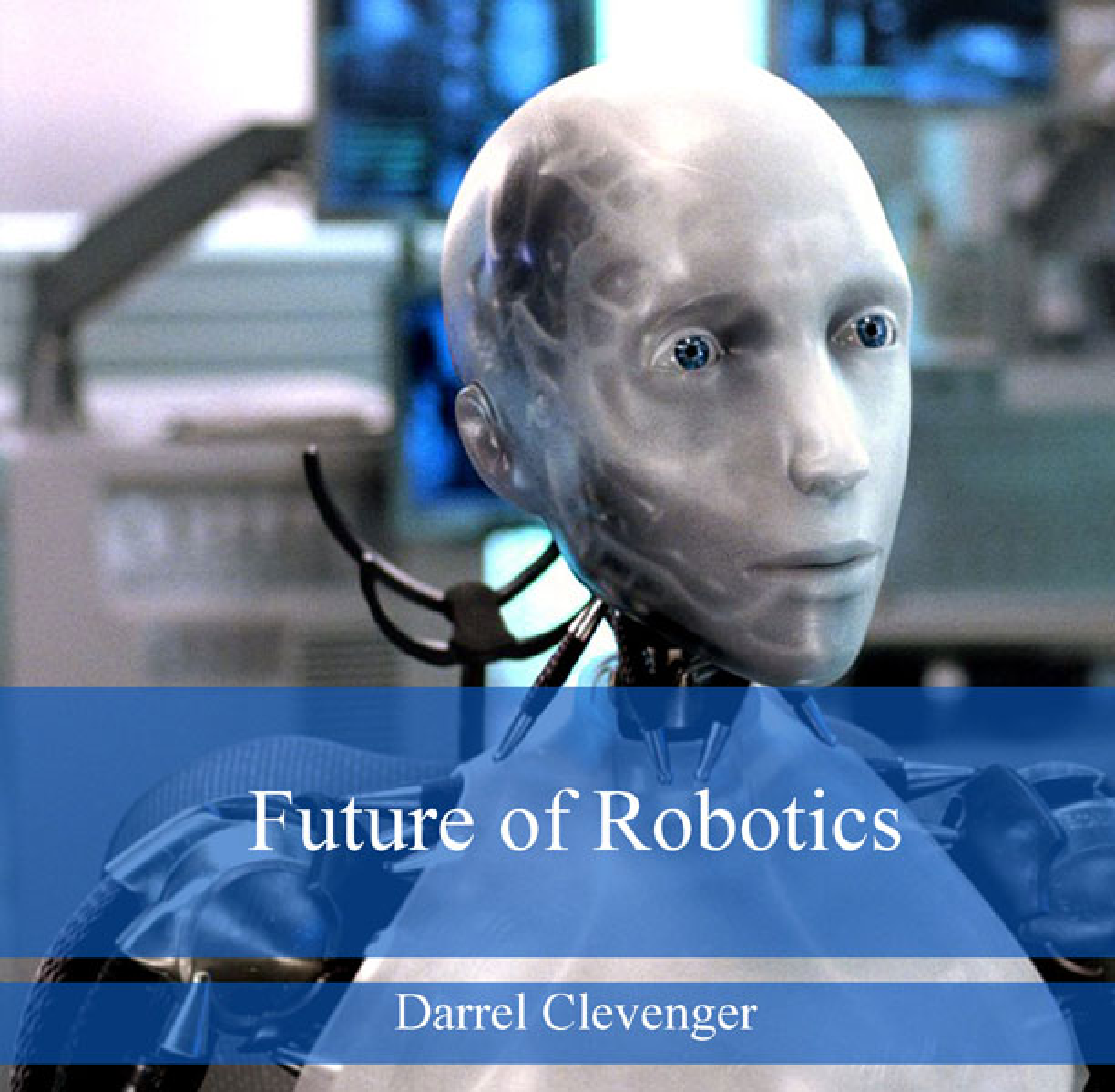

Future of Robotics

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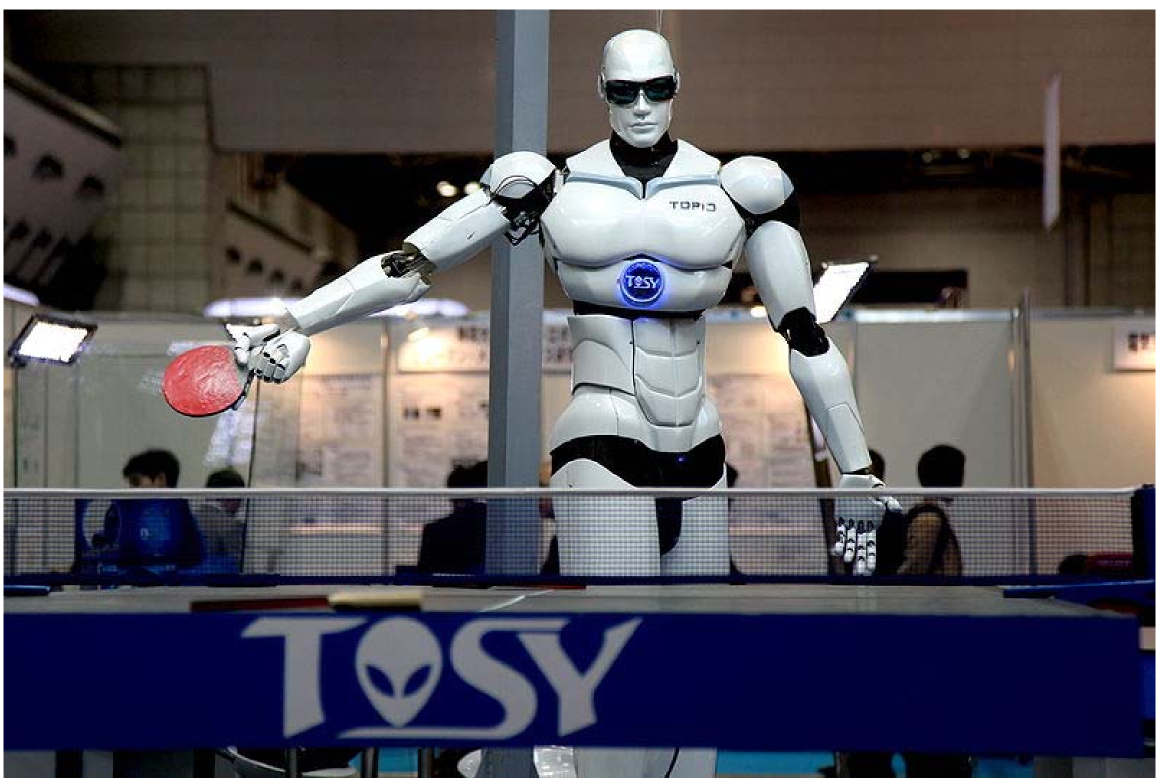
Humanoid Robots

A **humanoid robot** is a robot with its overall appearance, based on that of the human body, allowing interaction with made-for-human tools or environments. In general humanoid robots have a torso with a head, two arms and two legs, although some forms of humanoid robots may model only part of the body, for example, from the waist up. Some humanoid robots may also have a 'face', with 'eyes' and 'mouth'. Androids are humanoid robots built to aesthetically resemble a human.

Introduction



TOSY's TOPIO, a humanoid robot, can play ping pong.

A humanoid robot is an autonomous robot because it can adapt to changes in its environment or itself and continue to reach its goal. This is the main difference between humanoid and other kinds of robots. In this context, some of the capacities of a humanoid robot may include, among others:

- self-maintenance (like recharging itself)
- autonomous learning (learn or gain new capabilities without outside assistance, adjust strategies based on the surroundings and adapt to new situations)
- avoiding harmful situations to people, property, and itself
- safe interacting with human beings and the environment

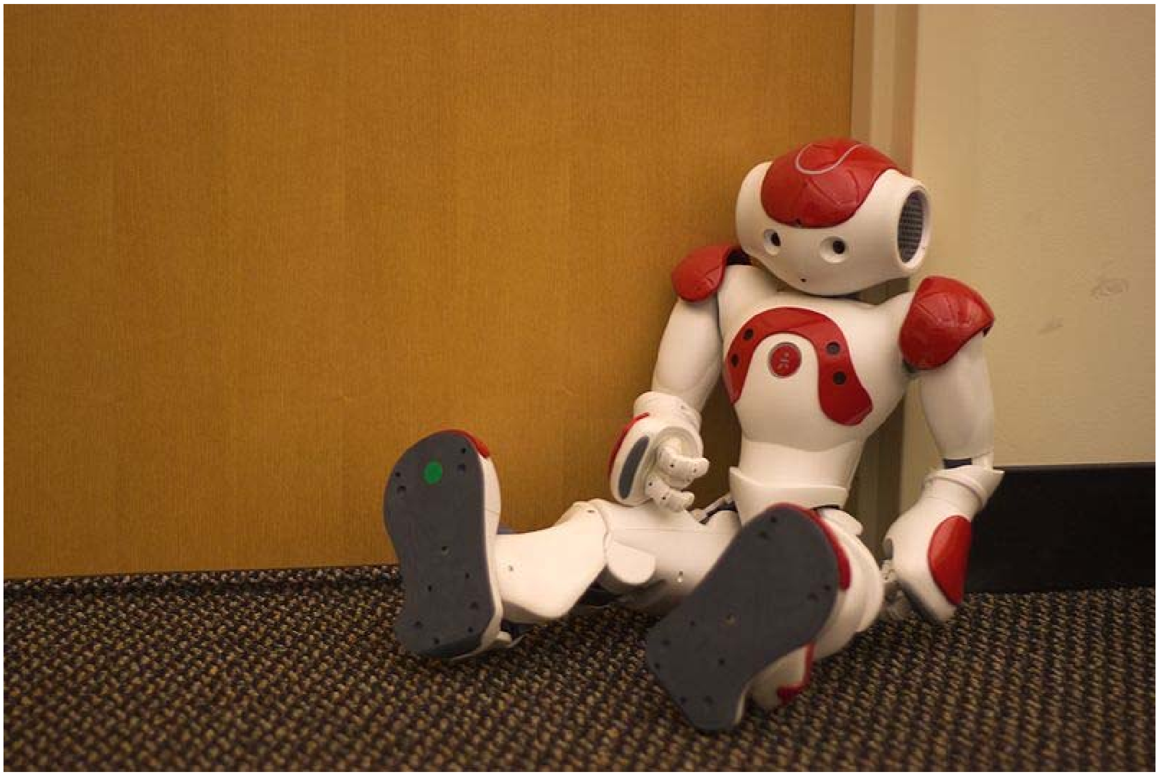
Like other mechanical robots, humanoid refer to the following basic components too: Sensing, Actuating and Planning and Control. Since they try to simulate the human structure and behavior and they are autonomous systems, most of the times humanoid robots are more complex than other kinds of robots.

This complexity affects all robotic scales (mechanical, spatial, time, power density, system and computational complexity), but it is more noticeable on power density and system complexity scales. In the first place, most current humanoids aren't strong enough even to jump and this happens because the power/weight ratio is not as good as in the human body. The dynamically balancing *Dexter* can jump, but poorly so far. On the other hand, there are very good algorithms for the several areas of humanoid construction, but it is very difficult to merge all of them into one efficient system (the system complexity is very high). Nowadays, these are the main difficulties that humanoid robots development has to deal with.

Humanoid robots are created to imitate some of the same physical and mental tasks that humans undergo daily. Scientists and specialists from many different fields including engineering, cognitive science, and linguistics combine their efforts to create a robot as human-like as possible. Their creators' goal for the robot is that one day it will be able to both understand human intelligence, reason and act like humans. If humanoids are able to do so, they could eventually work in cohesion with humans to create a more productive and higher quality future. Another important benefit of developing androids is to understand the human body's biological and mental processes, from the seemingly simple act of walking to the concepts of consciousness and spirituality.

There are currently two ways to model a humanoid robot. The first one models the robot like a set of rigid links, which are connected with joints. This kind of structure is similar to the one that can be found in industrial robots. Although this approach is used for most of the humanoid robots, a new one is emerging in some research works that use the knowledge acquired on biomechanics. In this one, the humanoid robot's bottom line is a resemblance of the human skeleton.

Purpose



Nao (robot) is a robot created for companionship. It also competes in the RoboCup soccer championship.

Enon was created to be a personal assistant. It is self-guiding and has limited speech recognition and synthesis. It can also carry things.

Humanoid robots are used as a research tool in several scientific areas.

Researchers need to understand the human body structure and behavior (biomechanics) to build and study humanoid robots. On the other side, the attempt to simulate the human body leads to a better understanding of it.

Human cognition is a field of study which is focused on how humans learn from sensory information in order to acquire perceptual and motor skills. This knowledge is used to develop computational models of human behavior and it has been improving over time.

It has been suggested that very advanced robotics will facilitate the enhancement of ordinary humans.

Although the initial aim of humanoid research was to build better orthosis and prosthesis for human beings, knowledge has been transferred between both disciplines. A few examples are: powered leg prosthesis for neuromuscularly impaired, ankle-foot orthosis, biological realistic leg prosthesis and forearm prosthesis.

Besides the research, humanoid robots are being developed to perform human tasks like personal assistance, where they should be able to assist the sick and elderly, and dirty or dangerous jobs. Regular jobs like being a receptionist or a worker of an automotive manufacturing line are also suitable for humanoids. In essence, since they can use tools and operate equipment and vehicles designed for the human form, humanoids could theoretically perform any task a human being can, so long as they have the proper software. However, the complexity of doing so is deceptively great.

They are becoming increasingly popular for providing entertainment too. For example, Ursula, a female robot, sings, dances, and speaks to her audiences at Universal Studios. Several Disney attractions employ the use of animatrons, robots that look, move, and speak much like human beings, in some of their theme park shows. These animatrons look so realistic that it can be hard to decipher from a distance whether or not they are actually human. Although they have a realistic look, they have no cognition or physical autonomy.

Humanoid robots, especially with artificial intelligence algorithms, could be useful for future dangerous and/or distant space exploration missions, without having the need to turn back around again and return to Earth once the mission is completed.

Sensors

A sensor is a device that measures some attribute of the world. Being one of the three primitives of robotics (besides planning and control), sensing plays an important role in robotic paradigms.

Sensors can be classified according to the physical process with which they work or according to the type of measurement information that they give as output. In this case, the second approach was used.

Proprioceptive Sensors

Proprioceptive sensors sense the position, the orientation and the speed of the humanoid's body and joints.

In human beings inner ears are used to maintain balance and orientation. Humanoid robots use accelerometers to measure the acceleration, from which velocity can be calculated by integration; tilt sensors to measure inclination; force sensors placed in robot's hands and feet to measure contact force with environment; position sensors, that indicate the actual position of the robot (from which the velocity can be calculated by derivation) or even speed sensors.

Exteroceptive Sensors

Exteroceptive sensors give the robot information about the surrounding environment allowing the robot to interact with the world. The exteroceptive sensors are classified according to their functionality.

Proximity sensors are used to measure the relative distance (range) between the sensor and objects in the environment. They perform the same task that vision and tactile senses do in human beings. There are other kinds of proximity measurements, like laser ranging, the usage of stereo cameras, or the projection of a colored line, grid or pattern of dots to observe how the pattern is distorted by the environment. To sense proximity, humanoid robots can use sonars and infrared sensors, or tactile sensors like bump sensors, whiskers (or feelers), capacitive and piezoresistive sensors.

An artificial hand holding a lightbulb.

Arrays of tactels can be used to provide data on what has been touched. The Shadow Hand uses an array of 34 tactels arranged beneath its polyurethane skin on each finger tip. Tactile sensors also provide information about forces and torques transferred between the robot and other objects.

Vision refers to processing data from any modality which uses the electromagnetic spectrum to produce an image. In humanoid robots it is used to recognize objects and determine their properties. Vision sensors work most similarly to the eyes of human beings. Most humanoid robots use CCD cameras as vision sensors.

Sound sensors allow humanoid robots to hear speech and environmental sounds, and perform as the ears of the human being. Microphones are usually used for this task.

Actuators

Actuators are the motors responsible for motion in the robot.

Humanoid robots are constructed in such a way that they mimic the human body, so they use actuators that perform like muscles and joints, though with a different structure. To achieve the same effect as human motion, humanoid robots use mainly rotary actuators. They can be either electric, pneumatic, hydraulic, piezoelectric or ultrasonic.

Hydraulic and electric actuators have a very rigid behavior and can only be made to act in a compliant manner through the use of relatively complex feedback control strategies . While electric coreless motor actuators are better suited for high speed and low load applications, hydraulic ones operate well at low speed and high load applications.

Piezoelectric actuators generate a small movement with a high force capability when voltage is applied. They can be used for ultra-precise positioning and for generating and handling high forces or pressures in static or dynamic situations.

Ultrasonic actuators are designed to produce movements in a micrometer order at ultrasonic frequencies (over 20 kHz). They are useful for controlling vibration, positioning applications and quick switching.

Pneumatic actuators operate on the basis of gas compressibility. As they are inflated, they expand along the axis, and as they deflate, they contract. If one end is fixed, the other will move in a linear trajectory. These actuators are intended for low speed and low/medium load applications. Between pneumatic actuators there are: cylinders, bellows, pneumatic engines, pneumatic stepper motors and pneumatic artificial muscles.

Planning and Control

In planning and control the essential difference between humanoids and other kinds of robots (like industrial ones) is that the movement of the robot has to be human-like, using legged locomotion, especially biped gait. The ideal planning for humanoid movements during normal walking should result in minimum energy consumption, like it happens in the human body. For this reason, studies on dynamics and control of these kinds of structures become more and more important.

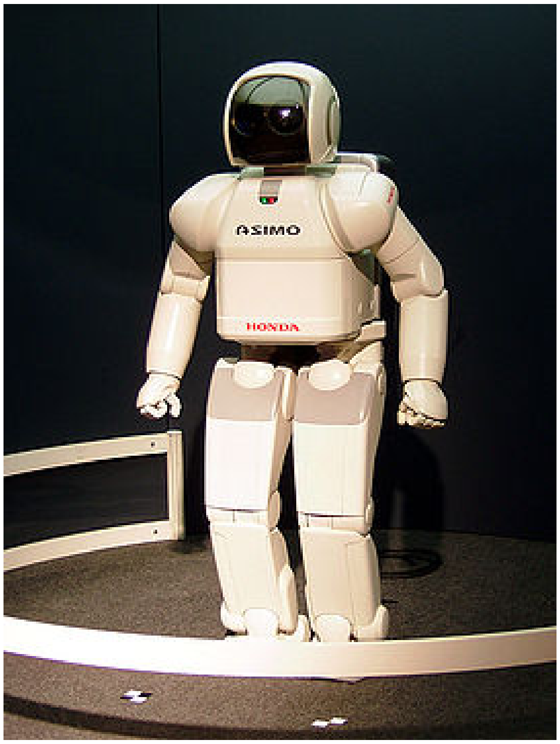
To maintain dynamic balance during the walk, a robot needs information about contact force and its current and desired motion. The solution to this problem relies on a major concept, the Zero Moment Point (ZMP).

Another characteristic about humanoid robots is that they move, gather information (using sensors) on the "real world" and interact with it, they don't stay still like factory manipulators and other robots that work in highly structured environments. Planning and Control have to focus about self-collision detection, path planning and obstacle avoidance to allow humanoids to move in complex environments.

There are features in the human body that can't be found in humanoids yet. They include structures with variable flexibility, which provide safety (to the robot itself and to the people), and redundancy of movements, i.e., more degrees of freedom and therefore wide task availability. Although these characteristics are desirable to humanoid robots, they will bring more complexity and new problems to planning and control.

ASIMO

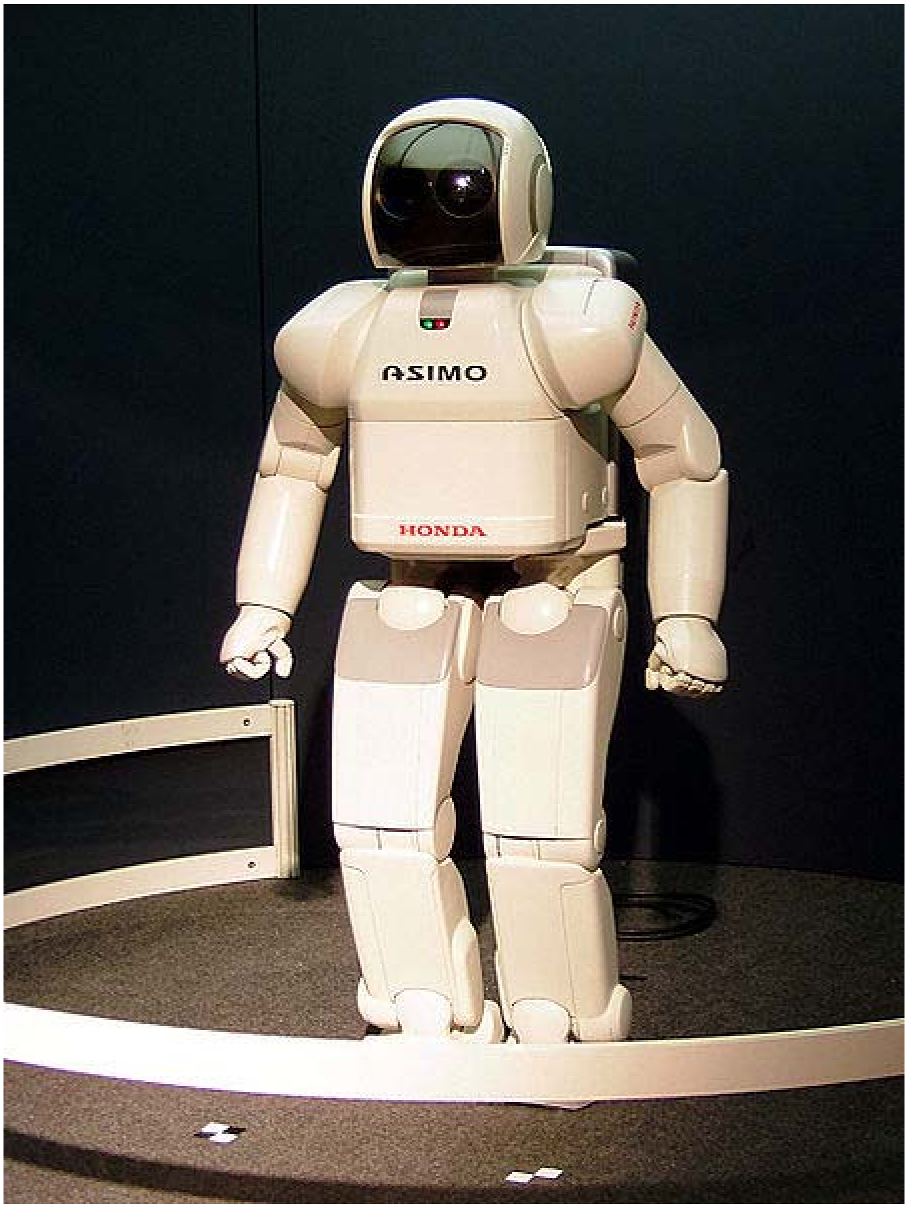
Honda ASIMO



ASIMO (2000) at the Expo 2005

Manufacturer	Honda
Year of creation	2000

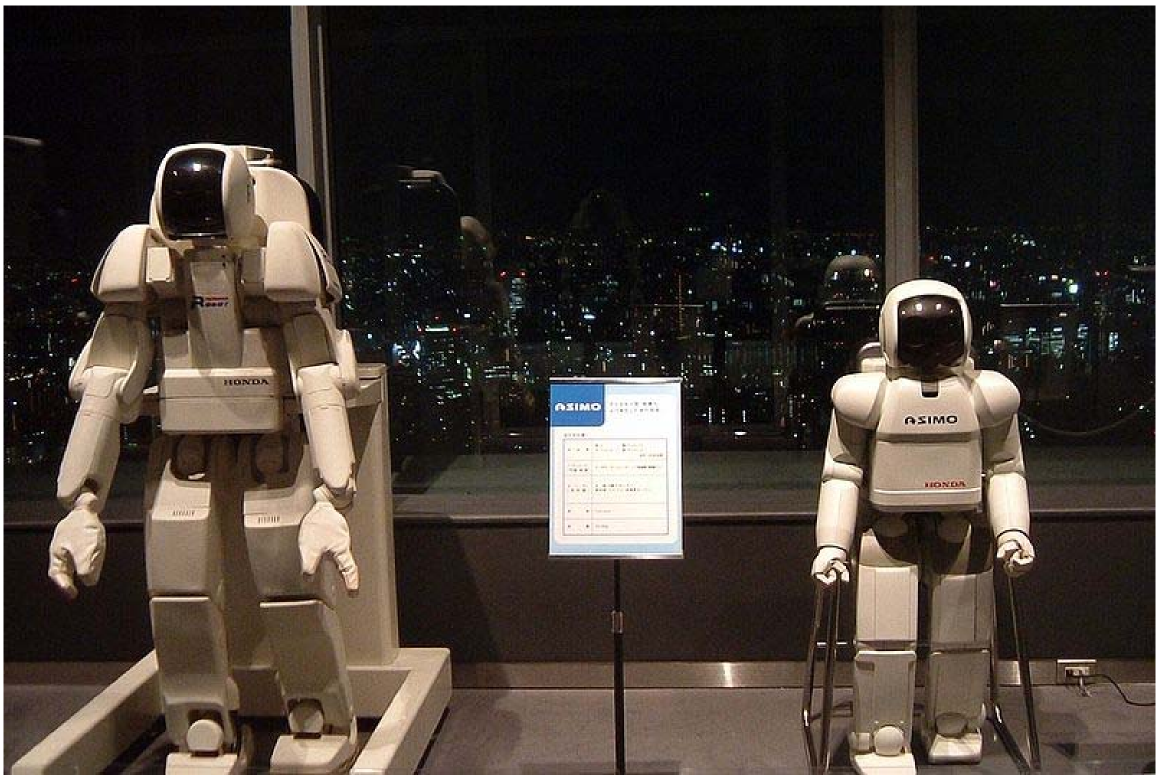
ASIMO (アシモ *ashimo*?) is a humanoid robot created by Honda. Standing at 130 centimeters (4 feet 3 inches) and weighing 54 kilograms (119 pounds), the robot resembles a small astronaut wearing a backpack and can walk or run on two feet at speeds up to 6 km/h (3.7 mph), matching EMIEW.



ASIMO (2000) at the Expo 2005

ASIMO was created at Honda's Research & Development *Wako Fundamental Technical Research Center* in Japan. It is the current model in a line of twelve that began in 1986 with E0. ASIMO resembles a child in size and is the most human-like robot HONDA has made so far. The robot has 7 DOF (Degrees of freedom) in each arm — two joints of 3 DOF, shoulder and wrist, giving "Six degrees of freedom" and 1 DOF at the elbow; 6 DOF in each leg — 3 DOF at the crotch, 2 DOF at the ankle and 1 DOF at the knee; and 3 DOF in the neck joint. The hands have 2 DOF — 1 DOF in each thumb and 1 in each finger. This gives a total of 34 DOF in all joints.

The name is an acronym for "**A**dvanced **S**tep in **I**nnovative **MO**bility". Online magazine *The Future Of Things* (TFOT) states that Honda did not name the robot in reference to science fiction writer and inventor of the Three Laws of Robotics, Isaac Asimov. The name ASIMO is also a pun meaning “feet, too”. アシ (ashi) is commonly translated as “feet” but can also refer to the lower leg from the knee down and モ (mo) is a particle meaning “also” or “too”, thus ASIMO (アシモ ashimo) roughly translated can mean “it has feet, too” as is appropriate for a robot with legs. The transliteration of アシモ as “asimo” uses the Kunrei system of romanization rather than the more familiar Hepburn system of romanization which renders it as “ashimo”. In both cases it should be pronounced “ah she mow” to match the original Japanese pronunciation.



P3 model (left) compared to ASIMO

As of February 2009, there are over 100 ASIMO units in existence. Each costs under ¥100 million ($1 million USD) to manufacture.

Development history

Experimental models

Humanoid prototype models

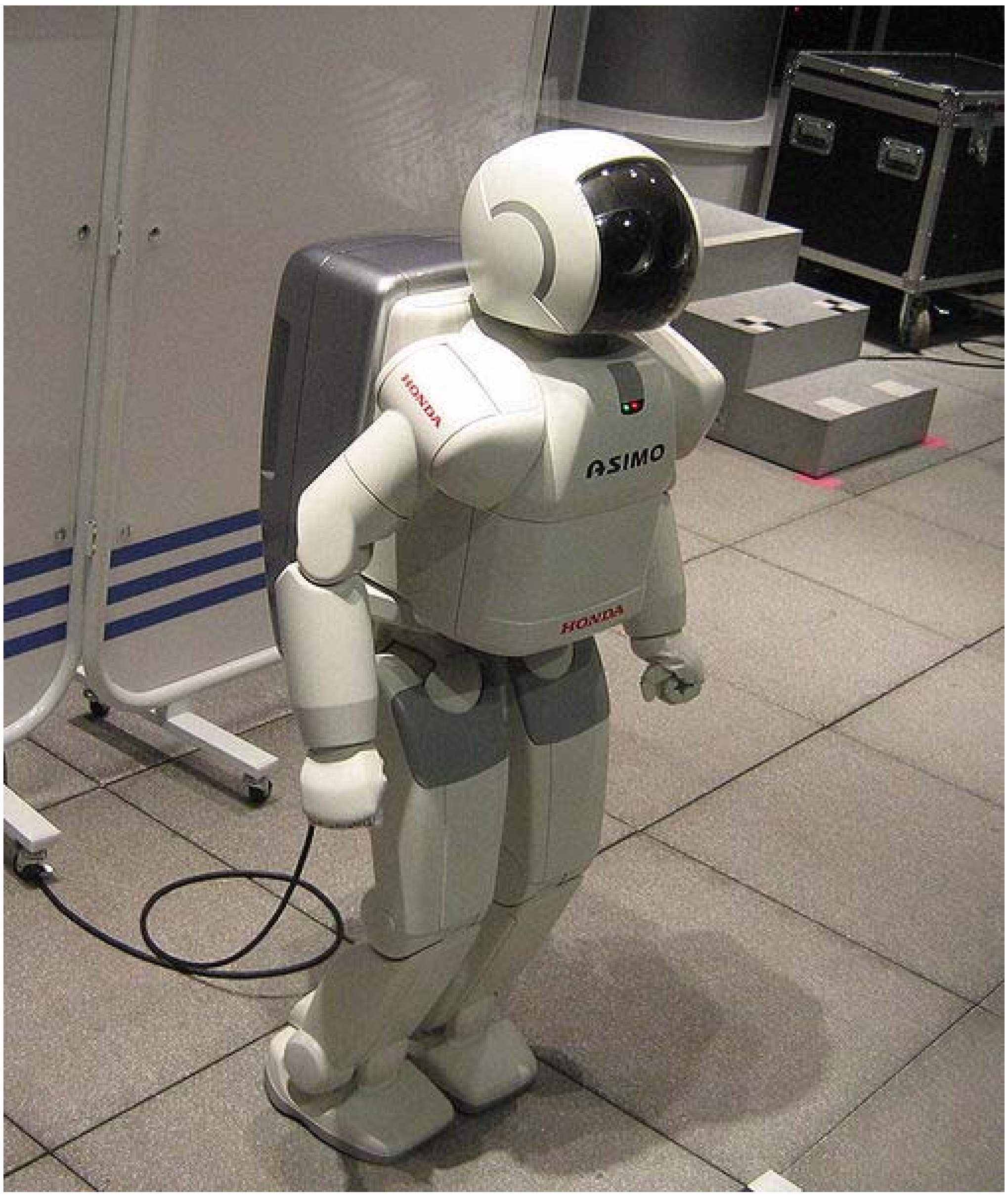
The P series took the E series the logical step forwards with the addition of arms. This also increased the degrees of freedom to 30 in the P1

ASIMO

- **ASIMO** unveiled in 2000
    - **ASIMO for hire** unveiled in 2001
    - **intelligent ASIMO** unveiled in 2002
- **next-gen ASIMO** unveiled in 2004
- **new ASIMO** unveiled in 2005

Features and technology

Specifications



Original ASIMO

Model	2000	2004	2005

Mass	52 kg ?	54 kg	
Height	120 cm	130 cm	
Width	45 cm	45 cm	
Depth	44 cm	37 cm	
Walking speed	1.6 km/hour	2.5 km/hour	2.7 km/hour 1.6 km/hour (carrying 1 kg)
Running speed	-	3 km/hour	6 km/hour (straight) 5 km/hour (circling)
Airborne time	-	0.05 seconds	0.08 seconds
Battery	Nickel metal hydride 38.4 V / 10 Ah / 7.7 kg 4 hours to fully charge	Lithium ion 51.8 V / 6 kg 3 hours to fully charge	
Continuous operating time	30 minutes	40 mins to 1 hour (walking)	
Degrees of Freedom	26 (two in the head, five in each arm, six in each leg, one per hand)	34 (three in the head, seven in each arm, two in each hand, one in the torso, six in each leg)	

Asimo can be operated from a workstation and also by a remote controller. Honda has also created a 3D CPU to power Asimo consisting of three stacked dice: a processor, a signal converter and some memory. ASIMO runs the VxWorks operating system.

Recognition technology

With 2000's ASIMO model Honda added features that enable ASIMO to interact better with humans. These features fall under 5 categories:

ASIMO walking alongside a human while holding hands

Moving objects

Using the visual information captured by the camera mounted in its head, ASIMO detects the movements of multiple objects, assessing distance and direction. Common applications of this feature would include: the ability to follow the movements of people with its camera, to follow a person, or greet a person when he or she approaches.

Postures and gestures

ASIMO interprets the positioning and movement of a hand, recognizing postures and gestures. Because of this ASIMO can react to and be directed by not only voice commands, but also to the natural movements of human beings. This enables it to, for example, recognize when a handshake is offered or when a person waves and respond accordingly. It can also recognize movement directions such as pointing.

Environment

ASIMO recognizes the objects and terrain of its environment and acts in a way that is safe for both itself and nearby humans. For example, recognizing potential hazards such as stairs, and by stopping and starting to avoid hitting humans or other moving objects.

Distinguishing sounds

ASIMO's ability to identify the source of sounds has been improved, and it can distinguish between voices and other sounds. It responds to its name, faces people when spoken to, and recognizes sudden, unusual sounds such as that of a falling object or a collision, and faces in that direction. It can respond to questions, either by a brief nod, a shake of the head or a verbal answer.

Facial recognition

ASIMO can recognize faces, even when ASIMO or the human being is moving. It can individually recognize approximately 10 different faces. Once they are registered it can address them by name.

Network integration

Utilizing networks ASIMO can provide information and function better for various commercial applications such as reception. Its abilities fall under 2 categories:

Integration with user's network system

By connecting with a user's network ASIMO can offer many useful functions such as greeting visitors and informing personnel of the visitor's arrival by transmitting messages and pictures of the visitor's face and guide visitors to a predetermined location.

Internet connectivity

By accessing information via the Internet, ASIMO can, for example, become a provider of news and weather updates.

Actroid

Repliee Q2 can mimic such human functions as blinking, breathing and speaking, with the ability to recognize and process speech and touch, and then respond in kind.

DER 01, an actroid at Expo 2005 in Aichi.

An **Actroid** is a humanoid robot and android with strong visual human-likeness developed by Osaka University and manufactured by Kokoro Company Ltd. (the animatronics division of Sanrio). It was first unveiled at the 2003 International Robot Exhibition in Tokyo, Japan. Several different versions of the product have been produced since then. In most cases, the robot's appearance has been modeled after an average young woman of Japanese descent.

The Actroid woman is a pioneer example of a real machine similar to imagined machines called by the science fiction terms *android* or *gynoid*, so far used only for fictional robots. It can mimic such lifelike functions as blinking, speaking, and breathing. The "Repliee" models are interactive robots with the ability to recognise and process speech and respond in kind.

Technology

Internal sensors allow Actroid models to react with a natural appearance by way of air actuators placed at many points of articulation in the upper body. Early models had 42 points of articulation, later models have 47. So far, movement in the lower body is limited. The operation of the robot's sensory system in tandem with its air powered movements make it quick enough to react to or fend off intrusive motions, such as a slap or a poke. Artificial intelligence possessed by the android gives it the ability to react differently to more gentle kinds of touch, such as a pat on the arm.

The Actroid can also imitate human-like behavior with slight shifts in position, head and eye movements and the appearance of breathing in its chest. Additionally, the robot can be "taught" to imitate human movements by facing a person who is wearing reflective dots at key points on their body. By tracking the dots with its visual system and computing limb and joint movements to match what it sees, this motion can then be "learned" by the robot and repeated.

The skin is composed of silicone and appears highly realistic. The compressed air that powers the robot's servo motors, and most of the computer hardware that operates the A.I., are external to the unit. This is a contributing factor to the robot's lack of locomotion capabilities. When displayed, the Actroid has always been either seated or standing with firm support from behind.

The interactive Actroids can also communicate on a rudimentary level with humans by speaking. Microphones within those Actroids record the speech of a human, and this sound is then filtered to remove background noise - including the sounds of the robot's own operation. Speech recognition software is then used to convert the audio stream into words and sentences, which can then be processed by the Actroid's A.I. A verbal response is then given through speakers external to the unit.

Further interactivity is achieved through non-verbal methods. When addressed, the interactive Actroids use a combination of "floor sensors and omnidirectional vision sensors" in order to maintain eye contact with the speaker. In addition, the robots can respond in limited ways to body language and tone of voice by changing their own facial expressions, stance and vocal inflection.

Models

The original Repliee Q1 had a "sister" model, Repliee R1, which is modeled after a 5-year-old Japanese girl.

More advanced models were present at Expo 2005 in Aichi to help direct people to specific locations and events. Four unique visages were given to these robots. The ReplieeQ1-expo was modeled after a presenter for NHK news. To make the face of the Repliee Q2 model, the faces of several young Japanese women were scanned and the images combined into an average composite face.

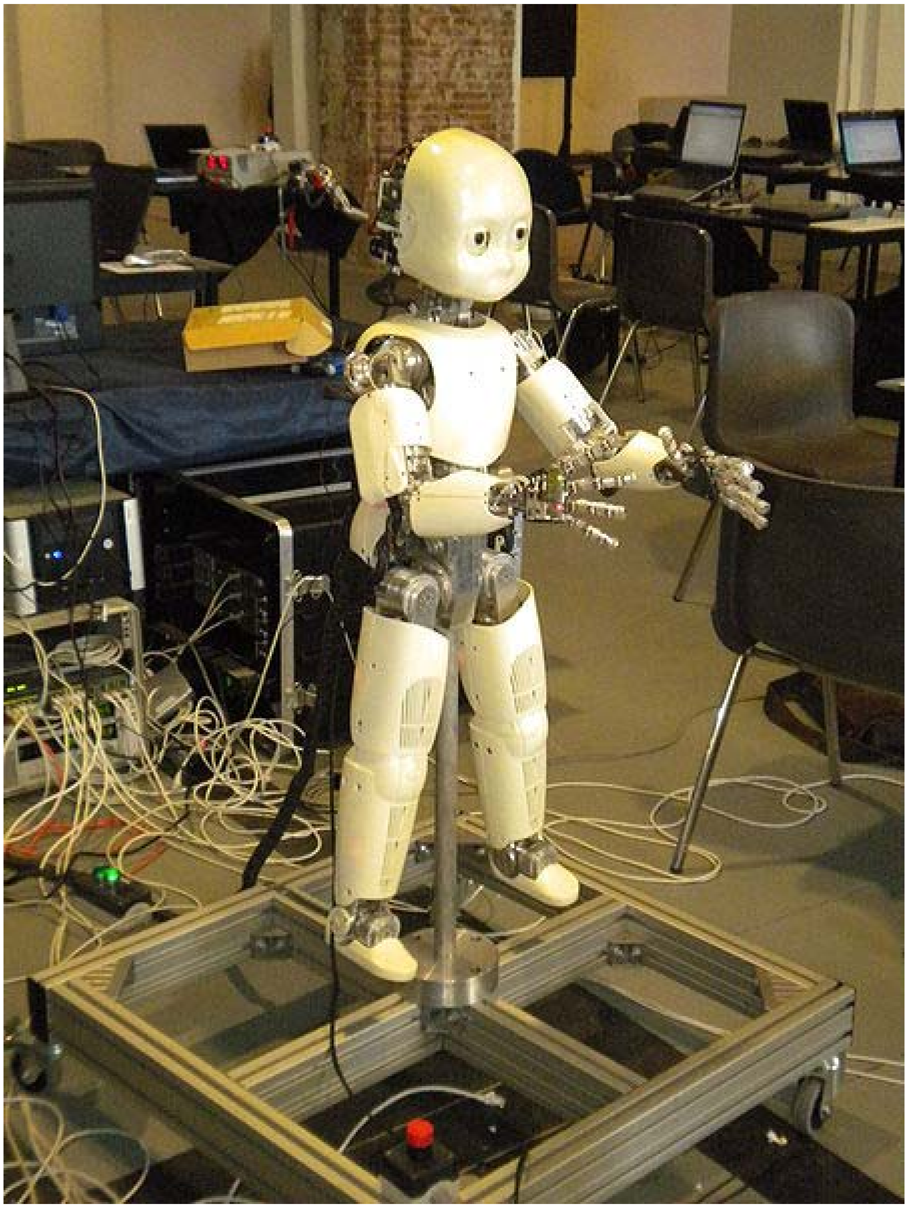
The newer model Actroid-DER2 made a recent tour of U.S. cities. At NextFest 2006, the robot spoke English and was displayed in a standing position and dressed in a black vinyl bodysuit. A different Actroid-DER2 was also shown in Japan around the same time. This new robot has more realistic features and movements than its predecessor.

In July 2006, another appearance was given to the robot. This model was built to look like its male co-creator, roboticist Hiroshi Ishiguro, and named Geminoid HI-1. Controlled by a motion-capture interface, Geminoid HI-1 can imitate Ishiguro's body and facial movements, and it can reproduce his voice in sync with his motion and posture. Ishiguro hopes to develop the robot's human-like presence to such a degree that he could use it to teach classes remotely, lecturing from home while the Geminoid interacts with his classes at Osaka University.

Actroid timeline

Date	Development
2003 November	Actroid is unveiled at the International Robot Exhibition.
2004 January	Model "Actroid ReplieeQ1" developed at Osaka University.
2004 December	"Actroid ReplieeQ1-expo" developed for Expo 2005 in Aichi.
2005 March	"Actroid-expo" models shown at the 2005 Expo; three at help booths, another on stage as an emcee.
2005 June	"Actroid-DER" (Dramatic Entertainment Robot) rental-only model introduced.
2005 July	Ishiguro research team develops the "Actroid ReplieeQ2" at Osaka University.
2006 July	Geminoid HI-1 produced in the image of Hiroshi Ishiguro.
2006 October	"Actroid-DER2" units available.
2008 October	Release of the "Actroid-DER3" units.
2009	Release of the "Actroid Sara"
Spring 2010	Actroid will enter the market, being sold for $20,000 at select stores in Japan.

iCub



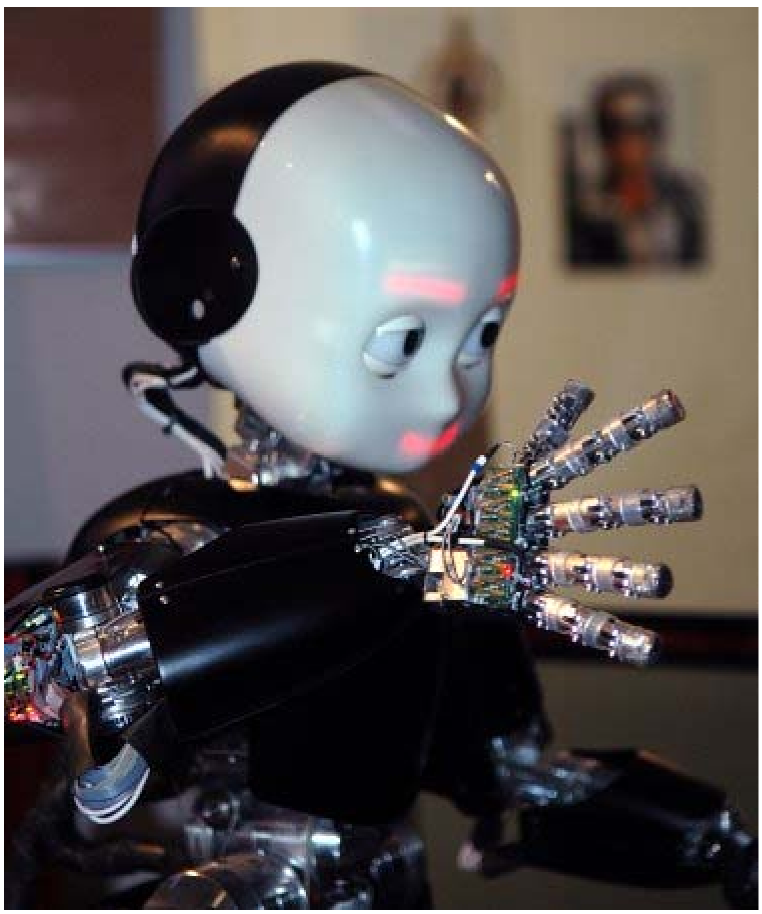
An iCub robot mounted on a supporting frame. The robot is 104 cm high and weighs around 22 kg

An **iCub** is a 1 metre high humanoid robot testbed for research into human cognition and artificial intelligence.

It was designed by the RobotCub Consortium, of several European universities and is now supported by other projects such as ITALK. The robot is open-source, with the hardware design, software and documentation all released under the GPL license. The name is a partial acronym, *cub* standing for Cognitive Universal Body. Initial funding for the project was €8.5 million from Unit E5 – Cognitive Systems and Robotics – of the European Commission's Seventh Framework Programme, and this ran for five years from 1 September 2004 until 1 September 2010.

The motivation behind the strongly humanoid design is the embodied cognition hypothesis, that human-like manipulation plays a vital role in the development of human cognition. A baby learns many cognitive skills by interacting with its environment and other humans using its limbs and senses, and consequently its internal model of the world is largely determined by the form of the human body. The robot was designed to test this hypothesis by allowing cognitive learning scenarios to be acted out by an accurate reproduction of the perceptual system and articulation of a small child so that it could interact with the world in the same way that such a child does.

Specifications



An iCub at a live demo making facial expressions

The dimensions of the iCub are similar to that of a 3.5 year old child. The robot is controlled by an on-board PC104 controller which communicates with actuators and sensors using CANBus.

It utilises tendon driven joints for the hand and shoulder, with the fingers flexed by teflon-coated cable tendons running inside teflon-coated tubes, and pulling against spring returns. Joint angles are measured using custom-designed Hall-effect sensors and the robot can be equipped with torque sensors. The finger tips can be equipped with tactile touch sensors, and a distributed capacitive sensor skin is being developed.

The software library is largely written in C++ and uses YARP for external communication via Gigabit Ethernet with off-board software implementing higher level functionality, the development of which has been taken over by the RobotCub Consortium. The robot was not designed for autonomous operation, and is consequently not equipped with onboard batteries or processors required for this —instead an umbilical cable provides power and a network connection.

In its final version, the robot has 53 actuated degrees of freedom organized as follows:

- 7 in each arm
- 9 in each hand (3 for the thumb, 2 for the index, 2 for the middle finger, 1 for the coupled ring and little finger, 1 for the adduction/abduction)
- 6 in the head (3 for the neck and 3 for the cameras)
- 3 in the torso/waist
- 6 in each leg

The head has stereo cameras in a swivel mounting where eyes would be located on a human and microphones on the side. It also has lines of red LEDs representing mouth and eyes mounted behind the face panel for making facial expressions.

Since the first robots were constructed the design has undergone several revisions and improvements, for example smaller and more dexterous hands, and lighter, more robust legs with greater joint angles and which permit walking rather than just crawling.

iCubs in the world

There are about twenty iCubs in various laboratories mainly in Europe but also one in the USA. These were built by the RobotCub partners or other projects and form a small but lively community of scientists that use the iCub to study embodied cognition in artificial systems. Most of the financial support comes from the European Commission's Unit E5 or the Italian Institute of Technology (IIT). The robots are constructed by the IIT and cost €200,000-250,000 each depending upon the version.

HRP-4C

The **HRP-4C** is a humanoid robot created by the National Institute of Advanced Industrial Science and Technology, a Japanese research facility, and publicly demonstrated on March 16, 2009. It is 158 cm (5 feet, 2 inches) tall and weighs 43 kg (95 pounds) including battery. Its shape and joints are based on the 1997–1998 Japanese body dimension database (though many have noted that the hands seem oversized). It is capable of recognizing ambient sounds and, by using the vocal synthesizer Vocaloid, can sing. Recent upgrades have allowed HRP-4C to mimic human facial and head movements as well as execute dance steps, resulting in the most human-like performance yet at Tokyo's Digital Content Expo in 2010. The HRP-4C is considered to be a gynoid.

REEM

REEM-A and **REEM-B** are the first and second prototypes of humanoid robots created by PAL Robotics. REEM-B can recognize and grasp objects, lift heavy weights and go around by itself inside building complex, avoiding obstacles (Simultaneous localization and mapping). The robot accepts voice commands and recognize faces.

Specifications

Model

REEM-A(2006)

REEM-B(2008)

Weight
40 kg
60 kg
Height
140 cm
147 cm
Walking speed
1.5 km/h
1.5 km/h
Continuous operating time
90 minutes
120 minutes
Degrees of Freedom
30
41
Payload of the arms
2 kg
12 kg
Main CPU
Intel Pentium M (1.6 GHz)

Intel Core Duo (1.66 GHz)
Geode(500 MHz)

HUBO

HUBO	
Hangul	휴보
Revised Romanization	Hyubo
McCune–Reischauer	Hyubo

Albert HUBO, the latest humanoid version of the HUBO robots, can make expressive gestures with its 5 separate fingers.

HUBO (휴보 KHR-3) is a walking humanoid robot, head mounted on a life-size walking bipedal frame, developed by the Korea Advanced Institute of Science and Technology (KAIST) and released on January 6, 2005. Hubo is short form for "***hu***manoid ro***bo***t."

Hubo has voice recognition and synthesis faculties, as well as sophisticated vision in which its two eyes move independently of one another.

Development history

Korea's history in robotics engineering is relatively short. KAIST only began research in 2000, led by professor Oh Jun-ho. The first prototype KHR-1 was developed without a head or arms released in 2003, followed by KHR-2 in 2004.

Latest breakthroughs

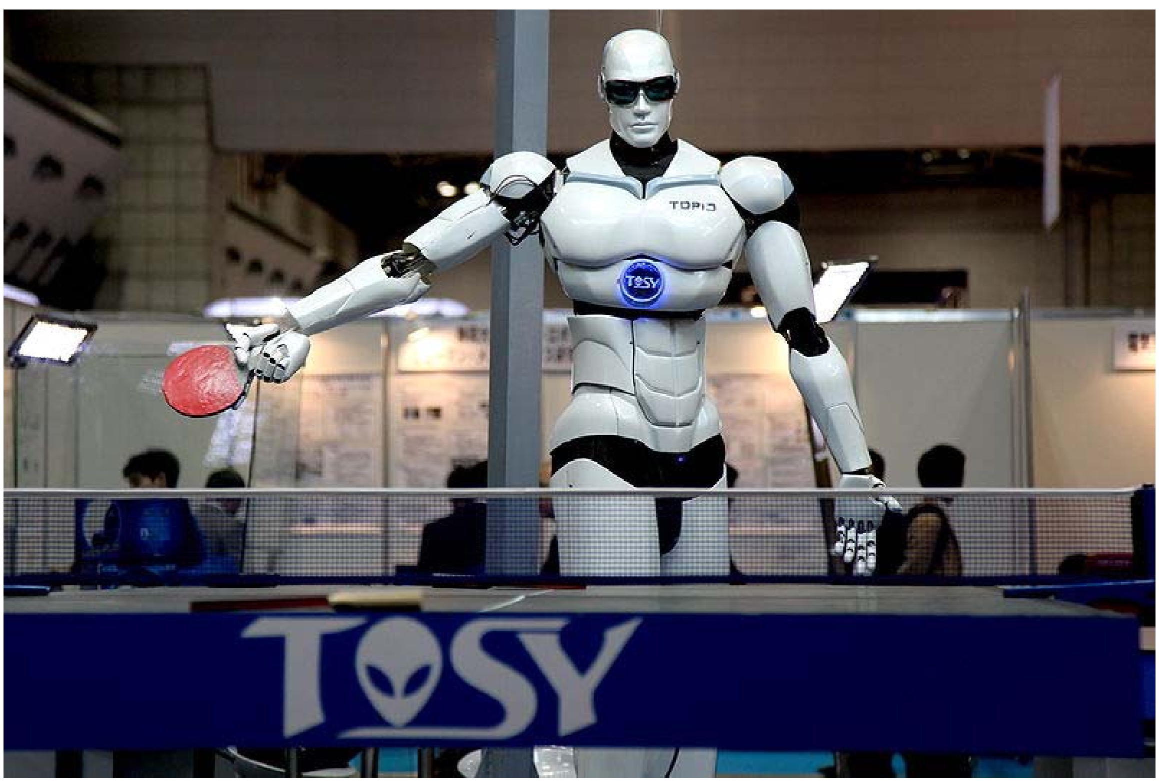
In November 5', KAIST, Korea and Dallas, Texas based Hanson Robotics, Inc (HRI) released the world's first android head mounted on a life-size walking bi-pedal frame at the APEC Summit in Seoul, Korea. The walking frame was the latest in Hubo technology, while the head was an exact recreation of the late physicist, Albert Einstein. The android was able to speak and cover a wide range of natural facial expressions, built upon prior HRI development on the Philip K. Dick android, which made its official debut at the Wired Magazine NextFest 05' in Chicago, Illinois.

The humanoid prototype was officially dubbed "Albert Einstein Hubo".

Prototypes

- KHR-1 in 2003
- KHR-2 in 2004

TOPIO



TOPIO 3.0 at Tokyo International Robot Exhibition (IREX) 2009

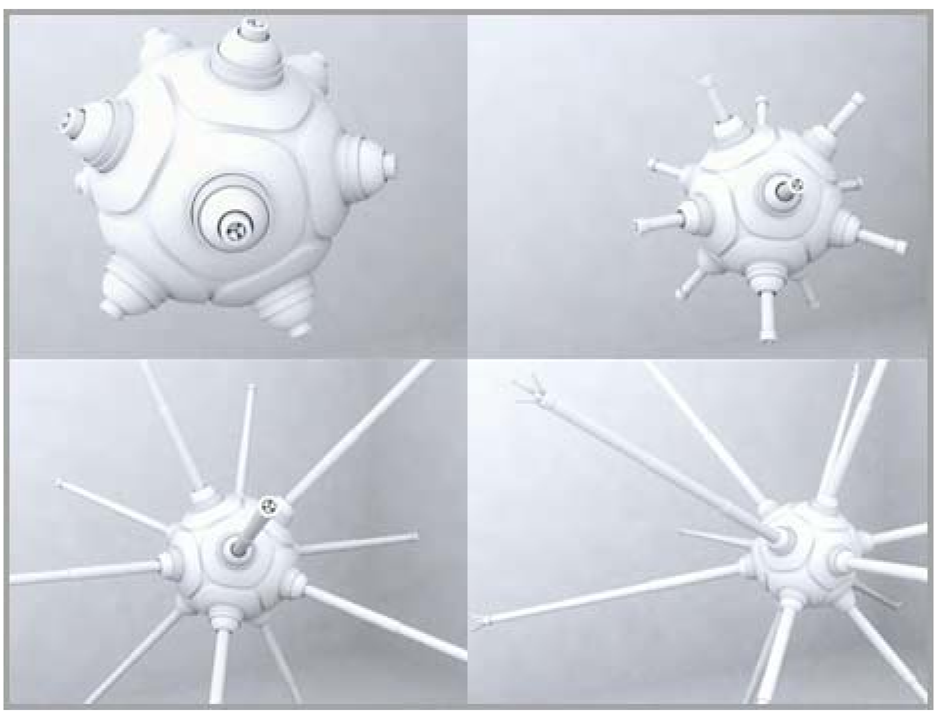
TOPIO ("**TO**SY **Pi**ng Pong Playing Rob**o**t") is a bipedal humanoid robot designed to play table tennis against a human being. It has been developed since 2005 by **TOSY,** a robotics firm in Vietnam. It was publicly demonstrated at the Tokyo International Robot Exhibition (IREX) on November 28, 2007. TOPIO 3.0 (the latest version of TOPIO) stands approximately 1.88 m tall and weighs 120 kg. Every TOPIO uses an advanced artificial intelligence system to learn and continuously improve its skill level while playing.

Chapter- 2

Modular Robots

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

Utility fog



Visualization of foglet with arms retracted and extended

Diagram of a 100-micrometer foglet

Utility fog is a term suggested by Dr. John Storrs Hall to describe a hypothetical collection of tiny robots together performing a certain function.

Conception

Hall thought of it as a nanotechnological replacement for car seatbelts. The robots would be microscopic, with extending arms reaching in several different directions, and could perform three-dimensional lattice reconfiguration. Grabbers at the ends of the arms would allow the robots (or **foglets**) to mechanically link to one another and share both information and energy, enabling them to act as a continuous substance with mechanical and optical properties that could be varied over a wide range. Each foglet would have substantial computing power, and would be able to communicate with its neighbors.

In the original application as a replacement for seatbelts, the swarm of robots would be widely spread-out, and the arms loose, allowing air flow between them. In the event of a collision the arms would lock into their current position, as if the air around the passengers had abruptly frozen solid. The result would be to spread any impact over the entire surface of the passenger's body.

While the foglets would be micro-scale, construction of the foglets would require full molecular nanotechnology. Each bot would be in the shape of a dodecahedron with 12 arms extending outwards. Each arm would have four degrees of freedom. When linked together the foglets would form an octet truss. The foglets' bodies would be made of aluminum oxide rather than combustible diamond to avoid creating a fuel air explosive.

In Science Fiction

The idea of nanobotic swarms was detailed as early as in 1964 by Stanislaw Lem in the novel *The Invincible*, and explored in some recent SciFi novels, such as Prey (2002), written by Michael Crichton.

In the postcyberpunk comic series *Transmetropolitan,* there are a race of beings known as foglets. Through a complicated technical process, their consciousness is transferred into a cloud of billions of foglet robots—a process they see as stripping away their biological limitations and leaving them with only personal amusement. The now-vacant body is then used as fuel to jump-start the foglet. (Issue 6 page 19) They can spread themselves so thin they seem invisible, and come together as a pink cloud of dust with digital faces when they wish to be seen. (Issue 6 and beyond)

A suggestion was made by Jim Al-Khalili that the chameleonic external surface of a TARDIS could be composed of utility fog in the programme "How To Make A Tardis", broadcast as part of the nostalgic *Doctor Who* Night on BBC2 late in 1999.

Self-reconfiguring modular robot

Modular self-reconfiguring robotic systems or **self-reconfigurable modular robots** are autonomous kinematic machines with variable morphology. Beyond conventional actuation, sensing and control typically found in fixed-morphology robots, self-reconfiguring robots are also able to deliberately change their own shape by rearranging the connectivity of their parts, in order to adapt to new circumstances, perform new tasks, or recover from damage.

For example, a robot made of such components could assume a worm-like shape to move through a narrow pipe, reassemble into something with spider-like legs to cross uneven terrain, then form a third arbitrary object (like a ball or wheel that can spin itself) to move quickly over a fairly flat terrain; it can also be used for making "fixed" objects, such as walls, shelters, or buildings.

In some cases this involves each module having 2 or more connectors for connecting several together. They can contain electronics, sensors, computer processors, memory, and power supplies; they can also contain actuators that are used for manipulating their location in the environment and in relation with each other. A feature found in some cases is the ability of the modules to automatically connect and disconnect themselves to and from each other, and to form into many objects or perform many tasks moving or manipulating the environment.

By saying "self-reconfiguring" or "self-reconfigurable" it means that the mechanism or device is capable of utilizing its own system of control such as with actuators or stochastic means to change its overall structural shape. Having the quality of being "modular" in "self-reconfiguring modular robotics" is to say that the same module or set of modules can be added or removed to the system, as opposed to being generically "modularized" in the broader sense. The underlying intent is to have an indefinite number of identical modules, or a finite and relatively small set of identical modules, in a mesh or matrix structure of self-reconfigurable modules.

Self-reconfiguration is also different from the concept of self-replication, and self-replication is not necessarily a quality that a self-reconfigurable module or collection of such modules can or must possess. A matrix of N-number of modules does not need to be able to increase the quantity of modules to greater than N to be considered self-reconfigurable. It is sufficient for self-reconfigurable modules to be a device that is produced at a conventional factory, where dedicated machines stamp or mold components, and factory workers on an assembly line assemble the components to build each module.

There are two basic types of methods of segment articulation that self-reconfigurable mechanisms can utilize to reshape their structures, chain reconfiguration and lattice reconfiguration.

Structure and control

Modular robots are usually composed of multiple building blocks of a relatively small repertoire, with uniform docking interfaces that allow transfer of mechanical forces and moments, electrical power and communication throughout the robot.

The modular building blocks usually consist of some primary structural actuated unit, and potentially additional specialized units such as grippers, feet, wheels, cameras, payload and energy storage and generation.

A taxonomy of architectures

Modular self-reconfiguring robotic systems can be generally classified into several architectural groups by the geometric arrangement of their unit (lattice vs. chain). Several systems exhibit hybrid properties.

- **Lattice architectures** have units that are arranged and connected in some regular, space-filling three-dimensional pattern, such as a cubical or hexagonal grid. Control and motion are executed in parallel. Lattice architectures usually offer simpler computational representation that can be more easily scaled to complex systems.

- **Chain/tree architectures** have units that are connected together in a string or tree topology. This chain or tree can fold up to become space filling, but underlying architecture is serial. Chain architectures can reach any point in space, and are therefore more versatile but more computationally difficult to represent and analyze. Tree architectures may resemble a bush robot

Modular robotic systems can also be classified according to the way by which units are reconfigured (moved) into place.

- **Deterministic reconfiguration** relies on units moving or being directly manipulated into their target location during reconfiguration. The exact location of each unit is known at all times. Reconfiguration times can be guaranteed, but sophisticated feedback control is necessary to assure precise manipulation. Macro-scale systems are usually deterministic.

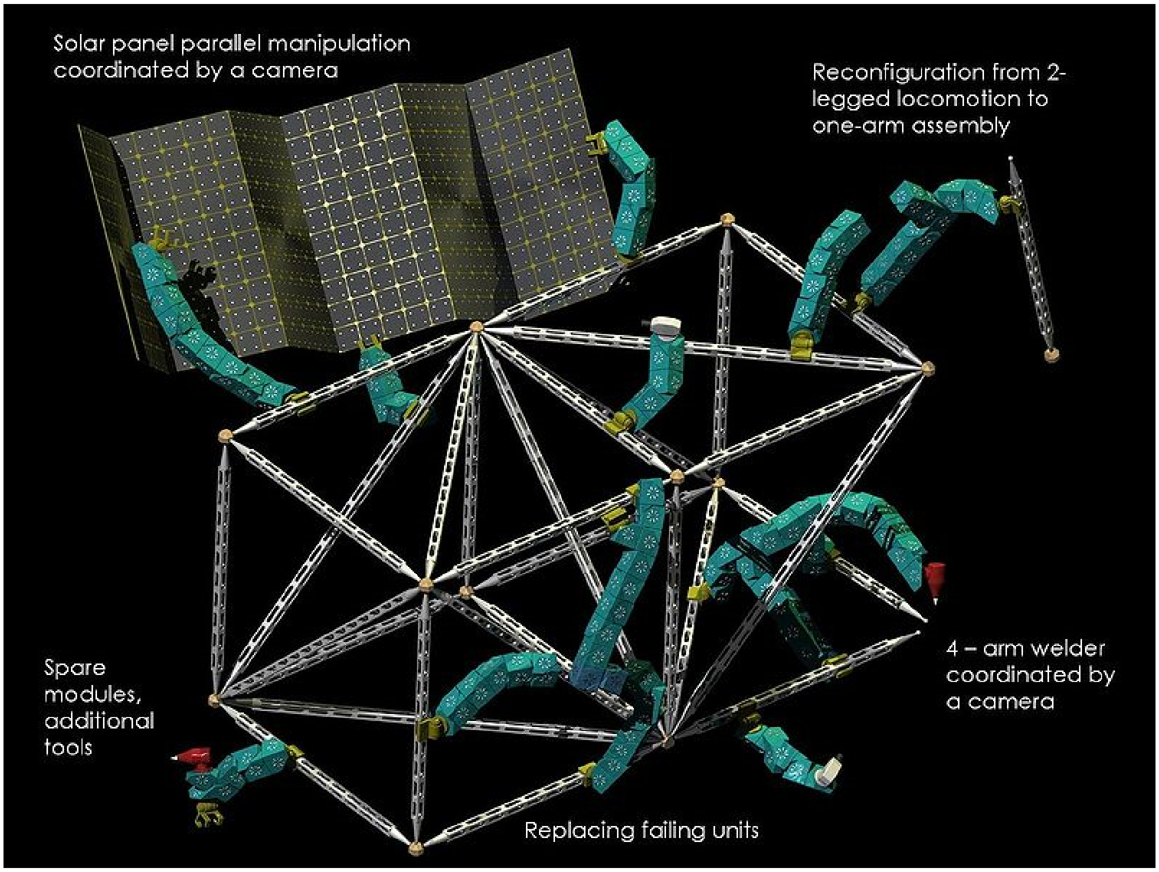
- **Stochastic reconfiguration** relies on units moving around using statistical processes (like Brownian motion). The exact location of each unit only known when it is connected to the main structure, but it may take unknown paths to move between locations. Reconfiguration times can be guaranteed only statistically. Stochastic architectures are more favorable at micro scales.

Other modular robotic systems exist which are not self-reconfigurable, and thus do not formally belong to this family of robots though they may have similar appearance. For example, self-assembling systems may be composed of multiple modules but cannot dynamically control their target shape. Similarly, tensegrity robotics may be composed of multiple interchangeable modules but cannot self-reconfigure.

Motivation and inspiration

There are two key motivations for designing modular self-reconfiguring robotic systems.

- **Functional advantage**: Self reconfiguring robotic systems are potentially more **robust** and more **adaptive** than conventional systems. The reconfiguration ability allows a robot or a group of robots to disassemble and reassemble machines to form new morphologies that are better suitable for new tasks, such as changing from a legged robot to a snake robot and then to a rolling robot. Since robot parts are interchangeable (within a robot and between different robots), machines can also replace faulty parts autonomously, leading to self-repair.



Autonomous modular robotics in space

- **Economic advantage**: Self reconfiguring robotic systems can potentially lower overall robot cost by making a range of complex machines out of a single (or relatively few) types of mass-produced modules.

Both these advantages have not yet been fully realized. A modular robot is likely to be inferior in performance to any single custom robot tailored for a specific task. However, the advantage of modular robotics is only apparent when considering multiple tasks that would normally require a set of different robots.

The added degrees of freedom make modular robots more versatile in their potential capabilities, but also incur a performance tradeoff and increased mechanical and computational complexities.

The quest for self-reconfiguring robotic structures is to some extent inspired by envisioned applications such as long-term space missions, that require long-term self-sustaining robotic ecology that can handle unforeseen situations and may require self repair. A second source of inspiration are biological systems that are self-constructed out of a relatively small repertoire of lower-level building blocks (cells or amino acids, depending on scale of interest). This architecture underlies biological systems' ability to physically adapt, grow, heal, and even self replicate – capabilities that would be desirable in many engineered systems.

Application areas

Given these advantages, where would a modular self-reconfigurable system be used? While the system has the promise of being capable of doing a wide variety of things, finding the "killer application" has been somewhat elusive. Here are several examples:

Space exploration

One application that highlights the advantages of self-reconfigurable systems is long-term space missions. These require long-term self-sustaining robotic ecology that can handle unforeseen situations and may require self repair. Self-reconfigurable systems have the ability to handle tasks that are not known a priori especially compared to fixed configuration systems. In addition, space missions are highly volume and mass constrained. Sending a robot system that can reconfigure to achieve many tasks is better than sending many robots that each can do one task.

Telepario

Another example of an application has been coined "telepario" by CMU professors Todd Mowry and Seth Goldstein. What the researchers propose to make are moving, physical, three-dimensional replicas of people or objects, so lifelike that human senses would accept them as real. This would eliminate the need for cumbersome virtual reality gear and overcome the viewing angle limitations of modern 3D approaches. The replicas would mimic the shape and appearance of a person or object being imaged in real time, and as the originals moved, so would their replicas. One aspect of this application is that the main development thrust is geometric representation rather than applying forces to the environment as in a typical robotic manipulation task.

Bucket of stuff

A third long term vision for these systems has been called "bucket of stuff". In this vision, consumers of the future have a container of self-reconfigurable modules say in their garage, basement, or attic. When the need arises, the consumer calls forth the robots to achieve a task such as "clean the gutters" or "change the oil in the car" and the robot assumes the shape needed and does the task. One source of inspiration for the development of these systems comes from the application. A second source is biological systems that are self-constructed out of a relatively small repertoire of lower-level building blocks (cells or amino acids, depending on scale of interest). This architecture underlies biological systems' ability to physically adapt, grow, heal, and even self replicate – capabilities that would be desirable in many engineered systems.

History and state of the art

The roots of the concept of modular self-reconfigurable robots can be traced back to the "quick change" end effector and automatic tool changers in computer numerical controlled machining centers in the 1970s. Here, special modules each with a common connection mechanism could be automatically swapped out on the end of a robotic arm. However, taking the basic concept of the common connection mechanism and applying it to the whole robot was introduced by Toshio Fukuda with the CEBOT (short for cellular robot) in the late 1980s.

The early 1990s saw further development from Greg Chirikjian, Mark Yim, Joseph Michael, and Satoshi Murata. Chirikjian, Michael, and Murata developed lattice reconfiguration systems and Yim developed a chain based system. While these researchers started with from a mechanical engineering emphasis, designing and building modules then developing code to program them, the work of Daniela Rus and Wei-min Shen developed hardware but had a greater impact on the programming aspects. They started a trend towards provable or verifiable distributed algorithms for the control of large numbers of modules.

One of the more interesting hardware platforms recently has been the MTRAN II and III systems developed by Satoshi Murata et al. This system is a hybrid chain and lattice system. It has the advantage of being able to achieve tasks more easily like chain systems, yet reconfigure like a lattice system.

More recently new efforts in stochastic self-assembly have been pursued by Hod Lipson and Eric Klavins. A large effort at CMU headed by Seth Goldstein and Todd Mowry has started looking at issues in developing millions of modules.

Many tasks have been shown to be achievable, especially with chain reconfiguration modules. This demonstrates the versatility of these systems however, the other two advantages, robustness and low cost have not been demonstrated. In general the prototype systems developed in the labs have been fragile and expensive as would be expected during any initial development.

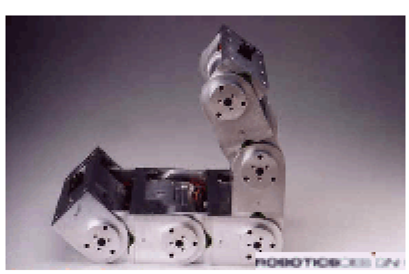
There is a growing number of research groups actively involved in modular robotics research. To date, about 30 systems have been designed and constructed, some of which are shown below.

Physical systems created			
System	**Class, DOF**	**Author**	**Year**
CEBOT	Mobile	Fukuda et al. (Tsukuba)	1988
Polypod	chain, 2, 3D	Yim (Stanford)	1993
Metamorphic	lattice, 6, 2D	Chirikjian (Caltech)	1993
Fracta	lattice, 3 2D	Murata (MEL)	1994
Fractal Robots	lattice, 3D	Michael(UK)	1995
Tetrobot	chain, 1 3D	Hamline et al. (RPI)	1996

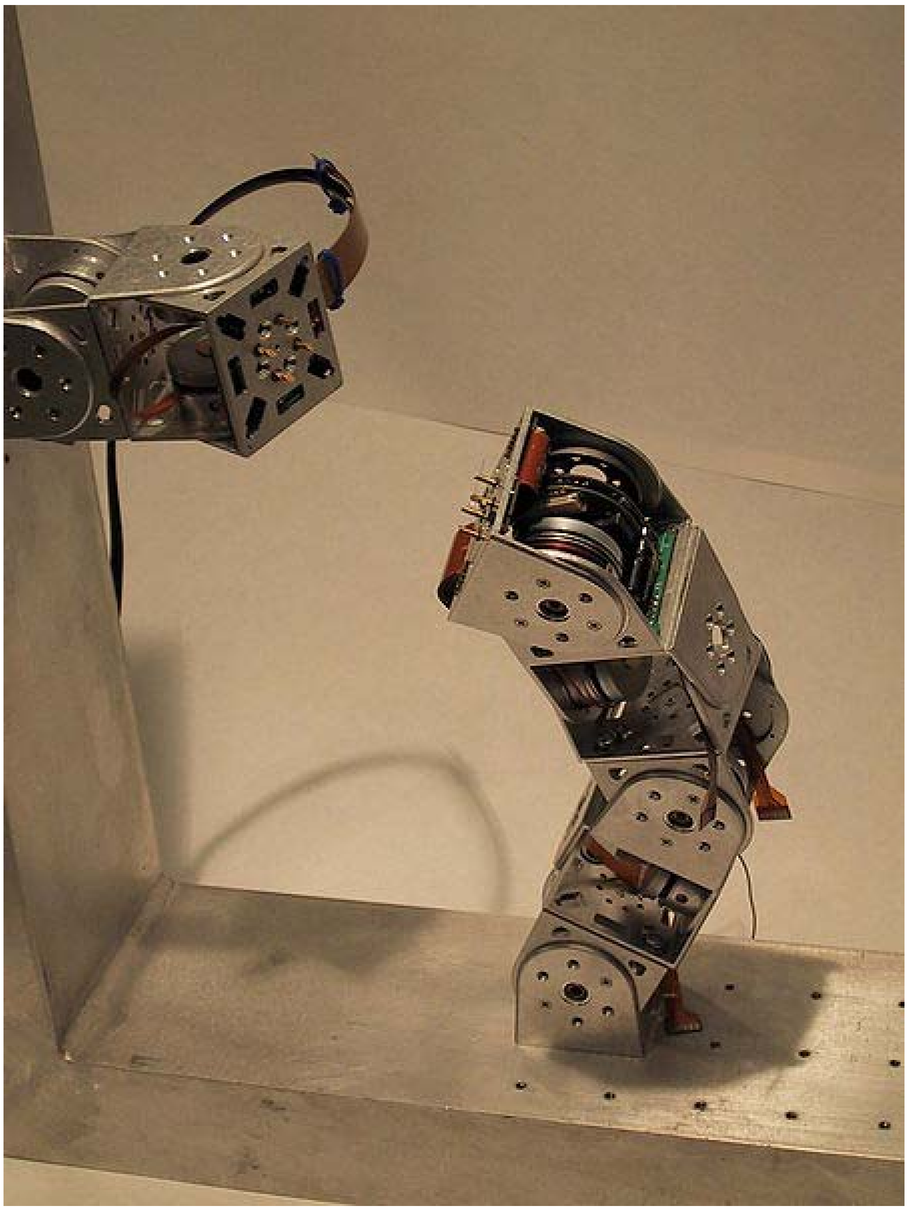
ANAT Robot	Chain/tree, 8D	Charles Khairallah (CA)	1997
3D Fracta	lattice, 6 3D	Murata et al. (MEL)	1998
Molecule	lattice, 4 3D	Kotay & Rus (Dartmouth)	1998
CONRO	chain, 2 3D	Will & Shen (USC/ISI)	1998
PolyBot	chain, 1 3D	Yim et al. (PARC)	1998
TeleCube	lattice, 6 3D	Suh et al., (PARC)	1998
Vertical	lattice, 2D	Hosakawa et al., (Riken)	1998
Crystalline	lattice, 4 2D	Vona & Rus, (Dartmouth)	1999
I-Cube	lattice, 3D	Unsal, (CMU)	1999
M-TRAN I	hybrid, 2 3D	Murata et al.(AIST)	1999
Pneumatic	lattice, 2D	Inou et al., (TiTech)	2002
Uni Rover	mobile, 2 2D	Hirose et al., (TiTech)	2002
M-TRAN II	hybrid, 2 3D	Murata et al., (AIST)	2002
Atron	lattice, 1 3D	Stoy et al., (U.S Denmark)	2003
S-bot	mobile, 3 2D	Mondada et al., (EPFL)	2003
Stochastic	lattice, 0 3D	White, Kopanski, Lipson (Cornell)	2004
Superbot	hybrid, 3 3D	Shen et al., (USC/ISI)	2004
Y1 Modules	Chain, 1 3D	Gonzalez-Gomez et al., (UAM)	2004
M-TRAN III	hybrid, 2 3D	Kurokawa et al., (AIST)	2005
AMOEBA-I	Mobile, 7 3D	Liu JG et al., (SIA)	2005
Catom	lattice, 0 2D	Goldstein et al., (CMU)	2005
Stochastic-3D	lattice, 0 3D	White, Zykov, Lipson (Cornell)	2005
Molecubes	chain, 1 3D	Zykov, Mytilinaios, Lipson (Cornell)	2005
Prog. parts	lattice, 0 2D	Klavins, (U. Washington)	2005
Miche	lattice, 0 3D	Rus et al., (MIT)	2006
GZ-I Modules	Chain, 1 3D	Zhang & Gonzalez-Gomez (U. Hamburg, UAM)	2006
Evolve	Chain, 2 3D	Chang Fanxi, Francis (NUS)	2008
Odin	Hybrid, 3 3D	?, Modular Robotics Research Lab, USD	200?

Some current systems

ANAT Robot (1997)



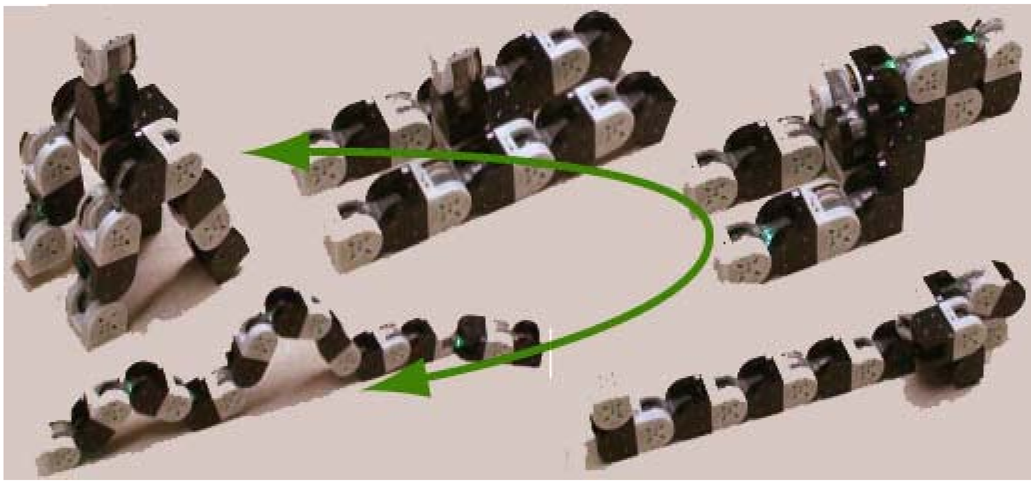
A chain/tree hyper-redundant modular robotic system invented by Charles Khairallah from Robotics Design Inc. in Montreal, Quebec, Canada. This robot is designed with ANAT Technology and is currently used for industrial manipulating under the name ANAT AMI-100, and Robotics Design's patented U and H shaped modules, of which this robot is composed, form the other robots in the ANAT robotics family. This robot can re-configure and/or self-reconfigure to form different shapes, due to its LEGO-like sets of modules with 1 degree of freedom each. Configurations range from mobile robots (ANATROLLER), manipulators (ANAT AMI-100) to walking robots (ANAT Walker).



PolyBot G3 (2002)

A chain self-reconfiguration system. Each module is about 50 mm on a side, and has 1 rotational DOF. It is part of the PolyBot modular robot family that has demonstrated many modes of locomotion including walking: biped, 14 legged, slinky-like, snake-like: concertina in a gopher hole, inchworm gaits, rectilinear undulation and sidewinding gaits, rolling like a tread at up to 1.4m/s, riding a tricycle, climbing: stairs, poles pipes, ramps etc. More information can be found at the polybot webpage at PARC.

M-TRAN III (2005)



M-TRAN III

A hybrid type self-reconfigurable system. Each module is two cube size (65 mm side), and has 2 rotational DOF and 6 flat surfaces for connection. It is the 3rd M-TRAN prototypes. Compared with the former (M-TRAN II), speed and reliability of connection is largely improved. As a chain type system, locomotion by CPG (Central Pattern Generator) controller in vaious shapes has been demonstrated by M-TRAN II. As a lattice type system, it can change its configuration, e.g., between a 4 legged walker to a caterpillar like robot.

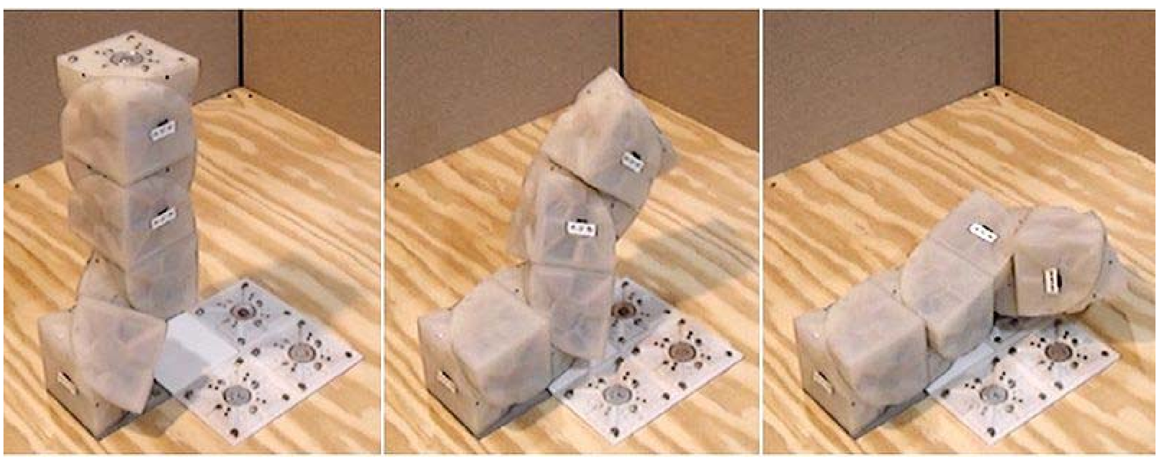
AMOEBA-I (2005)

AMOEBA-I, a three-module reconfigurable mobile robot was developed in Shenyang Institute of Automation (SIA), Chinese Academy of Sciences (CAS) by Liu J G et al..AMOEBA-I has nine kinds of non-isomorphic configurations and high mobility under unstructured environments.Four generations of its platform have been developed and a series of researches have been carried out on their reconfiguration mechanism, non-isomorphic configurations, tipover stability, and reconfiguration planning. Experiments have demonstrated that such kind structure permits good mobility and high flexibility to uneven terrain. Being hyper-redundant, modularized and reconfigurable, AMOEBA-I has many possible applications such as Urban Search and Rescue (USAR) and space exploration.

Stochastic-3D (2005)

High spatial resolution for arbitrary three-dimensional shape formation with modular robots can be accomplished using lattice system with large quantities of very small, prospectively microscopic modules. At small scales, and with large quantities of modules, deterministic control over reconfiguration of individual modules will become unfeasible, while stochastic mechanisms will naturally prevail. Microscopic size of modules will make the use of electromagnetic actuation and interconnection prohibitive, as well, as the use of on-board power storage.

Three large scale prototypes were built in attempt to demonstrate dynamically programmable three-dimensional stochastic reconfiguration in a neutral-buoyancy environment. The first prototype used electromagnets for module reconfiguration and interconnection. The modules were 100 mm cubes and weighed 0.81 kg. The second prototype used stochastic fluidic reconfiguration and interconnection mechanism. Its 130 mm cubic modules weighed 1.78 kg each and made reconfiguration experiments excessively slow. The current third implementation inherits the fluidic reconfiguration principle. The lattice grid size is 80 mm, and the reconfiguration experiments are under way. More information can be found at the CCSL Stochastic Modular Robotics webpage.



Molecubes in motion

Molecubes (2005)

This chain self-reconfiguring system was built by the Cornell Computational Synthesis Lab to physically demonstrate artificial kinematic self-reproduction. Each module is a 0.65 kg cube with 100 mm long edges and one rotational degree of freedom. The axis of rotation is aligned with the cube's longest diagonal. Physical self-reproduction of a three- and a four-module robots was demonstrated. It was also shown that, disregarding the gravity constraints, an infinite number of self-reproducing chain meta-structures can be built from Molecubes.

The Programmable Parts (2005)

The programmable parts are stirred randomly on an air-hockey table by randomly actuated air jets. When they collide and stick, they can communicate and decide whether to stay stuck, or if and when to detach. Local interaction rules can be devised and optimized to guide the robots to make any desired global shape. More information can be found at the programmable parts web page.

SuperBot (2006)

The SuperBot modules fall into the chain/tree architecture. The modules have three degrees of freedom each. The design is based on two previous systems: Conro (by the same research group) and MTRAN (by Murata et al.). Each module can connect to another module through one of its six dock connectors. They can communicate and share power through their dock connectors. Several locomotion gaits have been developed for different arrangements of modules. For high-level communication the modules use hormone-based control, a distributed, scalable protocol that does not require the modules to have unique ID's.

Miche (2006)

The Miche system is a modular lattice system capable of arbitrary shape formation. Each module is an autonomous robot module capable of connecting to and communicating with its immediate neighbors. When assembled into a structure, the modules form a system that can be virtually sculpted using a computer interface and a distributed process. The group of modules collectively decide who is on the final shape and who is not using algorithms that minimize the information transmission and storage. Finally, the modules not in the structure let go and fall off under the control of an external force, in this case gravity. More details at Miche (Rus et al.).

Quantitative accomplishment

- The robot with most active modules has 56 units <polybot centipede, PARC>
- The smallest actuated modular unit has a size of <add>mm <add refs>
- The largest actuated modular unit (by volume) has the size of 8 m^3 <(GHFC)giant helium filled catoms, CMU>
- The strongest actuation modules are able to lift 5 identical horizontally cantilevered units.<PolyBot g1v5, PARC>
- The fastest modular robot can move at 23 unit-sizes/second.<CKbot, dynamic rolling, ISER'06>
- The largest simulated system contained many 100,000's of units.

Challenges, solutions, and opportunities

Since the early demonstrations of early modular self-reconfiguring systems, the size, robustness and performance has been continuously improving. In parallel, planning and control algorithms have been progressing to handle thousands on units. There are, however, several key steps that are necessary for these systems to realize their promise of *adaptability, robustness and low cost*. These steps can be broken down into challenges in the hardware design, in planning and control algorithms and in application. These challenges are often intertwined.

Hardware design challenges

The extent to which the promise of self-reconfiguring robotic systems can be realized depends critically on the numbers of modules in the system. To date, only systems with up to about 50 units have been demonstrated, with this number stagnating over almost a decade. There are a number of fundamental limiting factors that govern this number:

- Limits on strength, precision, and field robustness (both mechanical and electrical) of bonding/docking interfaces between modules
- Limits on motor power, motion precision and energetic efficiency of units, (i.e. specific power, specific torque)
- Hardware/software design. Hardware that is designed to make the software problem easier. Self-reconfiguring systems have more tightly coupled hardware and software than any other existing system.

Planning and control challenges

Though algorithms have been developed for handling thousands of units in ideal conditions, challenges to scalability remain both in low-level control and high-level planning to overcome realistic constraints:

- Algorithms for parallel-motion for large scale manipulation and locomotion
- Algorithms for robustly handling a variety of failure modes, from misalignments, dead-units (not responding, not releasing) to units that behave erratically.
- Algorithms that determine the optimal configuration for a given task
- Algorithms for optimal (time, energy) reconfiguration plan
- Efficient and scalable (asynchronous) communication among multiple units

Application challenges

Though the advantages of Modular self-reconfiguring robotic systems is largely recognized, it has been difficult to identify specific application domains where benefits can be demonstrated in the short term. Some suggested applications are

- Space exploration and Space colonization applications, e.g. Lunar colonization
- Construction of large architectural systems
- Deep sea exploration/mining
- Search and rescue in unstructured environments

- Rapid construction of arbitrary tools under space/weight constraints
- Disaster relief shelters for displaced peoples
- Shelters for impoverished areas which require little on-the-ground expertise to assemble

Grand Challenges

Several robotic fields have identified ''Grand Challenges'' that act as a catalyst for development and serve as a short-term goal in absence of immediate ''killer apps''. The Grand Challenge is not in itself a research agenda or milestone, but a means to stimulate and evaluate coordinated progress across multiple technical frontiers. Several Grand Challenges have been proposed for the modular self-reconfiguring robotics field:

- **Demonstration of a system with >1000 units**. Physical demonstration of such a system will inevitably require rethinking key hardware and algorithmic issues, as well as handling noise and error.

- **Robosphere**. A self-sustaining robotic ecology, isolated for a long period of time (1 year) that needs to sustain operation and accomplish unforeseen tasks without *any* human presence.

- **Self replication** A system with many units capable of self replication by collecting scattered building blocks will require solving many of the hardware and algorithmic challenges.

- **Ultimate Construction** A system capable of making objects out of the components of, say, a wall.

- **Biofilter analogy** If the system is ever made small enough to be injected into a mammal, one task may be to monitor molecules in the blood stream and allow some to pass and others not to, somewhat like the Blood-brain barrier. As a challenge, an analogy may be made where system must be able to:
    - be inserted into a hole one module's diameter.
    - travel some specified distance in a channel that is say roughly 40 x 40 module diameters in area.
    - form a barrier fully conforming to the channel (whose shape is non-regular, and unknown beforehand).
    - allow some objects to pass and others not to (not based on size).
    - Since sensing is not the emphasis of this work, the actual detection of the passable objects should be made trivial.

Inductive Transducers

A unique potential solution that can be exploited is the use of inductors as transducers. This could be useful for dealing with docking and bonding problems. At the same time it could also be beneficial for its capabilities of docking detection (alignment and finding distance), power transmission, and (data signal) communication. A proof-of-concept video can be seen here. The rather limited exploration down this avenue is probably a consequence of the historical lack of need in any applications for such an approach.

Modular Robotics Google Group

Modular Robotics Google Group is an open public forum dedicated to announcements of events in the field of Modular Robotics. This medium is used to disseminate calls to workshops, special issues and other academic activities of interest to modular robotics researchers. The founders of this Google group intend it to facilitate the exchange of information and ideas within the community of modular robotics researchers around the world and thus promote acceleration of advancements in modular robotics. Anybody who is interested in objectives and progress of Modular Robotics can join this Google group and learn about the new developments in this field.

Chapter- 3

Sports Robots

RoboCup

RoboCup is an international robotics competition founded in 1997. The aim is to develop autonomous soccer robots with the intention of promoting research and education in the field of artificial intelligence. The name *RoboCup* is a contraction of the competition's full name, "Robot Soccer World Cup", But there are many other stages of the competition such as "Search and Rescue" and "Robot Dancing".

The official goal of the project:

> *By mid-21st century, a team of fully autonomous humanoid robot soccer players shall win the soccer game, complying with the official rule of the FIFA, against the winner of the most recent World Cup.*

RoboCup Leagues

Team rUNSWift competing in the Standard Platform League at RoboCup 2010 in Singapore.

Team Osaka's humanoid robots

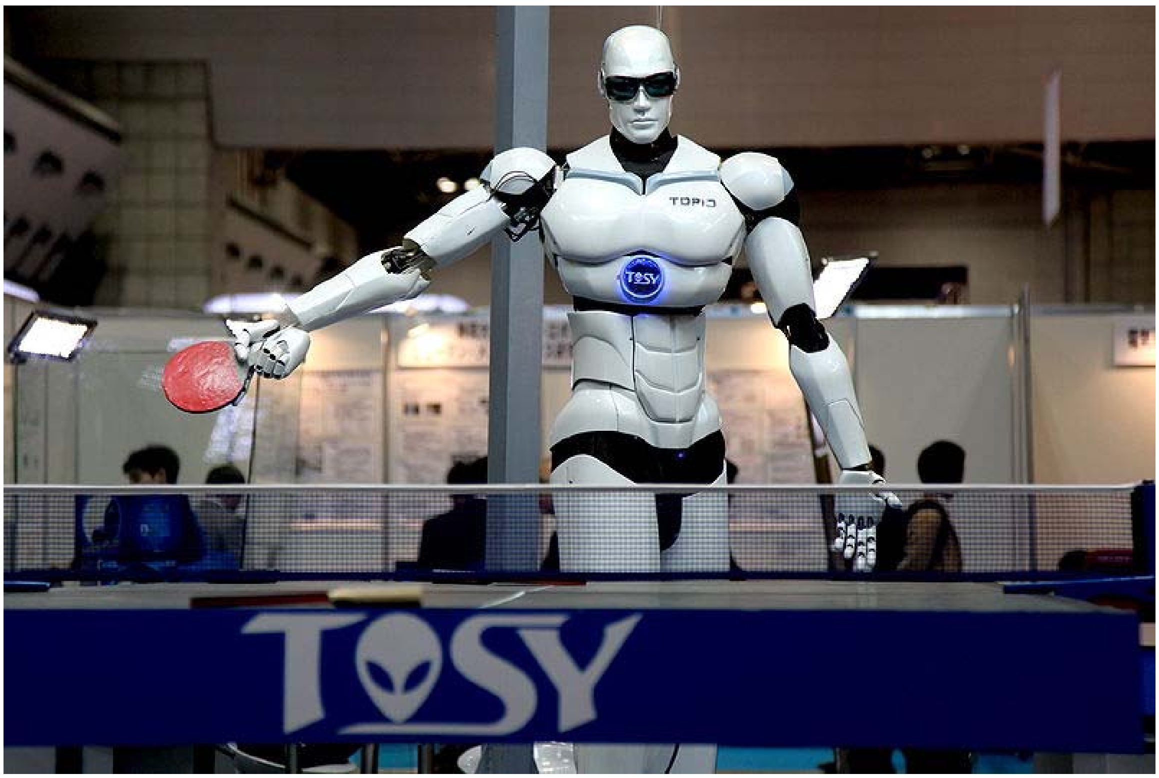
The contest currently has four major competition domains, each with a number of leagues and subleagues:

- *RoboCup Soccer*
  - Standard Platform League | Standard Platform League Homepage (formerly Four Legged League)
  - Small Size League | Small Size League Homepage
  - Middle Size League | Middle Size League Homepage
  - Simulation League
    - 2D Soccer Simulation
    - 3D Soccer Simulation | Soccer Simulation 3D League Homepage
    - 3D Development
    - Mixed Reality Soccer Competition | Soccer Mixed Reality Competition Homepage (formerly Physical Visualization)
  - Humanoid League Humanoid League homepage
- *RoboCup Rescue* Rescue Leagues Homepage
  - Rescue Robot League
  - Rescue Simulation League
- *RoboCup@Home* , which debuted in 2006, and focuses on the introduction of autonomous robots to human society.
- *RoboCupJunior*
  - Soccer Challenge
  - Dance Challenge

- Rescue Challenge
- General

Each team is fully autonomous in all RoboCup leagues. Once the game starts, the only input from any human is from the referee.

TOPIO



TOPIO 3.0 at Tokyo International Robot Exhibition (IREX) 2009

TOPIO ("**TO**SY **Pi**ng Pong Playing Rob**o**t") is a bipedal humanoid robot designed to play table tennis against a human being. It has been developed since 2005 by **TOSY,** a robotics firm in Vietnam. It was publicly demonstrated at the Tokyo International Robot Exhibition (IREX) on November 28, 2007. TOPIO 3.0 (the latest version of TOPIO) stands approximately 1.88 m tall and weighs 120 kg. Every TOPIO uses an advanced artificial intelligence system to learn and continuously improve its skill level while playing.

Development history

TOPIO 2.0 was playing table tennis at Nuremberg International Toy Fair 2009

Time	Place	Event	Notes
November, 2005	TOSY Robotics	Project TOPIO was started	
July, 2007	TOSY Robotics	First experiment version of TOPIO demonstrated	8 degrees of freedom, 1 leg, hydraulic system
28 November 2007	Tokyo International Robot Exhibition, Japan	TOPIO 1.0 publicly demonstrated	20 degrees of freedom, 6 legs, hydraulic system

5 February, 2009	Nuremberg International Toy Fair, Germany	TOPIO 2.0 publicly demonstrated	42 degrees of freedom, 2 legs, DC servo motors
25 November 2009	Tokyo International Robot Exhibition, Japan	TOPIO 3.0 publicly demonstrated	39 degrees of freedom, 2 legs, Brushless DC servo motors
4-9 February 2010	Nuremberg International Toy Fair, Germany	TOPIO 3.0 publicly demonstrated	39 degrees of freedom, 2 legs, Brushless DC servo motors
8-11 June 2010	AUTOMATICA Munich, Germany	TOPIO 3.0 publicly demonstrated	39 degrees of freedom, 2 legs, Brushless DC servo motors

Specifications

TOPIO 1.0 demonstrated at Tokyo International Robot Exhibition 2007

	TOPIO 1.0	**TOPIO 2.0**	**TOPIO 3.0**
Height	185 cm	215 cm	188 cm
Mass	300 kg	60 kg	120 kg
Power supply	Hydraulic	Li-Po battery, 48V 20AH	Li-Po battery, 48V 20AH
Actuator	Hydraulic cylinder	DC Servo Motor	Brushless DC Servo Motor
Legs	6	2	2
High speed camera	2	2	2

Continuous shots	6	5	10
Degrees of freedom	20 Two in the head Six in each arm One in each leg (6 legs)	42 Three in the head Seven in each arm Six in each leg (2 legs) Three in the torso Five in each hand	39 Two in the head Seven in each arm Six in each leg (2 legs) One in the torso Five in each hand

Chapter- 4

Military Robot

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
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

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.

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.

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.

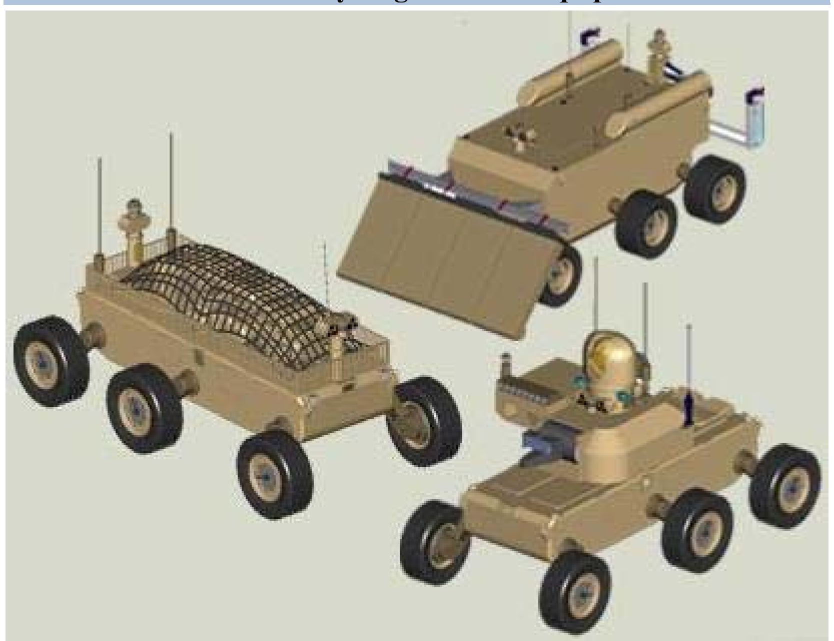
MATILDA (Military robot)

Mesa Associate's Tactical Integrated Light-Force Deployment Assembly (*MATILDA*) is a remote control military robot designed by Mesa Robotics. As with many other contemporary military robot designs, it is small and relatively portable; MATILDA is 30 inches long, 12 inches tall, 21 inches wide, and weighs 61 pounds, (28 kilograms) counting the batteries. Also like other military robots, MATILDA has a modular design.

The robot can be configured with cameras, an explosive disrupter unit for disabling bombs, or a manipulator arm. MATILDA is a treaded robot, with a top speed of 3 feet per second. Should a tread be damaged, it can be replaced with a new one within 5 minutes.

Multifunctional Utility/Logistics and Equipment vehicle

Multifunctional Utility/Logistics and Equipment vehicle



From top to bottom:XM1218, XM1217, XM1219

Type	Unmanned Ground Combat Vehicle
Place of origin	United States
Specifications	
Weight	2.5 tons

The **Multifunction Utility/Logistics and Equipment** (MULE) vehicle is an autonomous Unmanned Ground Combat Vehicle developed by Lockheed Martin Missiles and Fire Control for the United States Army's BCT Modernization program.

Description

The Multifunctional Utility/Logistics and Equipment Vehicle is a 2.5-ton Unmanned Ground Vehicle (UGV) that will support dismounted and air assault operations. The MULE is sling-loadable under military rotorcraft and features a common chassis. As the program's centerpiece, the Common Mobility Platform (CMP) chassis provides superior mobility built around advanced propulsion and articulated suspension system. This system gives the MULE the ability to negotiate complex terrain, obstacles, and gaps that a dismounted BCT squad will encounter.

The MULE's unique, highly advanced 6x6 independent articulated suspension, coupled with in-hub motors powering each wheel, provides extreme mobility in complex terrain, far exceeding that of vehicles utilizing more conventional suspension systems. It will climb at least a 1-meter step, far exceeding requirements, and provides the vehicle with the mobility performance and surefootedness required to safely follow dismounted troops over rough terrain, through rock and debris fields and over urban rubble. This technology also allows the MULE to cross 1-meter gaps, traverse side slopes greater than 40 percent, ford water to depths over 0.5 meters and overpass obstacles as high as 0.5 meters, while compensating for varying payload weights and center of gravity locations.

XM1219 ARV-Assault-Light

The ARV-A-L MULE Vehicle (ARV-A-L) (XM1219) will feature an integrated weapons and reconnaissance, surveillance, and target acquisition (RSTA) package to support the dismounted infantry's efforts to locate and destroy enemy platforms and positions. The ARV-A-L will support both anti-tank and anti-personnel weapons platforms that will be remotely operated by network linked Soldiers.

XM1218 Countermine

The Countermine MULE Vehicle (MULE-CM) (XM1218) would provide the capability to detect, mark, and neutralize anti-tank mines. The vehicle would be equipped with an integrated mine detection mission equipment package from the Ground Standoff Mine Detection System (GSTAMIDS). The XM1218 was canceled in December 2009.

XM1217 Transport

The XM1217 was canceled in December 2009 along with the XM1218. It would have been able to haul 1,900 to 2,400 pounds of equipment.

M-Gator & R-Gator

M-Gator in Iraq

In 1997 to 1998 the 261st Area Support Medical Battalion of the 44th Medical Brigade (ABN) brought a Gator to Bosnia for Operation SFOR2. It was an off the shelf commercial version Gator that was painted in Camouflage and equipped with a carrying tray on its hood as well as brackets to hold rifles. Its main purpose was for casualty evacuation and could hold two litters on the rear deck. It came in handy for utility work as well and was used mostly by the medical supply section for transporting supplies and equipment.

In 1997, the U.S. Army adopted a version of the Gator known as the M-Gator. The M-Gator is now also in use with the U.S. Marine Corps. Following the upgrades of the original Gator, it is known in its current version as the M-Gator A1, and features upgrades such as rollover protection. It is the 6x4 variant, and utilizes the three cylinder Yanmar diesel engine found in other Gator vehicles, and is also capable of using JP-8 fuel. The vehicle is capable of being air-dropped. The Gator has been used in Iraq and Afghanistan for supply deliveries and casualty evacuation, as it is more nimble off-road than an HMMWV. M-Gators are also used by Canadian Forces in Afghanistan.

The M-Gator has also been developed into an Unmanned Ground Vehicle, known as the R-Gator. It was developed by John Deere and iRobot. It is capable of autonomous operations such as waypoint following with obstacle avoidance, and following dismounted infantry soldiers, as well as other vehicles.

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.

Chapter- 5

Military Robots 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

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

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 Signal (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.

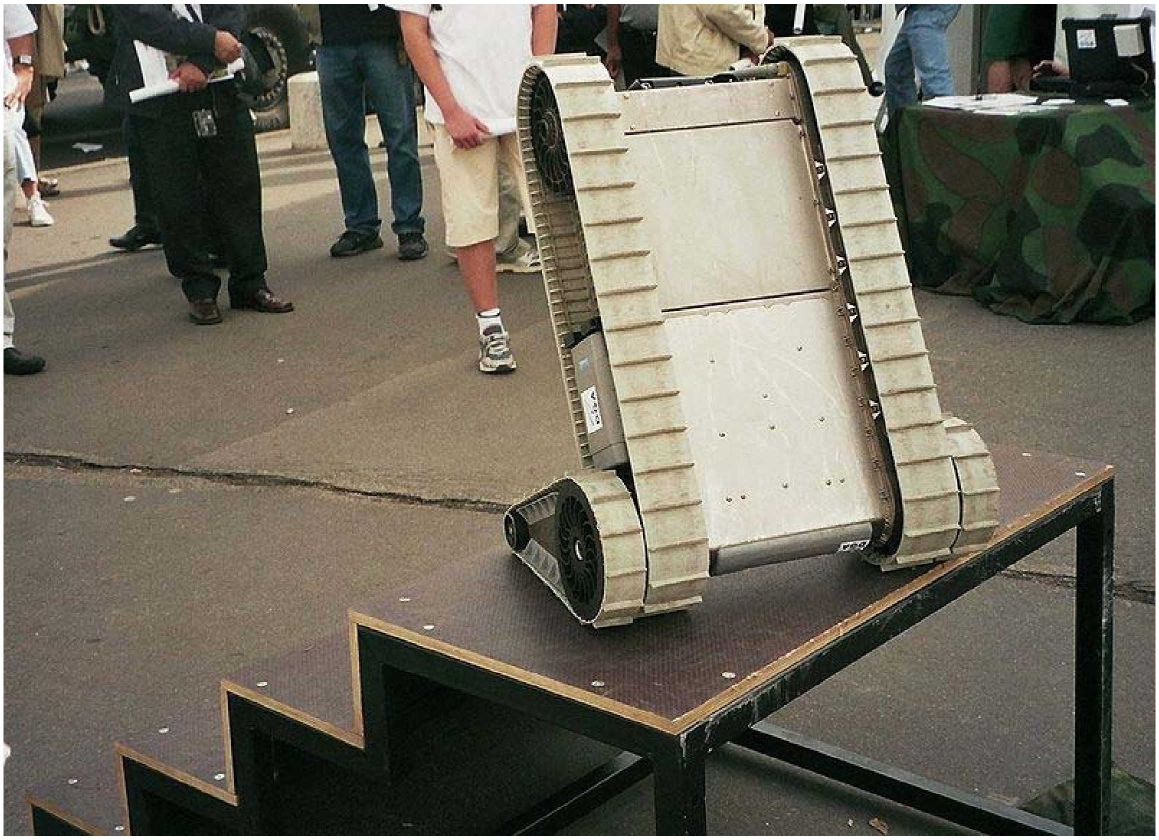
Supersonic missiles that are damaged may still have enough momentum to hit the ship—the only way to ensure the protection of the ship is either detonate the warhead of the missile or obliterate the missile.

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.

Guardium

The **Guardium** is a unmanned security vehicle (USV), created by G-NIUS. The unmanned vehicle can guard areas and attack any trespassers using lethal or less-lethal weaponry.

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 Ordinance 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.

General Atomics MQ-9 Reaper

MQ-9 Reaper

MQ-9 Reaper above Creech AFB.

Role	Unmanned Combat Air Vehicle
National origin	United States
Manufacturer	General Atomics Aeronautical Systems
First flight	2 February 2001
Primary users	United States Air Force U.S. Customs and Border Protection Royal Air Force Aeronautica Militare
Number built	>28
Unit cost	US$10.5 million for Reaper with sensors
Developed from	MQ-1 Predator
Developed into	General Atomics Avenger

The **General Atomics MQ-9 Reaper** (originally the **Predator B**) is an Unmanned Aerial Vehicle (UAV) developed by General Atomics Aeronautical Systems (GA-ASI) for use by the United States Air Force, the United States Navy, the Royal Air Force, and the Italian Air Force. The MQ-9 and other UAVs are referred to as Remotely Piloted Vehicles/Aircraft (RPV/RPA) by the U.S. Air Force to indicate their human ground controllers. The MQ-9 is the first hunter-killer UAV designed for long-endurance, high-altitude surveillance.

The MQ-9 is a larger and more capable aircraft than the earlier MQ-1 Predator, although it can be controlled by the same ground systems used to control MQ-1s. The Reaper has a 950-shaft-horsepower (712 kW) turboprop engine, far more powerful than the Predator's 115 hp (86 kW) piston engine. The increase in power allows the Reaper to carry 15 times more ordnance and cruise at three times the speed of the MQ-1. Although the MQ-9 can fly pre-programmed routes autonomously, the aircraft is always monitored or controlled by aircrew in the Ground Control Station (GCS) and weapons employment is always commanded by the pilot.

In 2008 the New York Air National Guard 174th Fighter Wing began the transition from F-16 piloted planes to MQ-9 Reaper UAVs, which are capable of remote controlled or autonomous flight operations, becoming the first all-UAV attack squadron.

Then U.S. Air Force (USAF) Chief of Staff General T. Michael Moseley said, "We've moved from using UAVs primarily in intelligence, surveillance, and reconnaissance roles before Operation Iraqi Freedom, to a true hunter-killer role with the Reaper." As of 2009 the U.S. Air Force's fleet stands at 195 Predators and 28 Reapers.

Design and development

With the success of the MQ-1 in combat, General Atomics anticipated the Air Force's desire for an upgraded aircraft and, using its own funds, set about redesigning Predator.

Prototype "Predator B"

General Atomics began development of the Reaper with the "Predator B-001", a proof-of-concept aircraft, which first flew on 2 February 2001. The B-001 was powered by an Allied Signal Garrett AiResearch TPE-331-10T turboprop engine with 950 shp (712 kW). It had an airframe that was based on the standard Predator airframe, except that the fuselage was made wider (and longer) and the wings were stretched from 48 feet (14.6 m) to 66 feet (20 m). The B-001 had a speed of 220 kts (390 km/h) and could carry a payload of 750 pounds (340 kilograms) to an altitude of 50,000 feet (15.2 kilometers) with an endurance of 30 hours.

GA refined the design, taking it in two separate directions. The first was with a jet-powered version. The "Predator B-002" was fitted with a Williams FJ44-2A turbofan engine with 10.2 kN (2,300 lbf, 1,040 kgf) thrust. It had payload capacity of 475 pounds (215 kilograms), a ceiling of 60,000 feet (18.3 kilometers) and endurance of 12 hours. The U.S. Air Force ordered two airframes for evaluation, delivered in 2007. The first two airframes delivered with prototypes B-001 and B-002 (now in the USAF museum at Wright-Patterson AFB). B-002 was originally equipped with the FJ-44 engine but it was removed and a TPE-331-10T was installed so that the USAF could take delivery of two aircraft in the same configuration.

The second direction the design took was the "Predator B-003", referred to by GA as the "Altair", which has a new airframe with an 84-foot (25.6 m) wingspan and a takeoff weight of about 7,000 pounds (3,175 kg). Like the Predator B-001, it is powered by a TP-331-10T turboprop. This variant has a payload capacity of 3,000 pounds (1,360 kg), a maximum ceiling of 52,000 feet (15.8 km), and an endurance of 36 hours.

Air Force version

First MQ-9 arrives at Creech AFB, March 2007.

In October 2001, the U.S. Air Force signed a contract with GA to purchase an initial pair of Predator B-003s for evaluation, with follow-up orders for production machines. The first test MQ-9s were delivered to the Air Force in 2002. The name "Altair" did not follow the aircraft into testing, with the Air Force continuing to refer to the system as "Predator B" until it was renamed Reaper ("Altair" instead became the designation for the unarmed NASA version); this is confusing, however, as the manufacturer uses the term to refer to the smaller B-001 prototype.

Operators, stationed at bases such as Creech Air Force Base, near Las Vegas, can hunt for targets and observe terrain using a number of sensors, including a thermal camera. One estimate has the on-board camera able to read a license plate from two miles (3 km) away. An operator's command takes 1.2 seconds to reach the drone via a satellite link. The MQ-9 is fitted with six stores pylons. The inner stores pylons can carry a maximum of 1,500 pounds (680 kilograms) each and allow carriage of external fuel tanks. The mid-wing stores pylons can carry a maximum of 600 pounds (270 kilograms) each, while the outer stores pylons can carry a maximum of 200 pounds (90 kilograms) each. An MQ-9 with two 1,000 pound (450 kilogram) external fuel tanks and a thousand pounds of munitions has an endurance of 42 hours. The Reaper has an endurance of 14 hours when fully loaded with munitions. The MQ-9 carries a variety of weapons including the GBU-12 Paveway II laser-guided bomb, the AGM-114 Hellfire II air-to-ground missiles, the AIM-9 Sidewinder. and recently, the GBU-38 JDAM (Joint Direct Attack Munition). Tests are underway to allow for the addition of the AIM-92 Stinger air-to-air missile. Air Force believes that the Predator B will give the service an improved "deadly persistence" capability, with the RPV flying over a combat area night and day waiting for a target to present itself. In this role an armed RPV neatly complements piloted strike aircraft. A piloted strike aircraft can be used to drop larger quantities of ordnance on a target while a cheaper RPV can be kept in operation almost continuously, with ground controllers working in shifts, carrying a lighter ordnance load to destroy targets.

By October, 2007 the U.S. Air Force owned nine Reapers, and was expected to decide whether to order full-rate production in 2009. On 18 May 2006, the Federal Aviation Administration (FAA) issued a certificate of authorization that allows the MQ-1 and MQ-9 aircraft to fly in U.S. civilian airspace to search for survivors of disasters. Requests had been made in 2005 for the aircraft to be used in search and rescue operations following Hurricane Katrina but, because there was no FAA authorization in place at the time, the planes were not used.

In September 2007, the MQ-9 deployed into Iraq at Balad, the largest U.S. air base in Iraq. On 28 October 2007 the *Air Force Times* reported an MQ-9 had achieved its first "kill", firing a Hellfire missile against "Afghanistan insurgents in the Deh Rawood region of the mountainous Oruzgan province. The strike was 'successful'," the United States Central Command Air Forces said.

An MQ-9 taking off in Afghanistan

Critics have stated that the USAF's insistence on qualified pilots flying RPVs is a bottleneck to expanding their deployment. Air Force Major General William Rew stated on 5 August 2008, "For the way we fly them right now"—fully integrated into air operations and often flying missions alongside manned aircraft—"we want pilots to fly them." This may be exacerbating losses of Air Force aircraft, in comparison with US Army operations.

The typical MQ-9 system consists of multiple aircraft, ground control station, communications equipment and links, maintenance spares, and military (or contractor) personnel. The crew consists of a pilot and sensor operator. To meet combat requirements, the MQ-9 tailors its capabilities using mission kits of various combinations of weapons and sensors payloads. The Raytheon AN/AAS-52 multi-spectral targeting sensor suite includes a color/monochrome daylight TV, infrared, and image-intensified

TV with laser rangefinder/target designator to designate targets for laser guided munitions. The Synthetic Aperture Radar system enables GBU-38 JDAM targeting, is capable of very fine resolution in both spotlight and strip modes, and has ground moving target indicator capability.

Navy version

General Atomics designed a naval version of the Reaper, named the "Mariner", for the U.S. Navy's Broad Area Maritime Surveillance (BAMS) program requirements. The design would have an increased fuel capacity in order to have an endurance of up to 49 hours. Proposed variations on the ultimate design included one designed for carrier operations with folding wings for carrier storage, shorter and more rugged landing gear, an arresting hook, cut-down or eliminated ventral flight surfaces and six stores pylons with a total load of 3,000 pounds (1,360 kilograms). The Northrop Grumman RQ-4N was announced the BAMS winner.

The US Customs and Border Protection has ordered a "Maritime Variant" of the MQ-9.

NASA version

NASA version Altair

NASA version Ikhana

NASA had initially expressed some interest in a production version of the B-002 turbofan-powered variant, but instead has leased an unarmed version of the Reaper, which carries the GA-ASI company name "Altair". Altair is one of the first 3 "Predator-B" airframes. The other 2 airframes, known as "Predator-B 001" and "Predator-B 002", had a maximum gross weight of 7,500 pounds. Altair differs from these models in that it has an 86-foot (26 m) long wingspan (20 feet greater than early and current MQ-9s). The Altair has enhanced avionics systems to better enable it to fly in FAA-controlled civil airspace and demonstrate "over-the-horizon" command and control capability from a ground station. These aircraft are used by NASA's Earth Science Enterprise as part of the NASA ERAST Program to perform on-location science missions.

In November 2006, NASA's Dryden Flight Research Center obtained an MQ-9 from General Atomics Aeronautical Systems Inc.. The aircraft has been named *Ikhana* and its main goal is the Suborbital Science Program within the Science Mission Directorate. NASA also acquired a ground control station in a mobile trailer. This aircraft was used extensively to survey the Southern California wildfires in 2007. The data were used to deploy firefighters to areas of the highest need.

Homeland Security version

An MQ-9 of the U.S. Customs and Border Protection agency

UAV Operators at Joint Base Balad (LSA Anaconda), Iraq, April 20, 2005

The United States Department of Homeland Security initially ordered one Reaper for border patrol duty, referred to as MQ-9 CBP-101. It began operations 4 October 2005, but on 25 April 2006, this aircraft crashed in the Arizona desert. The NTSB determined (Record Identification: CHI06MA121) that the cause of the crash was most likely a pilot error by the aircraft's ground-based pilot in the use of a checklist. During its operational period, the aircraft flew 959 hours on patrol and had a part in 2,309 arrests. It also contributed to the seizure of four vehicles and 8,267 pounds of marijuana. Because of these successes, a second Reaper, called "CBP-104" (initially referred to as "CBP-102"), was delivered in September 2006, and commenced limited border protection operations on 18 October 2006. The program was further expanded on 16 February 2009, including Canadian border patrols where US officials were concerned about the exploitation of the border by "drug smugglers, migrants and terrorists".

The CBP-101 was equipped with the Lynx SAR, AX-15 payload, ARC-210 radios, and other sensors and communications equipment; CBP-104 was enhanced with K_u band satellite command and control link and MTS-A EO/IR sensors.

The President's FY 2006 Emergency Supplemental budget request added $45 million for the Reaper program, and the FY 2007 Homeland Security Appropriations bill adds an additional $20 million. In October 2006, GA-ASI announced a $33.9 million contract to supply two more Reaper systems by Fall 2007.

U.S. Customs and Border Protection has six operational MQ-9s. One based in North Dakota, at the UAS Operations Center in Grand Forks, four in Arizona, at the UAS Operations Center in Sierra Vista and one based at Fort Drum, N.Y. The aircraft are equipped with GA-ASI's Lynx Synthetic Aperture Radar (Lynx SAR info/web page) and Raytheon's MTS-B ElectroOptical/Infrared sensors.

International versions

Australia

In September 2006, the General Atomics Mariner demonstrator aircraft was operated by the Australian Defence Science and Technology Organisation (DSTO) in an exercise designed to evaluate the aircraft's ability to aid in efforts to stem illegal fishing, drug running and illegal immigration. The Mariner operated from RAAF bases Edinburgh, South Australia and Learmonth, Western Australia in conjunction with a Royal Australian Navy Armidale class patrol boat, the Joint Offshore Protection Command and the Pilbara Regiment.

United Kingdom

On 27 September 2006, the U.S. Congress was notified by the Defense Security Cooperation Agency that the United Kingdom was seeking to purchase a pair of MQ-9 Reapers. They are operated by No. 39 Squadron RAF from Creech Air Force Base, Nevada. A third MQ-9 was in the process of being purchased by the RAF in 2007. On 4 January 2008 it became public that the United Kingdom wanted to purchase a further 10 MQ-9 Reapers, giving the Royal Air Force a fleet of 13 Reapers.

Germany

Germany has made a request to purchase five Reapers and four ground control stations, plus related support material and training. The request, being made through the Foreign Military Sales process, was presented to Congress through the Defense Security Cooperation Agency on 1 August 2008 and is valued at US$205 million. However, Germany did not go through with this procurement for the time being and decided to lease the IAI Heron offered by IAI and Rheinmetall instead, initially for the duration of one year, representing a stop-gap measure before a long-term decision on a MALE-system is being made.

Italy

On August 1, 2008, Italy submitted a FMS request through the Defense Security Cooperation Agency for four aircraft, four ground stations and five years of maintenance support, all valued at US$330 million. Italy ordered two more aircraft in November, 2009.

Operational history

US use

MQ-9 Reaper in Afghanistan in 2007

The California Office of Emergency Services requested NASA support for the Esperanza Fire, and in under 24 hours the General Atomics Altair (NASA variant of the Predator B) was launched on a 16 hour mission to map the perimeter of the fire. The Altair had just returned from a test mission a day before the Esperanza Fire started. The fire mapping research is a joint project with NASA and the US Forest Service.

On 25 April 2006, an MQ-9 operated by U.S. Customs and Border Protection crashed near Nogales, Arizona. The pilot, remotely operating the vehicle from Sierra Vista Municipal Airport, reported a momentary lockup of the displays on the primary control console. The pilot switched control to a secondary console, and in doing so inadvertently shut down the vehicle's engine, causing it to descend out of reach of communications and ultimately crash.

On 1 May 2007, the 432d Wing of the United States Air Force was activated to operate MQ-9 Reaper as well as MQ-1 Predator UAVs at Creech Air Force Base, Nevada. The pilots first flew combat missions in Iraq and Afghanistan in the summer of 2007. In October 2007 the USAF was flying operational missions in Afghanistan. As of 6 March 2008, according to USAF Lieutenant General Gary North, the Reaper has attacked 16 targets in Afghanistan using 500 lb (230 kg) bombs and Hellfire missiles. On 4 February

2008 the MQ-9 dropped a bomb on a truck carrying an insurgent mortar and team near Kandahar.

On 17 July 2008, the Air Force began flying Reaper missions within Iraq from Balad Air Base. It was reported on August 11, 2008 that the 174th Fighter Wing of the USAF will consist entirely of Reapers. By March 2009 the U.S. Air Force had 28 operational Reapers.

On 13 September 2009, a MQ-9 was flying a combat mission over Afghanistan when positive control of the aircraft was lost resulting in the drone flying out of control towards the Afghan border with Tajikistan. An F-15E Strike Eagle was sent to destroy it; the Reaper's engine was disabled with an AIM-9 missile. The satellite link with the vehicle was restored immediately after, leaving the operator no option other than to steer it into a mountainside along with its ordnance. It was the first time a US drone was destroyed intentionally by allied forces.

Beginning in September 2009, Reapers were deployed by the Africa Command to The Seychelles for use in Indian Ocean anti-piracy patrols.

As of July 2010, 38 Predators and Reapers have been lost during combat operations in Afghanistan and Iraq, with another 9 crashing during training operations in the U.S.

Non-US use

On 9 November 2007, the UK Ministry of Defence announced that its MQ-9 Reapers had begun operations in Afghanistan against the Taliban. In April 2008, following the crash of one of the UK's two Reapers, British special forces were sent to recover sensitive material from the wreckage before it was blown up to prevent the enemy from obtaining it.

Foster-Miller TALON

The SWORDS system allows soldiers to fire small arms weapons by remote control from as far as 1,000 meters away. This example is fitted with an M249 SAW.

Control station

The **Foster-Miller TALON** robot is a small, tracked military robot designed for missions ranging from reconnaissance to combat. Over 3000 TALON robots have been deployed to combat theaters.

Overview

Foster-Miller claims the TALON is one of the fastest robots in production, one that can travel through sand, water, and snow (up to 100 feet deep) as well as climb stairs. The TALON transmits in color, black and white, infrared, and/or night vision to its operator, who may be up to 1,000 m away. It can run off lithium-ion batteries for a maximum of 7 days on standby independently before needing recharging. It has an 8.5 hour battery life at normal operating speeds, 2 standard lead batteries providing 2 hours each and 1 optional Lithium Ion providing an additional 4.5 hours. It can also withstand repeated decontamination allowing it to work for long periods of time in contaminated areas. It was used in Ground Zero after the September 11th attacks working for 45 days with many decontaminations without electronic failure. This led to the further development of the HAZMAT TALON.

It weighs less than 100 lb (45 kg) or 60 lb (27 kg) for the Reconnaissance version. Its cargo bay accommodates a variety of sensor payloads. The robot is controlled through a two-way radio or a Fiber-optic link from a portable or wearable Operator Control Unit (OCU) that provides continuous data and video feedback for precise vehicle positioning.

Regular (IED/EOD) TALON: Carries sensors and a robotic manipulator, which is used by the U.S. Army for explosive ordnance disposal and disarming improvised explosive devices.

Special Operations TALON (SOTAL): Does not have the robotic arm manipulator but carries day/night color cameras and listening devices; lighter due to the absence of the arm, for reconnaissance missions.

SWORDS TALON: For small arms combat and guard roles. Tested in December 2003 in Kuwait prior to deployment in Iraq.

HAZMAT TALON: Uses chemical, gas, temperature, and radiation sensors that are displayed in real time to the user on a hand-held display unit. It is now being tested by the US Armament Research Development and Engineering Center ARDEC.

The robot costs approximately $60,000 in its standard form. Foster-Miller was subsequently bought out by QinetiQ, a United Kingdom military developer.

SWORDS

Foster-Miller TALON SWORDS units equipped with various weaponry.

SWORDS or the **Special Weapons Observation Reconnaissance Detection System**, is a weaponized version being developed by Foster-Miller for the US Army. The robot is composed of a weapons system mounted on the standard TALON chassis. The current price of one unit is $230,000; however, Foster-Miller claims that when it enters mass production the price may drop to between $150,000 and $180,000. Foster-Miller points out that in comparison, to train a US soldier to a basic level of expertise with BCT and/or AIT would cost $50,000 to $100,000. To train them for positions in Armor or Cavalry would cost approximately $100,000 to $200,000.

There are a variety of different weapons that can be placed on the SWORDS; M16 rifle, 5.56 mm SAW M249, 7.62 mm M240 machine gun, .50 cal M82 Barrett rifle, a six barreled 40 mm grenade launcher or quad 66 mm M202A1 FLASH incendiary weapon.

SWORDS units have demonstrated the ability to shoot precisely. It is not autonomous, but instead has to be controlled by a soldier using a small console to remotely direct the device and fire its weapons. Foster-Miller are currently at work on a "Game Boy" style controller with virtual-reality goggles for future operators.

In 2007, three SWORDS units were deployed to Iraq. Each unit is armed with a M249 machine gun. This deployment marks the first time that robots are carrying guns into battle; however, their weapons have remained unused as the Army has never given the go-ahead for using them. The Army stopped funding the SWORDS robots after deploying the initial three robots. Foster-Miller is working on a successor: the Modular Advanced Armed Robotic System (MAARS)

Deployment

The Talon has been deployed in military service since 2000 - for example, in Bosnia for the movement of munitions and EOD (explosive ordnance disposal) to get rid of grenades. It was also used in Ground Zero after the September 11th attacks in search and recovery. It is the only robot used in this effort that did not require any major repair. Foster-Miller claims the Talon was used for a classified mission by US Special Forces in the war against the Taliban in Afghanistan as well as in an EOD role. In Iraq its standard role has been performing EOD and IED destruction missions. Its combat SWORDS version is now being used there in a guard role protecting front line buildings from attack. According to Foster-Miller, the robot has performed around 20,000 EOD missions in the conflicts in Iraq and Afghanistan.

Samsung SGR-A1

The **Samsung SGR-A1** is a South Korean military robot sentry designed to replace human counterparts in the demilitarized zone at the South and North Korea border. It is a stationary system made by Samsung defense subsidiary Samsung Techwin.

History

In 2006, Samsung Techwin announced a $200,000, all weather, 5.56 mm robotic machine gun to guard the Korean DMZ. It is capable of tracking multiple moving targets using IR and visible light cameras, and is under the control of a human operator. The Intelligent Surveillance and Guard Robot can "identify and shoot a target automatically from over two miles away." The robot, which was developed by a South Korean university, uses "twin optical and infrared sensors to identify targets from 2.5 miles in daylight and around half that distance at night."

It is also equipped with communication equipment (a microphone and speakers), "so that passwords can be exchanged with human troops." If the person gives the wrong password, the robot can "sound an alarm or fire at the target using rubber bullets or a swivel-mounted K-3 machine gun." South Korea's soldiers in Iraq are "currently using robot sentries to guard home bases."

Chapter- 6

Developments related to Robotics

Agricultural robot

An **agricultural robot** or **agribot** is a robot deployed for agricultural purposes.

The main area of application of robots in agriculture is at the harvesting stage. Fruit picking robots and sheep shearing robots are designed to replace human labour. The agricultural industry is behind other complementary industries in using robots because the sort of jobs involved in agriculture are not straightforward, and many repetitive tasks are not exactly the same every time. In most cases, a lot of factors have to be considered (e.g., the size and colour of the fruit to be picked) before the commencement of a task. Robots can be used for other horticultural tasks such as pruning, weeding, spraying and monitoring.

Livestock robotics

Robots can also be used in livestock applications (livestock robotics) such as milking, washing and castrating.

Examples

- "Ag Ant", an inexpensive foot-long bot that works cooperatively.
- The Oracle Robot
- The Shear Magic Robot
- Fruit Picking Robot
- LSU's AgBot
- Harvest Automation is a company founded by former iRobot employees to develop robots for greenhouses

- Strawberry picking robot from Robotic Harvesting and Agrobot .

Robotic surgery

Robotic surgery, computer-assisted surgery, and robot-assisted surgery are terms for various technological developments that currently are developed to support a range of surgical procedures.

Robot-assisted surgery was developed to overcome limitations of minimally invasive surgery, Instead of directly moving the instruments the surgeon uses a computer console to manipulate the instruments attached to multiple robot arms. The computer translates the surgeon's movements, which are then carried out on the patient by the robot. Other features of the robotic system include, for example, an integrated tremor filter and the ability for scaling of movements (changing of the ratio between the extent of movements at the master console to the internal movements of the instruments attached to the robot). The console is located in the same operating room as the patient, but is physically separated from the operative workspace. Since the surgeon does not need to be in the immediate location of the patient while the operation is being performed, it can be possible for specialists to perform remote surgery on patients. Robots can perform surgery without a human surgeon .

History

The world's first surgical robot was the "Arthrobot", which was developed and used for the first time in Vancouver, BC, Canada in 1983. The robot was developed by a team led by Dr. James McEwen and Geof Auchinlek, in collaboration with orthopaedic surgeon, Dr. Brian Day. National geographic produced a movie on robotics which featured the Arthrobot. In related projects at that time, other medical robots were developed, including a robotic arm that performed eye surgery, and another that acted as an operating assistant, and handed the surgeon instruments in response to voice commands.

1985 a robot, the PUMA 560, was used to place a needle for a brain biopsy using CT guidance. In 1988, the PROBOT, developed at Imperial College London, was used to perform prostatic surgery. The ROBODOC from Integrated Surgical Systems was introduced in 1992 to mill out precise fittings in the femur for hip replacement. Further development of robotic systems was carried out by Intuitive Surgical with the introduction of the da Vinci Surgical System and Computer Motion with the *AESOP* and the ZEUS robotic surgical system. (Intuitive Surgical bought Computer Motion in 2003; ZEUS is no longer being actively marketed.)

The da Vinci Surgical System comprises three components: a surgeon's console, a patient-side robotic cart with 4 arms manipulated by the surgeon (one to control the camera and three to manipulate instruments), and a high-definition 3D vision system. Articulating surgical instruments are mounted on the robotic arms which are introduced into the body through cannulas. The device senses the surgeon's hand movements and translates them electronically into scaled-down micro-movements to manipulate the tiny proprietary instruments. It also detects and filters out any tremors in the surgeon's hand movements, so that they are not duplicated robotically. The camera used in the system provides a true stereoscopic picture transmitted to a surgeon's console. The da Vinci System is FDA cleared for a variety of surgical procedures including surgery for prostate cancer, hysterectomy and mitral valve repair, and is used in more than 800 hospitals in the Americas and Europe. The da Vinci System was used in 48,000 procedures in 2006 and sells for about $1.2 million. The new da Vinci HD SI released in April, 2009 currently sells for $1.75 million. The first robotic surgery took place at The Ohio State University Medical Center in Columbus, Ohio under the direction of Dr. Robert E. Michler, Professor and Chief, Cardiothoracic Surgery.<McConnell PI, Schneeberger EW, Michler RE. History and development of robotic cardiac surgery. Problems in General Surgery 2003;20:62-72.>

In September 2010, the Eindhoven University of Technology announced the development of the Sofie surgical system, the first surgical robot to employ force feedback.

- In 1997 a reconnection of the fallopian tubes operation was performed successfully in Cleveland using ZEUS.
- In May 1998, Dr. Friedrich-Wilhelm Mohr using the *Da Vinci surgical robot* performed the first robotically assisted heart bypass at the Leipzig Heart Centre in Germany.
- On 2 September 1999, Dr. Randall Wolf and Dr. Robert Michler performed the first robotically assisted heart bypass in the USA at The Ohio State University.
- In October 1999 the world's first surgical robotics *beating heart* coronary artery bypass graft (CABG) was performed in Canada by Dr. Douglas Boyd and Dr. Reiza Rayman using the ZEUS surgical robot.
- In 2001, Prof. Marescaux, while in New York, used the "Zeus" robot to remotely perform gall bladder surgery on a patient who was in Strasbourg, France.
- In September 2001, Dr. Michel Gagner, while in New York, used the Zeus robotic system to remotely perform a cholecystectomy on a woman who was in Strasbourg, France.
- In May 2006 the first AI doctor-conducted unassisted robotic surgery on a 34 year old male to correct heart arythmia. The results were rated as better than an above-average human surgeon. The machine had a database of 10,000 similar operations, and so, in the words of its designers, was "more than qualified to operate on any patient." The designers believe that *robots can replace half of all surgeons within 15 years*.
- In February 2008, Dr. Mohan S. Gundeti of the University of Chicago Comer Children's Hospital performed the first robotic pediatric neurogenic bladder reconstruction. The operation was performed on a 10-year-old girl.
- In January 2009, Dr. Todd Tillmanns reported the results of the largest multi-institutional study on the use of the da-Vinci robotic surgical system in gynecologic oncology and included learning curves for current and new users as a method to assess their acquisition of skills using the device.
- In January 2009, the first all-robotic-assisted kidney transplant was performed at Saint Barnabas Medical Center in Livingston, New Jersey by Dr. Stuart Geffner.

The same team performed eight more fully robotic-assisted kidney transplants over the next six months.

Advantages and disadvantages

Major advances aided by surgical robots have been remote surgery, minimally invasive surgery and unmanned surgery. Some major advantages of robotic surgery are precision, miniaturization, smaller incisions, decreased blood loss, less pain, and quicker healing time. Further advantages are articulation beyond normal manipulation and three-dimensional magnification, resulting in improved ergonomics. Robotic techniques are also associated with reduced duration of hospital stays, blood loss, transfusions, and use of pain medication.

With a the cost of the robot at $1,200,000 dollars and disposable supply costs of $1,500 per procedure, the cost of the procedure is higher. Additional surgical training is needed to operate the system. Patient surveys indicate they chose the procedure based on expectations of decreased morbidity, improved outcomes, reduced blood loss and less pain. Higher expectations may explain higher rates of dissatisfaction and regret.

The main advantage of this technique is that the incisions are very small and, consequently, patient recovery is quick. In traditional open-heart surgery, the surgeon makes a ten to twelve-inch incision, then accesses the heart by splitting the sternum (breast bone) and spreading open the rib cage. The patient is then placed on a heart-lung machine and the heart is stopped for the length of the surgery. Not only is this a way for bacteria that can cause infections to access the patient’s body, it also leads to a painful wound, which takes time to heal.

Because patient recovery after robot-assisted heart surgery is quicker, the hospital stay is shorter. On average patients leave the hospital two to five days earlier than patients who have undergone traditional open-heart surgery and return to work and normal activity 50% more quickly. Reduced recovery times are not only better for the patient, they also reduce the number of staff needed during surgery, nursing care required after surgery, and, therefore, the overall cost of hospital stays.

Compared with other minimally invasive surgery approaches, robot-assisted surgery gives the surgeon better control over the surgical instruments and a better view of the surgical site. In addition, surgeons no longer have to stand throughout the surgery and do not tire as quickly. Naturally occurring hand tremors are filtered out by the robot’s computer software. Finally, the surgical robot can continuously be used by rotating surgery teams (Gerhardus 2003). Gerhardus D (2003). Robot-assisted surgery: the future is here. Journal of Healthcare Management, Jul/Aug, 242-251. While the use of robotic surgery has become a item in the advertisement of medical services, critics point out that studies that indicate that long-term results are superior to those after laparoscopic surgery are lacking. The robotic system does not come cheap and has a learning curve. Data are absent to show that the increased costs can be justified. In the medical literature, very experienced surgeons tend to publish their results, these, however, may not be representative of surgeons with lesser experience.

The cost of robotic surgical systems lies between $750.000 and $1.2 million (as of 2005). Numerous financial feasibility studies have been done to determine whether it is really worth a hospital's while to purchase such a system and opinions differ dramatically. Surgeons report that, although the manufacturers of the systems provide training on this new technology, the learning phase is intensive and surgeons must operate on twelve to eighteen patients before they feel comfortable with the system. During the training phase, minimally invasive operations can take up to twice as long as traditional surgery, which ties up operating room and surgical staff time and keeps patients under anesthesia longer.

Applications

General surgery

In 2007, the. University of Illinois at Chicago medical team, lead by Prof. Pier Cristoforo Giulianotti, performed the world's first ever robotic pancreatectomy and also the Midwests fully robotic Whipple surgery. In April 2008, the same team of surgeons performed the world's first fully minimally invasive liver resection for living donor transplantation, removing 60% of the patient's liver, yet allowing him to leave the hospital just a couple of days after the procedure, in very good condition. Furthermore the patient can also leave with less pain than a usual surgery due to the four puncture holes and not a scar by a surgeon.

Cardiothoracic surgery

Robot-assisted MIDCAB and Endoscopic coronary artery bypass (TECAB) surgeries are being performed with the da Vinci system. Mitral valve repairs and replacements have been performed. East Carolina University, Greenville (Dr W. Randolph Chitwood), Saint Joseph's Hospital, Atlanta (Dr Douglas A. Murphy), and Good Samaritan Hospital, Cincinnati (Dr J. Michael Smith) have popularized this procedure and proved its durability with multiple publications. Since the first robotic cardiac procedure performed in the USA in 1999, The Ohio State University, Columbus (Dr. Robert E. Michler, Dr. Juan Crestanello, Dr. Paul Vesco) has performed CABG, mitral valve, esophagectomy, lung resection, tumor resections, among other robotic assisted procedures and serves as a training site for other surgeons. In 2002, surgeons at the Cleveland Clinic in Florida (Dr. Douglas Boyd and Kenneth Stahl) reported and published their preliminary experience with minimally invasive "hybrid" procedures. These procedures combined robotic revascularization and coronary stenting and further expanded the role of robots in coronary bypass to patients with disease in multiple vessels.

Cardiology and electrophysiology

The Stereotaxis Magnetic Navigation System (MNS) has been developed to increase precision and safety in ablation procedures for arrhythmias and atrial fibrillation while reducing radiation exposure for the patient and physician, and the system utilizes two magnets to remotely steerable catheters. The system allows for automated 3-D mapping of the heart and vasculature, and MNS has also been used in interventional cardiology for guiding stents and leads in PCI and CTO procedures, proven to reduce contrast usage and access tortuous anatomy unreachable by manual navigation. Dr. Andrea Natale has referred to the new Stereotaxis procedures with the magnetic irrigated catheters as "revolutionary."

The Hansen Medical Sensei robotic catheter system uses a remotely operated system of pulleys to navigate a steerable sheath for catheter guidance. It allows precise and more forceful positioning of catheters used for 3-D mapping of the heart and vasculature. The system provides doctors with estimated force feedback information and feasible manipulation within the left atrium of the heart. The Sensei has been associated with mixed acute success rates compared to manual, commensurate with higher procedural complications, longer procedure times but lower fluoroscopy dosage to the patient.

It was estimated that 70 to 90 hospitals in the United States now use minimally invasive surgical robots for heart surgery, and this number is expected to double by mid-2006 (Alt and Worrell 2004). At present, three types of heart surgery are being performed on a routine basis using robotic surgery systems (Kypson and Chitwood 2004). These three surgery types are:

Atrial septal defect repair — the repair of a hole between the two upper chambers of the heart, Mitral valve repair — the repair of the valve that prevents blood from regurgitating back into the upper heart chambers during contractions of the heart, Coronary artery bypass — rerouting of blood supply by bypassing blocked arteries that provide blood to the heart.

As surgeons' experience and robotic technology develop, it is expected that robot-assisted procedures will be applied to additional types of heart surgery.

Alt SJ & Worrell B (2004). More surgeons do minimally invasive heart surgery. Health Care Strategic Management, Apr, 1 & 11-19.

Kypson AP & Chitwood WR Jr. (2004). Robotic applications in cardiac surgery. International Journal of Advanced Robotic Systems, 1(2), 87-92.

Gastrointestinal surgery

Multiple types of procedures have been performed with either the *Zeus* or *da Vinci robot* systems, including bariatric surgery.

Gynecology

Robotic surgery in gynecology is one of the fastest growing fields of robotic surgery. This includes the use of the da Vinci surgical system in benign gynecology and gynecologic oncology. Robotic surgery can be used to treat fibroids, abnormal periods, endometriosis, ovarian tumors, pelvic prolapse, and female cancers. Using the robotic system, gynecologists can perform hysterectomies, myomectomies, and lymph node biopsies. The need for large abdominal incisions is virtually eliminated.

Robot assisted hysterectomies and cancer staging are being performed using da Vinci robotic system. The University of Tennessee, Memphis (Dr. Todd Tillmanns, Dr. Saurabh Kumar), Northwestern University (Dr. Patrick Lowe), Aurora Health Center (Dr. Scott Kamelle), West Virginia University (Dr. Jay Bringman) and The University of Tennessee, Chattanooga (Dr. Donald Chamberlain) have extensively studied the use of robotic surgery and found it to improve morbidity and mortality of patients with gynecologic cancers. They have also for the first time reported robotic surgery learning curves for current and new users as a method to assess acquisition of their skills using the device.

Neurosurgery

Several systems for stereotactic intervention are currently on the market. MD Robotic's NeuroArm is the world's first MRI-compatible surgical robot.

Orthopedics

The ROBODOC system was released in 1992 by Integrated Surgical Systems, Inc. which merged into CUREXO Technology Corporation. Also, The Acrobot Company Ltd. sells the "Acrobot Sculptor", a robot that constrains a bone cutting tool to a pre-defined volume. Another example is the CASPAR robot produced by U.R.S.-Ortho GmbH & Co. KG, which is used for total hip replacement, total knee replacement and anterior cruciate ligament reconstruction.

Pediatrics

Surgical robotics has been used in many types of pediatric surgical procedures including: tracheoesophageal fistula repair, cholecystectomy, nissen fundoplication, morgagni's hernia repair, kasai portoenterostomy, congenital diaphragmatic hernia repair, and others. On January 17, 2002, surgeons at Children's Hospital of Michigan in Detroit performed the nation's first advanced computer-assisted robot-enhanced surgical procedure at a children's hospital.

The Center for Robotic Surgery at Children's Hospital Boston provides a high level of expertise in pediatric robotic surgery. Specially-trained surgeons use a high-tech robot to perform complex and delicate operations through very small surgical openings. The results are less pain, faster recoveries, shorter hospital stays, smaller scars, and happier patients and families.

In 2001, Children's Hospital Boston was the first pediatric hospital to acquire a surgical robot. Today, surgeons use the technology for many procedures and perform more pediatric robotic surgeries than any other hospital in the world. Children's Hospital physicians have developed a number of new applications to expand the use of the robot, and train surgeons from around the world on its use.

Radiosurgery

The CyberKnife Robotic Radiosurgery System uses image-guidance and computer controlled robotics to treat tumors throughout the body by delivering multiple beams of high-energy radiation to the tumor from virtually any direction.

Urology

Removing the prostate gland for cancer, repair obstructed kidneys, repair bladder abnormalities and remove diseased kidneys. New minimally invasive robotic devices using steerable flexible needles are currently being developed for use in prostate brachytherapy. A few leading urologists in the field of robotic urological surgery are Drs. David Samadi, Ashutosh Tewari, Mani Menon, Peter Schlegel, Mehmood Akhtar, Douglas Scherr, Mohamad W. Salkini, Steven Sukin, and Vipul Patel.

In 2000, the first robot-assisted laparoscopic radical prostatectomy was performed.

Miniature robotics

As scientists seek to improve the versatility and utility of robotics in surgery, some are attempting to miniaturize the robots. For example, the University of Nebraska Medical Center has led a multi-campus effort to provide collaborative research on mini-robotics among surgeons, engineers and computer scientists. There may also be a day and age where nanorobots may be inserted into peoples bloodstreams to act as General Practitioners, or **GPs**; Analysing the problem and sending the information back to the hospital. This could one day remove the need of GPs.

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 Hanool 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.

Domestic robots in popular culture

Many cartoons feature robot maids, notably Rosie the Robot from *The Jetsons*. Maid Robots are especially prominent in anime (in Japanese, they are called Meido Robo or Meido Roboto), and their Artificial Intelligence ranges from rudimentary to fully sentient and emotional, while their appearance ranges from obviously mechanical to human-like.

Nanorobotics

Nanorobotics is the technology of creating machines or robots at or close to the microscopic scale of a nanometer (10^{-9} meters). More specifically, nanorobotics refers to the still largely hypothetical nanotechnology engineering discipline of designing and building **nanorobots**, devices ranging in size from 0.1-10 micrometers and constructed of nanoscale or molecular components. As of 2010 nobody has yet built artificial non-biological nanorobots: they remain a hypothetical concept. The names **nanobots**, **nanoids**, **nanites**, **nanomachines** or **nanomites** have also been used to describe these hypothetical devices.

Another definition is a robot that allows precision interactions with nanoscale objects, or can manipulate with nanoscale resolution. Following this definition even a large apparatus such as an atomic force microscope can be considered a nanorobotic instrument when configured to perform nanomanipulation. Also, macroscale robots or microrobots that can move with nanoscale precision can also be considered nanorobots.

Nanomachines are largely in the research-and-development phase, but some primitive molecular machines have been tested. An example is a sensor having a switch approximately 1.5 nanometers across, capable of counting specific molecules in a chemical sample. The first useful applications of nanomachines, if such are ever built, might be in medical technology, which might use them to identify and destroy cancer cells. Another potential application is the detection of toxic chemicals, and the measurement of their concentrations, in the environment. Recently, Rice University has demonstrated a single-molecule car developed by a chemical process and including buckyballs for wheels. It is actuated by controlling the environmental temperature and by positioning a scanning tunneling microscope tip.

Nanorobotics theory

Since nanorobots would be microscopic in size, it would probably be necessary for very large numbers of them to work together to perform microscopic and macroscopic tasks. These nanorobot swarms, both those incapable of replication (as in utility fog) and those capable of unconstrained replication in the natural environment (as in grey goo and its less common variants), are found in many science fiction stories, such as the Borg nanoprobes in *Star Trek* and The Outer Limits episode The New Breed. The word "nanobot" (also "nanite", "nanogene", or "nanoant") is often used to indicate this fictional context and is an informal or even pejorative term to refer to the engineering concept of nanorobots. The word nanorobot is the correct technical term in the nonfictional context of serious engineering studies.

Some proponents of nanorobotics, in reaction to the grey goo scare scenarios that they earlier helped to propagate, hold the view that nanorobots capable of replication outside of a restricted factory environment do not form a necessary part of a purported productive nanotechnology, and that the process of self-replication, if it were ever to be developed, could be made inherently safe. They further assert that their current plans for developing and using molecular manufacturing do not in fact include free-foraging replicators.

Approaches

Biochip

The joint use of nanoelectronics, photolithography, and new biomaterials provides a possible approach to manufacturing nanorobots for common medical applications, such as for surgical instrumentation, diagnosis and drug delivery. This method for manufacturing on nanotechnology scale is currently in use in the electronics industry. So, practical nanorobots should be integrated as nanoelectronics devices, which will allow tele-operation and advanced capabilities for medical instrumentation.

Nubots

Nubot is an abbreviation for "nucleic acid robots". Nubots are synthetic robotics devices at the nanoscale. Representative nubots include the several DNA walkers reported by Ned Seeman's group at NYU, Nales Pierce's group at Caltech, John Reif's group at Duke University, Chengde Mao's group at Purdue, and Andrew Turberfield's group at the University of Oxford.

Positional nanoassembly

Nanofactory Collaboration, founded by Robert Freitas and Ralph Merkle in 2000, is a focused ongoing effort involving 23 researchers from 10 organizations and 4 countries that is developing a practical research agenda specifically aimed at developing positionally-controlled diamond mechanosynthesis and a diamondoid nanofactory that would have the capability of building diamondoid medical nanorobots.

Bacteria based

This approach proposes the use of biological microorganisms, like the bacterium *Escherichia coli*. Thus the model uses a flagellum for propulsion purposes. The use of electromagnetic fields are normally applied to control the motion of this kind of biological integrated device, but has limited applications.

Open technology

A document with a proposal on nanobiotech development using open technology approaches has been addressed to the United Nations General Assembly. According to the document sent to the UN, in the same way that Open Source has in recent years accelerated the development of computer systems, a similar approach should benefit the society at large and accelerate nanorobotics development. The use of nanobiotechnology should be established as a human heritage for the coming generations, and developed as an open technology based on ethical practices for peaceful purposes. Open technology is stated as a fundamental key for such an aim.

Potential applications

Nanomedicine

Potential applications for nanorobotics in medicine include early diagnosis and targeted drug-delivery for cancer,, biomedical instrumentation surgery,, pharmacokinetics monitoring of diabetes, and health care.

In such plans, future medical nanotechnology is expected to employ nanorobots injected into the patient to perform work at a cellular level. Such nanorobots intended for use in medicine should be non-replicating, as replication would needlessly increase device complexity, reduce reliability, and interfere with the medical mission. Instead, medical nanorobots are posited to be manufactured in hypothetical, carefully controlled nanofactories in which nanoscale machines would be solidly integrated into a supposed desktop-scale machine that would build macroscopic products.

The most detailed theoretical discussion of nanorobotics, including specific design issues such as sensing, power communication, navigation, manipulation, locomotion, and onboard computation, has been presented in the medical context of nanomedicine by Robert Freitas. Some of these discussions remain at the level of unbuildable generality and do not approach the level of detailed engineering.