (multi-linked manipulator) and gripper assembly (or end effector) that is attached to a fixed surface.

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

Classification

Mobile robots may be classified by:

- The environment in which they travel:
 - Land or home robots. They are most commonly wheeled, but also include legged robots with two or more legs (humanoid, or resembling animals or insects).
 - Aerial robots are usually referred to as unmanned aerial vehicles (UAVs)
 - Underwater robots are usually called autonomous underwater vehicles (AUVs)
- The device they use to move, mainly:
 - Legged robot: human-like legs (i.e. an android) or animal-like legs.
 - Wheeled robot.
 - Tracks.

Mobile robot navigation

There are many types of mobile robot navigation:

Manual remote or tele-op

A manually tele-op'd robot is totally under control of a driver with a joystick or other control device. The device may be plugged directly into the robot, may be a wireless joystick, or may be an accessory to a wireless computer or other controller. A tele-op'd robot is typically used to keep the operator out of harm's way. Examples of manual remote robots include Robotics Design's ANATROLLER ARI-100 and ARI-50, Foster-Miller's Talon, iRobot's PackBot, and KumoTek's MK-705 Roosterbot.

Guarded tele-op

A guarded tele-op robot has the ability to sense and avoid obstacles but will otherwise navigate as driven, like a robot under manual tele-op. Few if any mobile robots offer only guarded tele-op.

Line-following robot

Some of the earliest Automated Guided Vehicles (AGVs) were line following mobile robots. They might follow a visual line painted or embedded in the floor or ceiling or an electrical wire in the floor. Most of these robots operated a simple "keep the line in the center sensor" algorithm. They could not circumnavigate obstacles; they just stopped and waited when something blocked their path. Many examples of such vehicles are still sold, by Transbotics, FMC, Egemin, HK Systems and many other companies.

Autonomously randomized robot

Autonomous robots with random motion basically bounce off walls, whether those walls are sensed with physical bumpers like the Roomba cleaners or with electronic sensors like the Friendly Robotics lawn mower. The simple algorithm of bump and turn 30 degrees leads eventually to coverage of most or all of a floor or yard surface.

Autonomously guided robot



Robot developers use ready-made autonomous bases and software to design robot applications quickly. Shells shaped like people or cartoon characters may cover the base to disguise it. *Courtesy of MobileRobots Inc*

An autonomously guided robot knows at least some information about where it is and how to reach various goals and or waypoints along the way. "Localization" or knowledge of its current location, is calculated by one or more means, using sensors such motor encoders, vision, Stereopsis, lasers and global positioning systems. Positioning systems often use triangulation, relative position and/or Monte-Carlo/Markov localization to determine the location and orientation of the platform, from which it can plan a path to its next waypoint or goal. It can gather sensor readings that are time- and location-stamped, so that a hospital, for instance, can know exactly when and where radiation levels exceeded permissible levels. Such robots are often part of the wireless enterprise network, interfaced with other sensing and control systems in the building. For instance, the PatrolBot security robot responds to alarms, operates elevators and notifies the command center when an incident arises. Other autonomously guided robots include the SpeciMinder and the Tug delivery robots for hospital labs, though the latter actually has people at the ready to drive the robot remotely when its autonomy fails. The Tug sends a letter to its tech support person, who then takes the helm and steers it over the Internet by looking through a camera low in the base of the robot.

Sliding autonomy

More capable robots combine multiple levels of navigation under a system called sliding autonomy. Most autonomously guided robots, such as the HelpMate hospital robot, also offer a manual mode. The Motivity autonomous robot operating system, which is used in the ADAM, PatrolBot, SpeciMinder, MapperBot and a number of other robots, offers full sliding autonomy, from manual to guarded to autonomous modes.

History

Date	Developments
1939–1945	During World War II the first mobile robots emerged as a result of technical advances on a number of relatively new research fields like computer science and cybernetics. They were mostly flying bombs. Examples are smart bombs that only detonate within a certain range of the target, the use of guiding systems and radar control. The V1 and V2 rockets had a crude 'autopilot' and automatic detonation systems. They were the predecessors of modern cruise missiles.
1948–1949	W. Grey Walter builds Elmer and Elsie, two autonomous robots that looked like turtles. Officially they were called Machina Speculatrix because these robots liked to explore their environment. Elmer and Elsie were equipped with a light sensor, if they found a light source they would move towards it, avoiding or moving obstacles on their way. These robots demonstrated that complex behaviour could arise from a simple design, Elmer and Elsie only had the equivalent of two nerve cells.
1961–1963	The Johns Hopkins University develops 'Beast'. Beast used a sonar to move around. When its batteries ran low it would find a power socket and plug itself in.
1969	Mowbot was the very first robot that would automatically mow the lawn. The Stanford Cart line follower was a mobile robot that was able to follow a white line, using a camera to see. It was radio linked to a large mainframe that made the calculations.
1970	At about the same time (1966–1972) the Stanford Research Institute is building and doing research on Shakey the Robot, a robot named after its jerky motion. Shakey had a camera, a rangefinder, bump sensors and a radio link. Shakey was the first robot that could reason about its actions. This means that Shakey could be given very general commands, and that the robot would figure out the necessary steps to accomplish the given task.
1976	The Soviet Union explores the surface of the Moon with Lunokhod 1, a lunar rover. In its Viking program the NASA sends two unmanned spacecrafts to Mars. The interest of the public in robots rises, resulting in robots that could be purchased for home use. These robots served entertainment or educational purposes. Examples include the RB5X, which still exists today and the HERO series.
1980	The Stanford Cart is now able to navigate its way through obstacle courses and make maps of its environment.
Early 1980s	The team of Ernst Dickmanns at Bundeswehr University of Munich builds the first robot cars, driving up to 55 mph on empty streets.
1987	Hughes Research Laboratories demonstrates the first cross-country map and sensor-based autonomous operation of a robotic vehicle.
1989	Mark Tilden invents BEAM robotics.
1990s	Joseph Engelberger, father of the industrial robotic arm, works with colleagues to

design the first commercially available autonomous mobile hospital robots, sold by Helpmate. The US Department of Defense funds the MDARS-I project, based on the Cybermotion indoor security robot.

1991 Edo. Franzi, André Guignard and Francesco Mondada developed Khepera, an autonomous small mobile robot intended for research activities. The project was supported by the LAMI-EPFL lab.

1993–1994 Dante I and Dante II were developed by Carnegie Mellon University. Both were walking robots used to explore live volcanoes.

1994 With guests onboard, the twin robot vehicles VaMP and VITA-2 of Daimler-Benz and Ernst Dickmanns of UniBwM drive more than one thousand kilometers on a Paris three-lane highway in standard heavy traffic at speeds up to 130 km/h. They demonstrate autonomous driving in free lanes, convoy driving, and lane changes left and right with autonomous passing of other cars.

1995 Semi-autonomous ALVINN steered a car coast-to-coast under computer control for all but about 50 of the 2850 miles. Throttle and brakes, however, were controlled by a human driver.

1995 In the same year, one of Ernst Dickmanns' robot cars (with robot-controlled throttle and brakes) drove more than 1000 miles from Munich to Copenhagen and back, in traffic, at up to 120 mph, occasionally executing maneuvers to pass other cars (only in a few critical situations a safety driver took over). Active vision was used to deal with rapidly changing street scenes.

1995 The Pioneer programmable mobile robot becomes commercially available at an affordable price, enabling a widespread increase in robotics research and university study over the next decade as mobile robotics becomes a standard part of the university curriculum.

1996–1997 NASA sends the Mars Pathfinder with its rover Sojourner to Mars. The rover explores the surface, commanded from earth. Sojourner was equipped with a hazard avoidance system. This enabled Sojourner to autonomously find its way through unknown martian terrain.

1999 Sony introduces Aibo, a robotic dog capable of seeing, walking and interacting with its environment. The PackBot remote-controlled military mobile robot is introduced.

2001 Start of the Swarm-bots project. Swarm bots resemble insect colonies. Typically they consist of a large number of individual simple robots, that can interact with each other and together perform complex tasks.

2002 Appears Roomba, a domestic autonomous mobile robot that cleans the floor.

2003 Axxon Robotics purchases Intellibot, manufacturer of a line of commercial robots that scrub, vacuum, and sweep floors in hospitals, office buildings and other commercial buildings. Floor care robots from Intellibot Robotics LLC operate completely autonomously, mapping their environment and using an array of sensors for navigation and obstacle avoidance.

2004 Robosapien, a biomorphic toy robot designed by Mark Tilden is commercially available.

In 'The Centibots Project' 100 autonomous robots work together to make a map of

an unknown environment and search for objects within the environment. In the first DARPA Grand Challenge competition, fully autonomous vehicles compete against each other on a desert course.

- 2005 Boston Dynamics creates a quadruped robot intended to carry heavy loads across terrain too rough for vehicles. Sony stops making Aibo and HelpMate halts production, but a lower-cost PatrolBot customizable autonomous service robot system becomes available as mobile robots continue the struggle to become commercially viable. The US
- 2006 Department of Defense drops the MDARS-I project, but funds MDARS-E, an autonomous field robot. TALON-Sword, the first commercially available robot with grenade launcher and other integrated weapons options, is released. Honda's Asimo learns to run and climb stairs. History is made with the DARPA Urban Grand Challenge, with six vehicles autonomously completing a complex course involving manned vehicles and obstacles. Kiva Systems clever robots proliferate in distribution operations; these smart shelving units sort themselves according to the popularity of their contents. The Tug becomes a popular means for hospitals to move large cabinets of stock
- 2007 from place to place, while the Speci-Minder with Motivity begins carrying blood and other patient samples from nurses' stations to various labs. Seekur, the first widely available, non-military outdoor service robot, pulls a 3-ton vehicle across a parking lot, drives autonomously indoors and begins learning how to navigate itself outside. Meanwhile, PatrolBot learns to follow people and detect doors that are ajar.
- 2008 Boston Dynamics released video footage of a new generation BigDog able to walk on icy terrain and recover its balance when kicked from the side.

Robotic Mapping



Robotic mapping can be used for serving robot guide

The problem of **Robotic mapping** is related to cartography. The goal is for an autonomous robot to be able to construct (or use) a map or floor plan and to localize itself in it.

Robotic mapping is that branch of one, which deals with the study and application of ability to construct map or floor plan by the autonomous robot and to localize itself in it.

Todd et al. (1994) have shown that evolutionarily shaped blind action may suffice to keep some animals alive. For some insects for example, the environment is not interpreted as a map, and they survive only with a triggered response.

But a slightly more elaborated navigation strategy dramatically enhances the capabilities of the robot. Cognitive maps (Tolman 1948) enable planning capacities, and use of current perceptions, memorized events, and expected consequences.

The problem can be decomposed in three processes (Levitt and Lawton 1990 ; Balakrishnan et al. 1999): map learning, localization, path-planning.

Available information

The robot has two sources of information: the idiothetic and the allothetic sources.

When in motion, a robot can use dead reckoning methods such as tracking the number of revolutions of its wheels; this corresponds to the idiothetic source and can give the absolute position of the robot, but it is subject to cumulative error which can grow quickly.

The allothetic source corresponds to the sensors of the robot, like a camera, a microphone, laser or sonar. The problem here is "perceptual aliasing". This means that two different places can be perceived as the same. For example, in a building, it may be impossible for to determine your location solely with the visual information, because all the corridors may look the same.

Map representation

The internal representation of the map can be "metric" or "topological":

- The metric framework is the most common for humans and considers a two dimensional space in which it places the objects. The objects are placed with precise coordinates. This representation is very useful, but is sensitive to noise and it is difficult to calculate precisely the distances.
- The topological framework only considers places and relations between them. Often, the distances between places are stored. The map is then a graph, in which the nodes corresponds to places and arcs correspond to the paths.

Many techniques use probabilistic representations of the map, in order to handle uncertainty.

There are three main methods of Map representations:

Free Space Maps

- Spatial graphs
- Voronoi diagrams
- Generalized Voronoi Diagrams

Object Maps

Composite Maps

- Point grids
- Area grids
- Quad trees

These employ the notion of a grid, but permit the resolution of the grid to vary so that it can become finer where more accuracy is needed and more coarse where the map is uniform.

Map learning

Map-learning cannot be separated from the localization process, and a difficulty arises when errors in localization are incorporated into the map. This problem is commonly referred to as Simultaneous localization and mapping (SLAM).

An important additional problem is to determine whether the robot is in a part of environment already stored or never visited. One way to solve this problem is by using electric beacons.

Path planning

Path planning is an important issue as it allows a robot to get from point A to point B. Path planning algorithms are measured by their computational complexity. The feasibility of real-time motion planning is dependent on the accuracy of the map (or floorplan), on robot localization and on the number of obstacles. Topologically, the problem of path planning is related to the shortest path problem problem of finding a route between two nodes in a graph.

Robot navigation

Outdoor robots can use GPS in a similar way to automotive navigation systems.

Alternative systems can be used with floor plan instead of maps for indoor robots, combined with localization wireless hardware.

Electric beacons also have been proposed for cheap robot navigational systems.

Autonomous robot

Autonomous robots are robots that can perform desired tasks in unstructured environments without continuous human guidance. Many kinds of robots have some degree of autonomy. Different robots can be autonomous in different ways. A high degree of autonomy is particularly desirable in fields such as space exploration, cleaning floors, mowing lawns, and waste water treatment.

Some modern factory robots are "autonomous" within the strict confines of their direct environment. It may not be that every degree of freedom exists in their surrounding environment, but the factory robot's workplace is challenging and can often contain chaotic, unpredicted variables. The exact orientation and position of the next object of work and (in the more advanced factories) even the type of object and the required task must be determined. This can vary unpredictably (at least from the robot's point of view).

One important area of robotics research is to enable the robot to cope with its environment whether this be on land, underwater, in the air, underground, or in space.

A fully autonomous robot has the ability to

- Gain information about the environment.
- Work for an extended period without human intervention.
- Move either all or part of itself throughout its operating environment without human assistance.
- Avoid situations that are harmful to people, property, or itself unless those are part of its design specifications.

An autonomous robot may also learn or gain new capabilities like adjusting strategies for accomplishing its task(s) or adapting to changing surroundings.

Autonomous robots still require regular maintenance, as do other machines.

Examples of progress towards commercial autonomous robots

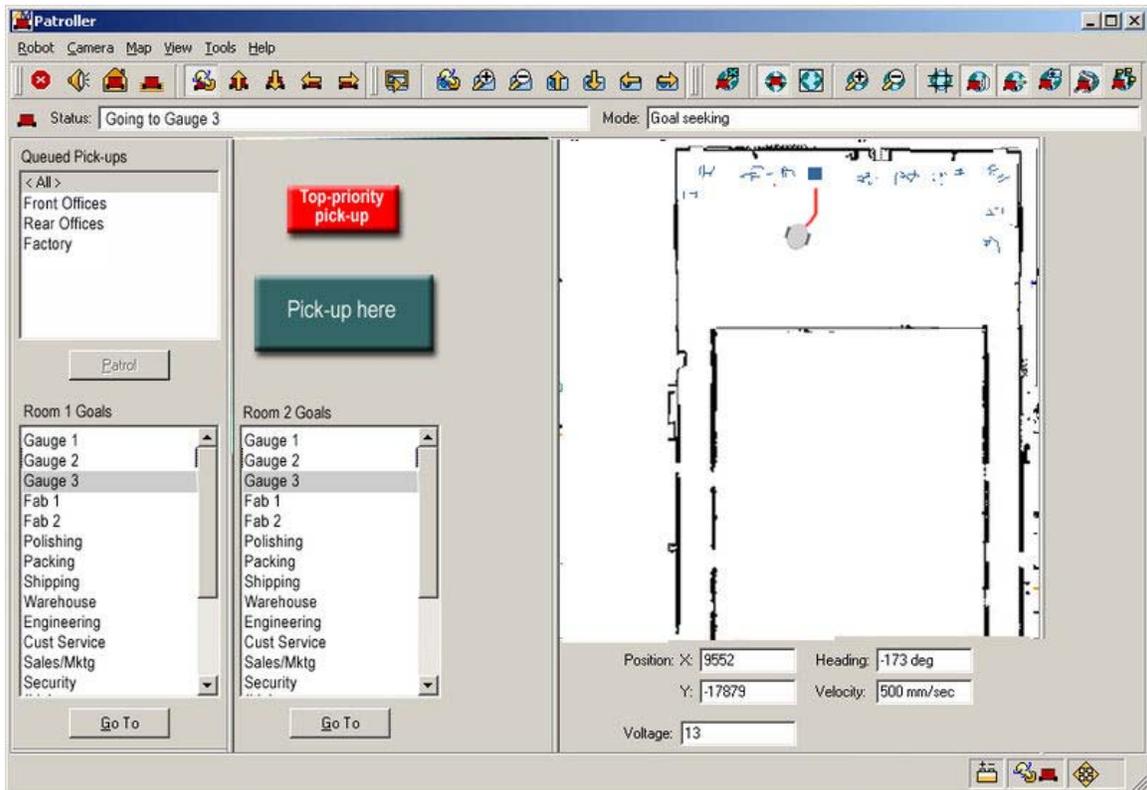
Self-maintenance



Exteroceptive sensors: 1. blue laser rangefinder senses up to 360 distance readings in a 180-degree slice; 2. 24 round golden ultrasonic sensors sample range readings in a 15-degree cone; 3. ten touch panels along the bottom detect shoes and other low-lying objects. 4. break beams between the lower and upper segments sense tables and other mid-level obstacles.

The first requirement for complete physical autonomy is the ability for a robot to take care of itself. Many of the battery powered robots on the market today can find and connect to a charging station, and some toys like Sony's *Aibo* are capable of self-docking to charge their batteries.

Self maintenance is based on "proprioception", or sensing one's own internal status. In the battery charging example, the robot can tell proprioceptively that its batteries are low and it then seeks the charger. Another common proprioceptive sensor is for heat monitoring. Increased proprioception will be required for robots to work autonomously near people and in harsh environments.



Robot GUI display showing battery voltage and other proprioceptive data in lower right-hand corner. The display is for user information only. Autonomous robots monitor and respond to proprioceptive sensors without human intervention to keep themselves safe and operating properly.

- Common proprioceptive sensors are

Thermal
Hall Effect
Optical
Contact

Sensing the environment

Exteroception is sensing things about the environment. Autonomous robots must have a range of environmental sensors to perform their task and stay out of trouble.

- Common exteroceptive sensors are

Electromagnetic spectrum
Sound
Touch
Chemical sensors (smell, odor)

Temperature
Range to things in the environment
Attitude (Inclination)

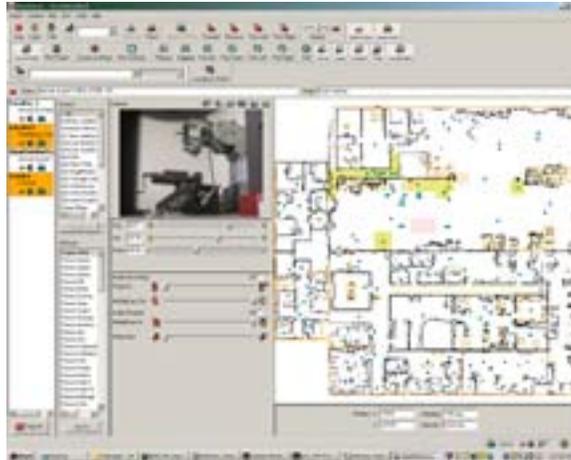
Some robotic lawn mowers will adapt their programming by detecting the speed in which grass grows as needed to maintain a perfect cut lawn, and some vacuum cleaning robots have dirt detectors that sense how much dirt is being picked up and use this information to tell them to stay in one area longer.

Task performance

The next step in autonomous behavior is to actually perform a physical task. A new area showing commercial promise is domestic robots, with a flood of small vacuuming robots beginning with iRobot and Electrolux in 2002. While the level of intelligence is not high in these systems, they navigate over wide areas and pilot in tight situations around homes using contact and non-contact sensors. Both of these robots use proprietary algorithms to increase coverage over simple random bounce.

The next level of autonomous task performance requires a robot to perform conditional tasks. For instance, security robots can be programmed to detect intruders and respond in a particular way depending upon where the intruder is.

Indoor position sensing and navigation



Robot interface GUI showing a robot building map with forbidden areas highlighted in yellow on the right side of the screen. Defined task sequences and goals are in the second column. The selected robot will then travel to any location clicked in the map, unless it is in a forbidden area. (Courtesy of MobileRobots Inc)

For a robot to associate behaviors with a place (localization) requires it to know where it is and to be able to navigate point-to-point. Such navigation began with wire-guidance in the 1970s and progressed in the early 2000s to beacon-based triangulation. Current commercial robots autonomously navigate based on sensing natural features. The first

commercial robots to achieve this were Pyxus' HelpMate hospital robot and the CyberMotion guard robot, both designed by robotics pioneers in the 1980s. These robots originally used manually created CAD floor plans, sonar sensing and wall-following variations to navigate buildings. The next generation, such as MobileRobots' PatrolBot and autonomous wheelchair both introduced in 2004, have the ability to create their own laser-based maps of a building and to navigate open areas as well as corridors. Their control system changes its path on-the-fly if something blocks the way.

At first, autonomous navigation was based on planar sensors, such as laser range-finders, that can only sense at one level. The most advanced systems now fuse information from various sensors for both localization (position) and navigation. Systems such as Motivity can rely on different sensors in different areas, depending upon which provides the most reliable data at the time, and can re-map a building autonomously.

Rather than climb stairs, which requires highly specialized hardware, most indoor robots navigate handicapped-accessible areas, controlling elevators and electronic doors. With such electronic access-control interfaces, robots can now freely navigate indoors. Autonomously climbing stairs and opening doors manually are topics of research at the current time.

As these indoor techniques continue to develop, vacuuming robots will gain the ability to clean a specific user specified room or a whole floor. Security robots will be able to cooperatively surround intruders and cut off exits. These advances also bring concomitant protections: robots' internal maps typically permit "forbidden areas" to be defined to prevent robots from autonomously entering certain regions.

Outdoor autonomous position-sensing and navigation

Outdoor autonomy is most easily achieved in the air, since obstacles are rare. Cruise missiles are rather dangerous highly autonomous robots. Pilotless drone aircraft are increasingly used for reconnaissance. Some of these unmanned aerial vehicles (UAVs) are capable of flying their entire mission without any human interaction at all except possibly for the landing where a person intervenes using radio remote control. But some drone aircraft are capable of a safe, automatic landing also.

Outdoor autonomy is the most difficult for ground vehicles, due to: a) 3-dimensional terrain; b) great disparities in surface density; c) weather exigencies and d) instability of the sensed environment.



The Seekur and MDARS robots demonstrate their autonomous navigation and security capabilities at an airbase.

In the US, the MDARS project, which defined and built a prototype outdoor surveillance robot in the 1990s, is now moving into production and will be implemented in 2006. The General Dynamics MDARS robot can navigate semi-autonomously and detect intruders, using the MRHA software architecture planned for all unmanned military vehicles. The Seekur robot was the first commercially available robot to demonstrate MDARS-like capabilities for general use by airports, utility plants, corrections facilities and Homeland Security.

The Mars rovers MER-A and MER-B (now known as Spirit rover and Opportunity rover) can find the position of the sun and navigate their own routes to destinations on the fly by:

- mapping the surface with 3-D vision
- computing safe and unsafe areas on the surface within that field of vision
- computing optimal paths across the safe area towards the desired destination
- driving along the calculated route;
- repeating this cycle until either the destination is reached, or there is no known path to the destination

The planned ESA Rover, ExoMars Rover, is capable of vision based relative localisation and absolute localisation to autonomously navigate safe and efficient trajectories to targets by:

- reconstructing 3D models of the terrain surrounding the Rover using a pair of stereo cameras
- determining safe and unsafe areas of the terrain and the general 'difficulty' for the Rover to navigate the terrain

- computing efficient paths across the safe area towards the desired destination
- driving the Rover along the planned path
- building up a 'Navigation Map' of all past navigation data

The DARPA Grand Challenge and DARPA Urban Challenge have encouraged development of even more autonomous capabilities for ground vehicles, while this has been the demonstrated goal for aerial robots since 1990 as part of the AUVSI International Aerial Robotics Competition.

Open problems in autonomous robotics

There are several open problems in autonomous robotics which are special to the field rather than being a part of the general pursuit of AI.

Energy autonomy & foraging

Researchers concerned with creating true artificial life are concerned not only with intelligent control, but further with the capacity of the robot to find its own resources through foraging (looking for food, which includes both energy and spare parts).

This is related to **autonomous foraging**, a concern within the sciences of behavioral ecology, social anthropology, and human behavioral ecology; as well as robotics, artificial intelligence, and artificial life.

Chapter-4

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. They move 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 carries 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. Courtesy Transbotics, Corp.

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, courtesy MobileRobots Inc

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 forkltruck 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.

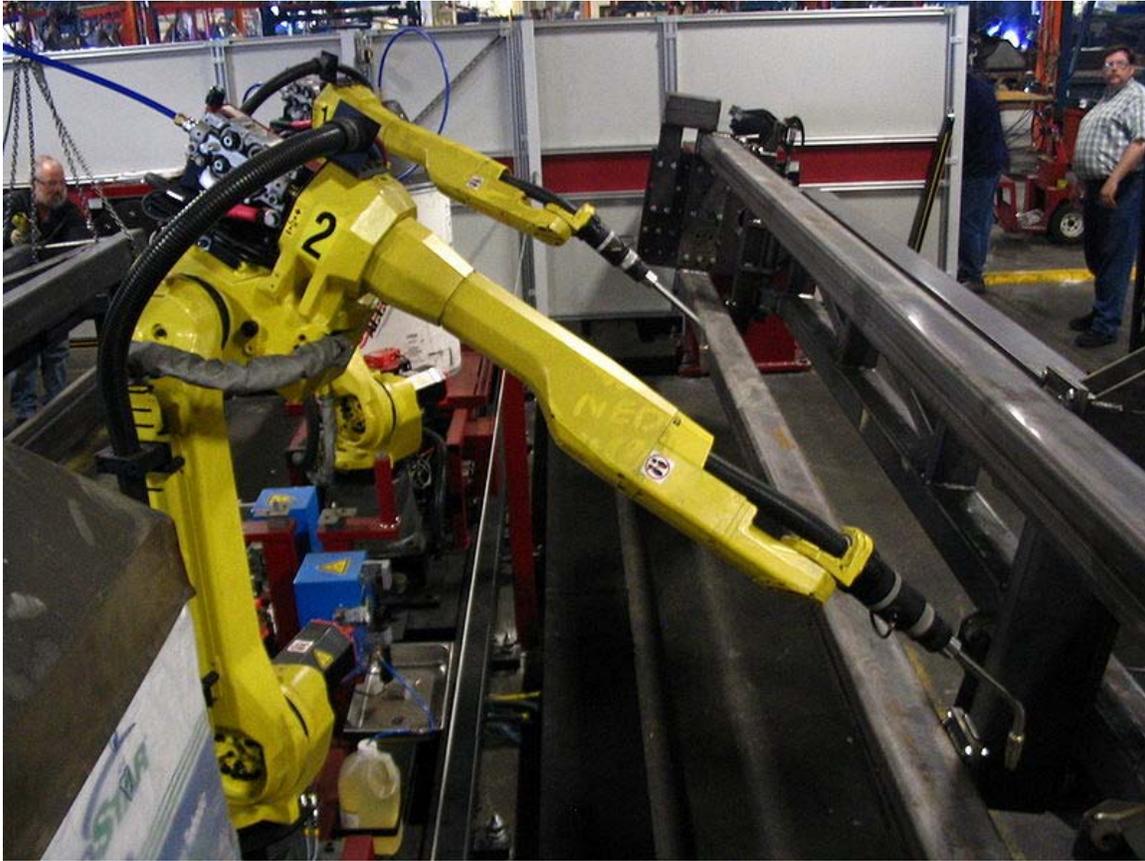
Chapter-5

Industrial Robot and Domestic Robot

Industrial Robot



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:

- 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.
- 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 (note: although accuracy is not an appropriate measure for robots, usually evaluated in terms of repeatability). 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.

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.

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 Automatrix 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.

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.

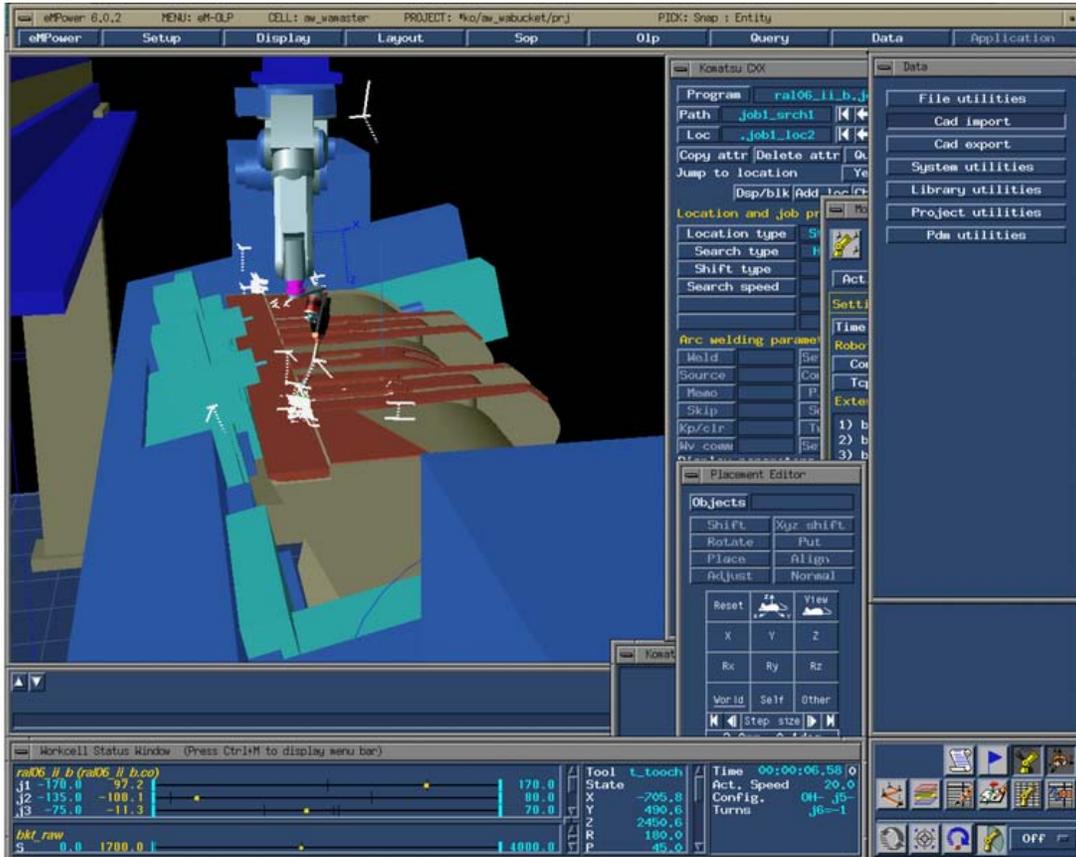
- *Repeatability* - how well the robot will return to a programmed position. This is not the same as accuracy. It may be that when told to go to a certain X-Y-Z position that it gets only to within 1 mm of that position. This would be its accuracy which may be improved by calibration. But if that position 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.

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.

- *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.

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:

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 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.

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.

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.

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.

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.



TOPIO, a robot can play table tennis with humans.

Types of robots

Humanoid robots

Lara is the first female humanoid robot with artificial muscles (metal alloy strands that instantly contract when heated by electric current) instead of electric motors (2006).

Asimo is one of the most advanced projects as of 2009.

Modular robots

Modular robots can be built from standard building blocks that can be combined in different ways.

- Utility fog
- M-Tran - a snake-like modular robot that uses genetic algorithms to evolve walking programs
- Self replicating robots - modular robots that can produce copies of themselves using existing blocks.
- Swarmanoid is a project that uses 3 specialized classes of robots (footbots, handbots and eyebots) to create an effective *swarm*. Such swarm should be able, for example, tidy a bedroom with each robot doing what it is best at.
- Self-Reconfiguring Modular Robotics

Educational toy robots

- Educational toy robots

Sports robots

- RoboCup
- TOPIO

Applications

- Caterpillar plans to develop remote controlled machines and expects to develop fully autonomous heavy robots by 2021. Some cranes already are remote controlled.
- It was demonstrated that a robot can perform a herding task.
- Robots are increasingly used in manufacturing (since 1960s). In auto industry they can amount for more than half of the "labor". There are even "lights off" factories such as an IBM keyboard manufacturing factory in Texas that are 100% automated.
- Robots such as HOSPI are used as couriers in hospitals, etc. Other hospital tasks performed by robots are receptionists, guides and porters helpers, (not to mention surgical robot helpers such as Da Vinci)
- Robots can serve as waiters and cooks.

Market evolution

Today's market is not fully mature. One or more software compatibility layers have yet to emerge to allow the development of a rich robotics ecosystem (similar to today's personal computers one). The most commonly used software in the robotics research are Free Software solutions such as Player/Stage or cross-platform technologies such as URBI.

Microsoft is currently working in this direction with its new proprietary software Microsoft Robotics Studio. The use of open source tools helps in continued improvement of the tools and algorithms for robotic research from the point one team leaves it.

Robotics Timeline

- Robots capable of manual labour tasks--
 - 2009 - robots that perform searching and fetching tasks in unmodified library environment, Professor Angel del Pobil (University Jaume I, Spain), 2004
 - 2015-2020 - every South Korean household will have a robot and many European, The Ministry of Information and Communication (South Korea), 2007
 - 2018 - robots will routinely carry out surgery, South Korea government 2007
 - 2022 - intelligent robots that sense their environment, make decisions, and learn are used in 30% of households and organizations - TechCast
 - 2030 - robots capable of performing at human level at most manual jobs Marshall Brain
 - 2034 - robots (home automation systems) performing most household tasks, Helen Greiner, Chairman of iRobot
- Military robots
 - 2015 - one third of US fighting strength will be composed of robots - US Department of Defense, 2006
 - 2035 - first completely autonomous robot soldiers in operation - US Department of Defense, 2006
 - 2038 - first completely autonomous robot flying car in operation - US Department of Technology, 2007
- Developments related to robotics from the Japan NISTEP 2030 report:
 - 2013-2014 — agricultural robots (AgRobots).
 - 2013-2017 — robots that care for the elderly
 - 2017 — medical robots performing low-invasive surgery
 - 2017-2019 — household robots with full use.
 - 2019-2021 — Nanorobots
 - 2021-2022 — Transhumanism

Legal rights for robots

According to research commissioned by the UK Office of Science and Innovation's Horizon Scanning Centre, robots could one day demand the same citizen's rights as humans. The study also warns that the rise of robots could put a strain on resources and the environment.

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.

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.

Domestic Robot



First generation Roomba vacuums the carpets in a domestic environment

A **domestic robot** is a robot used for household chores. Thus far, there are only a few limited models, though science fiction writers and other speculators have suggested that they could become more common in the future. In 2006, Bill Gates wrote an article for *Scientific American* titled "A Robot in Every Home".

Many domestic robots are used for basic household chores, such as the Electrolux Trilobite, Roomba and the SLAM based Neato Robotics vacuum cleaner robot. Others are educational or entertainment robots, such as the HERO line of the 1980s or the AIBO. While most domestic robots are simplistic, some are connected to WiFi home networks or smart environments and are autonomous to a high degree. There were an estimated 3,540,000 service robots in use in 2006, compared with an estimated 950,000 industrial robots.

Domestic robots in production

Working or chore robots

- Robotic mop:
 - Scooba (by iRobot)
 - Mint (by Evolution Robotics)
- Robotic vacuum cleaners:
 - CleanMate (by Infinuvo)
 - DC06 (by Dyson)
 - eVac (by The Sharper Image/ Evolution Robotics)
 - IClebo (by Yujin Robot)
 - Koolvac (by Koolatron)
 - Neato Robotics XV-11
 - Orazio (by Zuchetti)
 - Ottoro (by Hanoool robotics)
 - P3 International
 - picaBot
 - Roomba (by iRobot)
 - Robo Maxx
 - RoboMop
 - Trilobite (by Electrolux)
 - RC3000 (by Kärcher)
 - VSR8000 (by Siemens)
 - Navibot by Samsung
 - V-bot RV10 (by P3 International)
 - RV-88 by SungTung
- Ironing clothes:
 - Dressman (by Siemens AG).
- Pets:
 - Litter-Robot for cats
- A towel folding robot has now been developed in the USA but is not yet on sale.



Serving robot at the "*Ubiquitous Dream*" exhibition in Seoul, Korea on June 24, 2005

Home couriers

Home transport robots are a main element in the domestic robotic system, because they join specialized processes, moving objects at home (i.e. clothes from the bathroom to the washing machine or glasses from the table to the dishwasher):

- STR (by Iberobotics). It includes Wi-Fi and USB connection to (domotics) network.
- In 2006 Sharp said it has developed a humanoid robot that clears dishes from the table and puts them into a dishwasher. The robot (measuring 95x50x45cm) opens the door of the dishwasher, takes hold of teacups, rice bowls and plates, places them in the unit and closes the door

General helper robots

There are also general domestic helper robots, i.e. HRP-2.

Outdoors



Husqvarna automower in action.

- Robotic lawnmowers
 - RoboMower (by Friendly Robotics)
 - The Husqvarna Automower
 - Ambrogio by Zucchetti
- Automated pool cleaners are robots for cleaning swimming pools.

Entertainment

- Toy robots include
 - Sony's Aibo, a robot pet dog also used by many universities in the RoboCup autonomous soccer competition
 - Robosapien, a small humanoid remote controlled robot
 - Furby, an electronic toy that was the must-have toy of 1998.
 - Spykee, a consumer spy robot.

Social robots

- Robots whose main object is social interaction (partner robots) include:

- Wakamaru, a humanoid robot designed to provide company for the elderly and less mobile people, made by Mitsubishi Heavy Industries, on sale from 2005
- Paro, a robot baby seal intended to provide comfort to nursing home patients
- PaPeRo, a robot designed by NEC to study robot-human interaction.
- Sony's QRIO.
- NUVO
- PINO
- EMIEW
- Toyota Partner Robots, some of them mountable.

Chapter-6

Military Robots



Soviet TT-26 teletank, February 1940

Military robots are autonomous robots or remote-controlled devices designed for military applications.

Such systems are currently being researched by a number of militaries.

History



British soldiers with captured German Goliath remote-controlled demolition vehicles (Battle of Normandy, 1944).



Armed Predator drone.

Broadly defined, military robots date back to World War II and the Cold War in the form of the German Goliath tracked mines and the Soviet teletanks. The MQ-1 Predator drone was when "CIA officers began to see the first practical returns on their decade-old fantasy of using aerial robots to collect intelligence".

The use of robots in warfare, although traditionally a topic for science fiction, is being researched as a possible future means of fighting wars. Already several military robots have been developed by various armies.

Some believe the future of modern warfare will be fought by automated weapons systems. The U.S. Military is investing heavily in research and development towards testing and deploying increasingly automated systems. The most prominent system currently in use is the unmanned aerial vehicle (IAI Pioneer & RQ-1 Predator) which can be armed with Air-to-ground missiles and remotely operated from a command center in reconnaissance roles. DARPA has hosted competitions in 2004 & 2005 to involve private companies and universities to develop unmanned ground vehicles to navigate through rough terrain in the Mojave Desert for a final prize of \$2 Million. The field of artillery has also seen some promising research with an experimental weapons system named "Dragon Fire II" which automates the loading and ballistics calculations required for accurate predicted fire, providing a 12 second response time to artillery support requests. However, weapons of warfare have one limitation in becoming fully autonomous: there remain intervention points which requires human input to ensure that targets are not within restricted fire areas as defined by Geneva Conventions for the laws of war.

There have been some developments towards developing autonomous fighter jets and bombers. The use of autonomous fighters and bombers to destroy enemy targets is especially promising because of the lack of training required for robotic pilots, autonomous planes are capable of performing maneuvers which couldn't otherwise be done with human pilots (due to high amount of G-Force), plane designs don't require a life support system, and a loss of a plane doesn't mean a loss of a pilot. However, the largest draw back to robotics is their inability to accommodate for non-standard conditions. Advances in artificial intelligence in the near future may help to rectify this.

Examples

In development



The combat version of the Foster-Miller TALON, SWORDS.



XM1219 Armed Robotic Vehicle-Assault-Light (ARV-A-L) based on the MULE Vehicle.

- US Mechatronics has produced a working automated sentry gun and is currently developing it further for commercial and military use.
- MIDARS, a four-wheeled robot outfitted with several cameras, radar, and possibly a firearm, that automatically performs random or preprogrammed patrols around a military base or other government installation. It alerts a human overseer when it detects movement in unauthorized areas, or other programmed conditions. The operator can then instruct the robot to ignore the event, or take over remote control to deal with an intruder, or to get better camera views of an emergency. The robot would also regularly scan radio frequency identification tags (RFID) placed on stored inventory as it passed and report any missing items.
- Tactical Autonomous Combatant (TAC) units, described in Project Alpha study *'Unmanned Effects: Taking the Human out of the Loop'* -
- Autonomous Rotorcraft Sniper System is an experimental robotic weapons system being developed by the U.S. Army since 2005. It consists of a remotely operated sniper rifle attached to an unmanned autonomous helicopter. It is intended for use in urban combat or for several other missions requiring snipers. Flight tests are scheduled to begin in Summer 2009.

- The "Mobile Autonomous Robot Software" research program was started in December 2003 by the Pentagon who purchased 15 Segways in an attempt to develop more advanced military robots. The program was part of a \$26 million Pentagon program to develop software for autonomous systems.

Armored Combat Engineer Robot

The **Armored Combat Engineer Robot (ACER)** is a military robot created by Mesa Robotics. Roughly the size of a small bulldozer and weighing 2.25 tons, ACER is among the larger of the terrestrial military robots. Nonetheless, like many other military robots, it has a modular body, allowing for adjustments for its next mission. ACER is able to reach speeds of 6.3 mph, using treads for movement. Uses for this robot include clearing obstacles, removing explosives, hauling cargo and disabled vehicles, and serving as a platform for various other tasks, such as clearing buildings and disarming landmines.

BigDog



A pair of BigDog robots

BigDog is a dynamically stable quadruped robot created in 2005 by Boston Dynamics with Foster-Miller, the NASA Jet Propulsion Laboratory, and the Harvard University Concord Field Station. BigDog is 3 feet (0.91 m) long, stands 2.5 feet (0.76 m) tall, and weighs 240 pounds (110 kg), about the size of a small mule. It is capable of traversing difficult terrain at 4 miles per hour (6.4 km/h), carrying 340 pounds (150 kg), and climbing a 35 degree incline. Locomotion is controlled by an onboard computer that receives input from the robot's various sensors. Navigation and balance are also managed by the control system.

History

BigDog is funded by the Defense Advanced Research Projects Agency (DARPA) in the hopes that it will be able to serve as a robotic pack mule to accompany soldiers in terrain too rough for conventional vehicles. Instead of wheels or treads, BigDog uses four legs for movement, allowing it to move across surfaces that would defeat wheels. The legs contain a variety of sensors, including joint position and ground contact. BigDog also features a laser gyroscope and a stereo vision system.

BigDog was featured in episodes of *Web Junk 20* and *Hungry Beast*, and in articles in *New Scientist*, *Popular Science*, *Popular Mechanics*, and *The Wall Street Journal*.

On March 18, 2008, Boston Dynamics released video footage of a new generation of BigDog. The footage shows BigDog's ability to walk on icy terrain and recover its balance when kicked from the side.

Hardware

Big Dog is powered by a two-stroke, one-cylinder, 15-HP go-kart engine operating at over 9,000 RPM. The engine drives a hydraulic pump, which in turn drives the hydraulic leg actuators. Each leg has four actuators (two for the hip joint, and one each for the knee and ankle joints), for a total of 16. Each actuator unit consists of a hydraulic cylinder, servovalve, position sensor, and force sensor.

Onboard computing power is a ruggedized PC/104 board stack with a Pentium 4 class computer running QNX.

Dassault nEUROn

nEUROn



Role	Experimental Stealth Unmanned Combat Air Vehicle
Manufacturer	Dassault Aviation
First flight	scheduled for 2012 (as of 2010 parts are under construction)
Unit cost	€25 million
Developed from	AVE-C Moyen Duc

The **Dassault nEUROn** is an experimental Unmanned Combat Air Vehicle (UCAV) being developed by the French company Dassault Aviation. This delta wing stealth UCAV project is the final phase of the Dassault LOGIDUC 3-step stealth "combat drone" programme. Until June 2005, the UCAV nEUROn design was a full scale evolution of the twin-engine AVE-C Moyen Duc (2001) tactical UAV whose appearance was inspired by the stealth bomber Northrop Grumman B-2 Spirit. The full scale replica unveiled at the Paris Air Show 2005 revealed the original design was revised to a "less ambitious" single-engine delta.

The nEUROn development, originally planned by Dassault as "AVE Grand Duc", evolved to a European cooperation including Swedish Saab, Greek EAB, Swiss RUAG Aerospace, Spanish EADS CASA and Italian Alenia. As a "technology demonstrator", a reduced number of units will be produced to explore new operational concepts for a future generation of autonomous stealth fighter aircraft that will be produced in 2020 or 2025. However Dassault plan to primarily use the data collected by the demonstrator to

produce derived UCAVs. The French maker states the nEUROn's Adour engine (tuned from the SEPECAT Jaguar) will be replaced in the production version by a more powerful, specific, engine based on Snecma's M88 from the Dassault Rafale. According to the DGA, nEUROn test flights will be proceeded in France, Sweden and Italy in early 2010.

Program goals

The program has three stated goals:

1. To maintain and develop the skills of the participating European aerospace companies' design offices, which will not see any other new fighter programs before 2030 now that the Rafale, Eurofighter and JAS 39 Gripen projects are all complete or well underway.
2. To investigate and validate technologies that will be needed by 2015 to design next-generation combat aircraft.
3. To validate an innovative cooperation process by establishing a European industry team responsible for developing next-generation combat aircraft.

Platform

As a UCAV, nEUROn will be significantly larger and more advanced than other well-known UAV systems like the MQ-1 Predator, with ranges, payloads and capabilities that approach those of manned fighter aircraft. Although the project is not yet closely defined, illustrations and statements by the consortium partners indicate that the nEUROn is envisioned as a competitive system with the American J-UCAS program's Boeing X-45C or Northrop-Grumman X-47B.

Indeed, Saab's February 9, 2006 release notes that nEUROn will be a demonstrator measuring 10 m long by 12 m wide and weighing in at 5 tons. This is roughly the size of a Mirage 2000 fighter. The aircraft will have unmanned autonomous air-to-ground attack capabilities with precision guided munitions, relying on an advanced stealth airframe design to penetrate undetected. Another feature being contemplated is the ability to control squad flight in automatic mode from an advanced fighter like the Rafale or JAS 39 Gripen platform, grouping the nEUROns and controlling the group in a manner similar to many combat real-time strategy computer games.

Project history, developments

In 1999, Dassault Aviation launched its LOGIDUC stealth UCAV program, which gave birth to the Dassault AVE-D Petit Duc that flew in July 2000 as the first stealth UAV in Europe, and to the Dassault AVE-C Moyen Duc (2001). Dassault changed the third phase name "Grand Duc" - a full scale advanced version of the Moyen Duc - to the more European sounding nEUROn, as the French project was joined by European partners to reduce its development cost. Great Britain didn't join because it was already involved

with an American similar program, neither Germany who desisted officially because the country was unable to afford the financial participation.

During the 2003 Paris Air Show, French Minister of Defence Mme Michèle Alliot-Marie announced a major agreement signed between the French groups EADS France, Dassault Aviation and Thales. The agreement covered a joint-venture to "realise a new unmanned military technology that covers all future activity in combat and strategic reconnaissance aeronautics" *i.e.* LOGIDUC's phase three, "Grand Duc".

EADS leads a HALE (High Altitude, Long Endurance) UAV project.

Meanwhile, the French defence procurement agency, DGA, acting as the program executive on behalf of the participating countries, has entrusted development of the first nEUROn UCAV demonstrator to Dassault Aviation and its European partners. Sub-contracts have been made with the French industrial firms Thales and EADS France and also with five European firms, Saab (Sweden), EAB (Greece), Alenia (Italy), RUAG Aerospace (Switzerland) and EADS CASA (Spain).

Chief project manager Thierry Prunier comes from Dassault Aviation, and the deputy project managers are Mats Ohlson of Saab and Ermanno Bertolina of Alenia. There is a single link between the executive agency (DGA) and the prime contractor (Dassault), and it will be up to the executive agency to coordinate with the government agencies of the participating countries. It will be up to the prime contractor, meanwhile, to coordinate the work with the other industries.

After Spain joined the programme in early February 2006 (Belgium could join later), work breakdown among the European industrial partners was planned as follows::

-  **Dassault Aviation:** (launched European project in June 2003)

- Master builder
- Overall architectures & design
- Flight control system
- Final assembly
- Global testing (static & flight)

Dassault claims 50% of development and is responsible for the standalone LOGIDUC programme. The nEUROn (2010) will be the third Dassault stealth UAV prototype following the AVE-D Petit Duc (2000) & AVE-C Moyen Duc (2004). The nEUROn project replaces the LOGIDUC final phase AVE Grand Duc.

-  **Saab:** (joined on December 22, 2005)

- Overall design
- Equipped fuselage
- Avionics

Fuel system
Flight testing

Saab claims 25% of development and is also the coordinator for the other Swedish corporations involved.

-  **Alenia Aeronautica:** (joined in mid-2005)

Weapon firing system
Smart Integrated Weapon Bay
Air data system
Electrical system
Flight testing

Thanks to the technologies developed for the UAV prototype Sky-x (2003) Alenia Aeronautica claims to be the first industrial partner with 22% share of the entire programme.

-  **EADS CASA:** (joined on February 7, 2006)

Wing
Ground control station
Data-link integration

-  **EAB:** (joined on January 11, 2006)

Rear fuselage
Tail pipe
Integration bench.
Engine
Air to Air Missile
Communication System

-  **RUAG:** (joined in mid-2005)

Wind tunnel tests
Weapons carriage

-  **Thales:** (joined on June 14, 2005)

Data-link (STANAG 7085 compliant)
Command interface

-  **EADS France:** (joined in June 2003)

Undisclosed

Funding

The contract is valued at €405 million, and allows industry to begin a three-year system definition and design phase with related low-observability studies. This phase will be followed by the development and assembly phase, and by a first flight in 2011. It is planned that the 2-year flight-test program (2010–2012) will entail about 100 sorties, including the launch of a laser-guided bomb tentatively scheduled for 2012. The initial €400 million budget was increased by €5 million in 2006 due to the addition of a modular bomb bay including a designator and a laser-guided bomb.

On February 2006, DGA had announced that France will provide €202.5 million, half of the program's €405 million (\$480 million) budget, while the remaining funds will be supplied by the other participating member nations. In December 2005, the Swedish defence ministry reported the national share would be €75 million, of which €66 million would be financed by Saab AB. The cost of Spain's participation to the program is estimated at €35.5 million, spread over the 2007-2012 period.

Derived production UCAV unit cost is estimated by Dassault to €25 million.

Specifications

Data from

General characteristics

- **Crew:** 0
- **Length:** 9.5 m (31 ft 2 in)
- **Wingspan:** 12.5 m (41 ft 0 in)
- **Gross weight:** 6,000 kg (13,000 lb)

Performance

- **Maximum speed:** Mach 0.8

Armament

- Dual bomb bay
- Guided armaments carriage and firing abilities

Dragon Runner



Dragon Runner is a military robot built for urban combat. At 9 pounds (4 kg) it is light enough to be carried in a Marine's backpack. The original project was funded by the Marine Corps Warfighting Lab in conjunction with Carnegie Mellon University. It was designed at Carnegie Mellon University while the electronics and thermoplastic shell is developed and fabricated by Automatika, Inc.

The robot has four wheels, is 15 inches (38 cm) long, less than a foot wide, and 5 inches (13 cm) in height. The robot is very rugged, and can be thrown over fences, up or down stairwells, from a moving vehicle at 45 miles per hour (70 km/h), or even from a third-story window. It does not matter how it lands because neither side is the right side up. However, it was not designed to drive up or down stairs on its own. Instead, Dragon Runner was designed so that it could be carried up the stairway.

Use

Dragon Runner is designed for areas that are too dangerous for or inaccessible by human soldiers, particularly urban environments. Dragon Runner's front-mounted, tilting camera provides a video feed that is relayed back to its master controller by a wireless modem. It can save lives by providing soldiers with a view around corners and other obstructions that prevent them from seeing hidden enemies.

Dragon Runner can be operated in three different modes:

- Drive Mode: The robot drives around, transmitting images back to the operator.
- Sentry Mode: Dragon Runner remains stationary, using a microphone and sensors that can detect motion up to 30 feet (9.1 m) away. If it detects something, it will alert the operator.
- Watch Mode: The robot remains motionless and relays images back to the operator.

Modifications include flippers that enable it to climb stairs and treads that can all be snapped on quickly and easily in the field by a soldier with no tools.

In January 2010, under a contract worth £12m with QinetiQ UK, around 100 Dragon Runners were ordered by the British army to improve the ability of bomb disposal experts to find and deactivate improvised explosive devices on the front line in Afghanistan. The first in use were then already proving its worth against the threat of roadside bombs.

In current use

DRDO Daksh



Daksh - Remotely Operated Vehicle developed by DRDO

Daksh is an electrically powered and remotely controlled robot used for locating, handling and destroying hazardous objects safely. Daksh speaks for the ingenuity of the R&DE(E). It is a battery-operated robot on wheels and its primary role is to recover improvised explosive devices (IEDs). It locates IEDs with an X-ray machine, picks them up with a gripper-arm and defuses them with a jet of water. It has a shotgun, which can break open locked doors, and it can scan cars for explosives. Daksh can also climb staircases, negotiate steep slopes, navigate narrow corridors and tow vehicles. Alok Mukherjee, a scientist, said: "With a master control station (MCS), it can be remotely controlled over a range of 500 m in line of sight or within buildings. Ninety per cent of the robot's components are indigenous. The Army has placed orders for 20 Dakshs."

Description

Daksh is a remotely operated vehicle for defusing bombs, is currently under going trials. Developed by Defence Research and Development Organisation it is fully automated. It climbs stairs to reach hazardous materials. Using its robotized arm, it can lift a suspect object and scan it using its portable X-Ray device. If the object is a bomb, Daksh can defuse it with its water jet disrupter. Daksh can be armed with a shotgun, if necessary.

Total Containment Vessels

- Fully automated
- Can neutralise NBC weapons
- Has Radio frequency shield to jam remote signals for triggering a blast

Operator

- Indian Army

Goalkeeper CIWS

Goalkeeper CIWS



Goalkeeper CIWS on a British Invincible class aircraft carrier

Type	Close In Weapons System
Service history	
In service	1980-Present
Production history	
Designer	Signaal (now Thales Nederland)
Designed	1975
Manufacturer	Thales Navy Netherlands
Unit cost	€16 million
Produced	1979
Specifications	
Weight	6,372 kg with 1,190 rds of ammunition (above deck), 9,902 kg (total).
Height	3.71 m (above deck) 6.2 m (including deck penetration).
Crew	Automated, with human oversight

Caliber	30 mm
Barrels	7
Elevation	+85 to -25 degrees at 80 degrees/sec
Traverse	360°
Rate of fire	70 rounds/second (4,200 rounds/minute)
Muzzle velocity	1,109 m/s (MPDS round)
Effective range	350 to between 1,500 and 2,000 meters dependent on ammunition

Primary armament	1 x GAU-8/A Avenger 30 mm seven-barrel Gatling gun
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Goalkeeper is a Dutch close-in weapon system (CIWS), which defends ships against incoming missiles and ballistic shells. This system consists of an autocannon and an advanced radar which tracks incoming fire, determines its trajectory, then aims the gun and fires; all in only a matter of seconds. The system is fully automatic, needing no human input once activated. The name comes from the football/soccer position. The system is made by Thales Navy Netherlands. The system can also be deployed to protect airfields.

Development

Development of the system began in 1975 with Signaal (now Thales Nederland) working with General Electric, who supplied the GAU-8 gun. A prototype, the EX-83 was first demonstrated to the Royal Netherlands Navy in 1979.

Description

Target selection

Goalkeeper has two radar sub-systems; search and track, which operate in conjunction with one another to identify and prioritise targets before engaging the highest priority.

The 2D I band search radar, which can track up to 18 targets at once, generates a threat picture which the gun system uses to identify threats and prioritise. Once a target has been prioritised the engagement radar is slewed to the target bearing indicated by the search radar. The tracking radar operates in both I band and K band to enable quick acquisition on the threat bearing. Data from both the I band and K band return signals indicate target range and can be used to identify, and respond to the use of, electronic countermeasures (ECM). The dual band system also reduces the effect of clutter, which can mask the target at low altitude. A camera system on the assembly provides a visual fallback for the system operator.



Target hit by Goalkeeper

Target engagement

The GAU-8/A Avenger 30 mm Gatling gun, as used by the A-10 Thunderbolt II, was selected for the system. The 30 mm round has a greater mass than the M61 Vulcan used in the Phalanx CIWS so that it has greater stopping power despite the similar muzzle velocity and range.

The 30 mm round has a discarding nylon sleeve, or sabot, with a 21 mm sub-calibre tungsten penetrator. The nylon sabot provides a seal between penetrator and barrel, and reduces wear.

The tracking radar is capable of monitoring the line of fire and commanding minor adjustments.

Supersonic missiles that are damaged may still have enough momentum to hit the ship—the only way to ensure the protection of the ship is either detonate the warhead of the missile or obliterate the missile.

The system's reaction time to a Mach 2 sea-skimming missile like the Russian SS-N-22 Sunburn from automatic detection to kill is reported to be 5.5 seconds with the firing synchronised to start the engagement at a range of 1,500 m and ending with a kill at 300 m.

Comparison with Modern CIWS

Comparison of some modern CIWS			
	 AK-630	 Phalanx CIWS	 Goalkeeper CIWS
Weight	9,114 kg (20,090 lb)	6,200 kg (14,000 lb)	9,902 kg (21,830 lb)
Armament	30 mm (1.2 in) 6 barreled GSh-6-30 Gatling Gun	20 mm (0.79 in) 6 barreled M61 Vulcan Gatling Gun	30 mm (1.2 in) 7 barreled GAU-8 Gatling Gun
Rate of Fire	5000 rounds per minute	4500 rounds per minute	4200 rounds per minute
Range	4,000 m (13,000 ft)	3,600 m (11,800 ft)	2,000 m (6,600 ft)
Ammunition stowage	2000 rounds	1550 rounds	1190 rounds
Muzzle velocity	900 m (3,000 ft) per second	1,100 m (3,600 ft) per second	1,109 m (3,638 ft) per second
Elevation	-12 to +88 degrees	-25 to +85 degrees	-25 to +85 degrees
Traverse	360 degrees	-150 to +150 degrees	360 degrees

Specifications

- **Gun:** GAU-8/A Avenger 30 mm seven-barrel Gatling gun.
- **Height:** 3.71 m (above deck) 6.2 m (including deck penetration).
- **Weight:** 6,372 kg with 1,190 rds of ammunition (above deck), 9,902 kg (total).
- **Elevation** +85° to -25° at 80°/s.
- **Muzzle velocity:** 1,109 m/s (MPDS round).
- **Turret speed** 360° in 3.8 seconds
- **Rate of fire:** 70 rounds/second (4,200 rounds/minute).
- **Maximum burst size:** 1,000 rounds.

PackBot



PackBot being demonstrated by the French military

PackBot is a series of military robots by iRobot. More than 2000 PackBots are currently on station in Iraq and Afghanistan, with hundreds more on the way.

Current PackBot 510 variants



A U.S. Navy Explosive Ordnance Disposal Technician trains on iRobot's PCC, one of the remote control operation devices used to operate the Packbot.

PackBot 510 is the current base model. It uses a videogame-style hand controller to make it more familiar to young men and women. Configurations include:

- **PackBot 510 with EOD Bomb Disposal Kit** designed for improvised explosive device identification and disposal.
- **PackBot 510 with Fast Tactical Maneuvering Kit** designed for infantry troops tasked with improvised explosive device inspection. This is a lighter weight robot.
- **PackBot 510 with First Responder Kit** designed to help SWAT teams and other first responders with situational awareness.
- **PackBot 510 with HazMat Detection Kit** collects air samples to detect chemical and radiological agents.
- **PackBot 510 with Fido** utilizes the Fido Explosives Detector from ICx Technologies as a payload in order to "sniff" out explosive materials. With the Fido, the PackBot now has the capability of locating explosive devices and subsequently disarming them using on-board robotic capabilities.

- **PackBot 510 with REDOWL Sniper Detection Kit** utilizes the Acoustic Direction Finder from BioMimetic Systems to localize gunshots with azimuth, elevation, and range.

Previous PackBot variants



A U.S. Navy Sailor assigned to an explosive ordnance disposal team holds his M-4 carbine.

- **Packbot Scout** is the basic configuration. It has five payload bays for assignable purposes and can be dropped from a height of six feet (1.83m) onto concrete

without being damaged. The Packbot scout version weighs about 40 pounds (18 kg).

- **PackBot Explorer** has a camera head equipped with multiple cameras, laser pointers, audio and other sensors.
- **PackBot EOD** (explosive-ordnance disposal) can be controlled by radio or wired control to handle situations involving potential explosives, thereby reducing the risk of personal injury.

MARCBot



MARCBot extends its camera to search for suspected improvised explosive devices

MARCBot is a low cost robotic platform (costing about \$8000) used in Iraq for the inspection of suspicious objects. It is one of smallest and most commonly used robots in Iraq and looks like a small toy truck with an elevated mast on which a camera is mounted. This camera is used to look, for example, behind doors or through windows without placing human soldiers in danger. It is capable of running for 6 hours on a set of fully charged batteries and was developed with the input of soldiers in Iraq to meet their needs.

It was the first ground robot to draw blood in Iraq. One unit jury-rigged a Claymore antipersonnel mine on their units. If they suspected an ambush they would send the robot ahead. If an insurgent was seen the Claymore would be detonated.

Effects and impact

Advantages

Major Kenneth Rose of the US Army's Training and Doctrine Command outlined some of the advantages in robotic technology in warfare: "Machines don't get tired. They don't close their eyes. They don't hide under trees when it rains and they don't talk to their buddies ... A human's attention to detail on guard duty drops dramatically in the first 30 minutes ... Machines know no fear."

Increasing attention is also paid to how to make the robots more autonomous, with a view of eventually allowing them to operate on their own for extended periods of time, possibly behind enemy lines. For such functions, systems like the Energetically Autonomous Tactical Robot are being tried, which is intended to gain its own energy by foraging for plant matter.

Potential risks

In 2009, academics and technical experts attended a conference to discuss the impact of the hypothetical possibility that robots and computers could become self-sufficient and able to make their own decisions. They discussed the possibility and the extent to which computers and robots might be able to acquire any level of autonomy, and to what degree they could use such abilities to possibly pose any threat or hazard. They noted that some robots have acquired various forms of semi-autonomy, including being able to find power sources on their own and being able to independently choose targets to attack with weapons. They also noted that some computer viruses can evade elimination and have achieved "cockroach intelligence." They noted that self-awareness as depicted in science-fiction is probably unlikely, but that there were other potential hazards and pitfalls.

Some experts and academics have questioned the use of robots for military combat, especially when such robots are given some degree of autonomous functions. The US Navy has funded a report which indicates that as military robots become more complex, there should be greater attention to implications of their ability to make autonomous decisions.