74. Automation in Sports and Entertainment

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A service robot has to be intelligent, mobile, and able to cooperate with other robots and devices. We are on the way towards multirobot systems in which several robots, called multiagent systems (MAS), will act in a cooperative way together a common task. One of the newest application areas of service robots and especially MAS is the field of entertainment, leisure, and hobby. People have more free time, and modern information technologies lead to loneliness of humans (teleworking, telebanking, teleshopping, etc.). Entertainment robots are expected to be one of the real frontiers of the next decade.

In this chapter a short description of such robots will be given, including some application examples. Due to the broad range of possible applications of robots in entertainment, leisure, and hobby, the following classification has been made in order to give this contribution a basic structure: robot construction sets, sports assistants, promotion and public relations, robots in the entertainment industry, personal robots, humanoid robots, and competition robots.

As an example, robot soccer competitions will be described in more detail. Finally an outlook on future development trends will be given.

There are three *starting* points for the development of intelligent robots (Fig. 74.1):

- Conventional stationary robots
- Autonomous guided vehicles (AGVs)
- Walking machines.

Stationary industrial robots equipped with external sensors are used today, e.g., for assembly and disassembly operations, fueling of cars, etc. and were the first *intelligent* robots.

Mobile platforms with external sensors (AGVs) have been commercially available for some years and cover a broad application field. Mobile platforms are the real roots of service robots.

Walking machines or mechanisms have been well known for some decades. Usually they have four to six legs (multiped) and only in some cases two legs (biped) – from the viewpoint of control engineering walking on two legs is a very complex (nonlinear) stability problem. Biped walking machines equipped with external sensors are the basis for *humanoid* robots. Some prototypes of such robots are available today.

To give an idea about further developments, Fig. 74.1 shows possible development trends in robotics. We are now on the way from unintelligent industrial robots via intelligent industrial robots to intelligent mobile – including humanoid – robots to third-generation *advanced* robots able to interact and work symbiotically with us.

Robots in the 21st century will be used in all areas of modern life. The major challenges are:

- To develop robotic systems that can sense and interact usefully with humans
- To design robotic systems able to perform complex tasks with a high degree of autonomy.

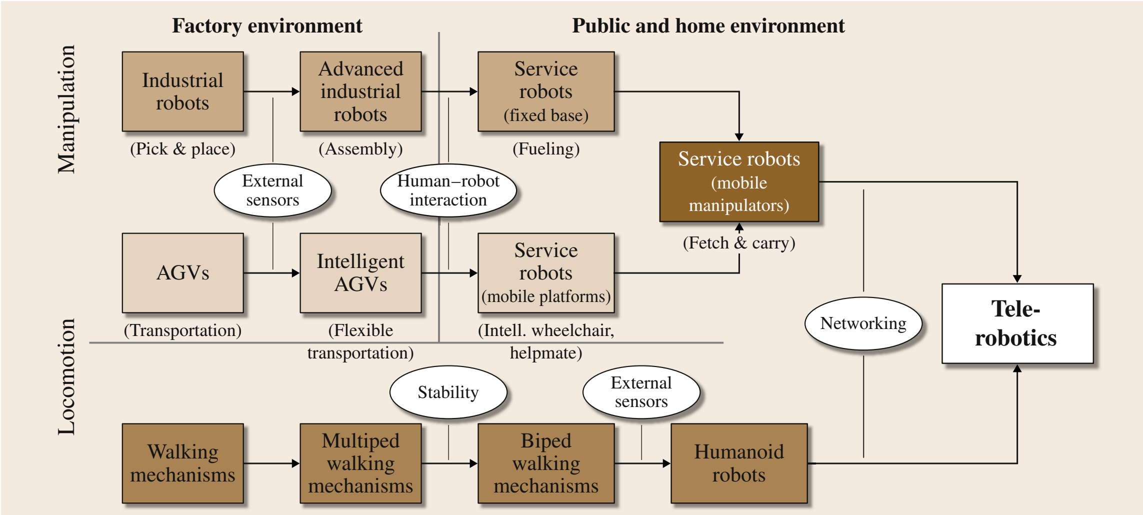

Fig. 74.1 From industrial to service robots (after [74.1])

In the same way that mobile phones and laptops have changed our daily lives, robots are poised to become a part of our everyday life. The robot systems of the next decades will thus be human assistants, helping people do what they want to do in a natural ad intuitive manner. These assistants will include: robot coworkers in the workplace, robot assistants for service professionals, robot companions in the home, robot servants and playmates, and robot agents for security and space.

The role of these robots of the future could be improved by embedding them into emerging information technology (IT) environments characterized by a growing spread of ubiquitous computing and communications and of ad hoc networks of sensors forming what has been termed *ambient intelligence.*

Currently available robots are far from this vision of the third generation, being able to understand their environments, their goals, and their own capabilities or to learn from their own experiences.

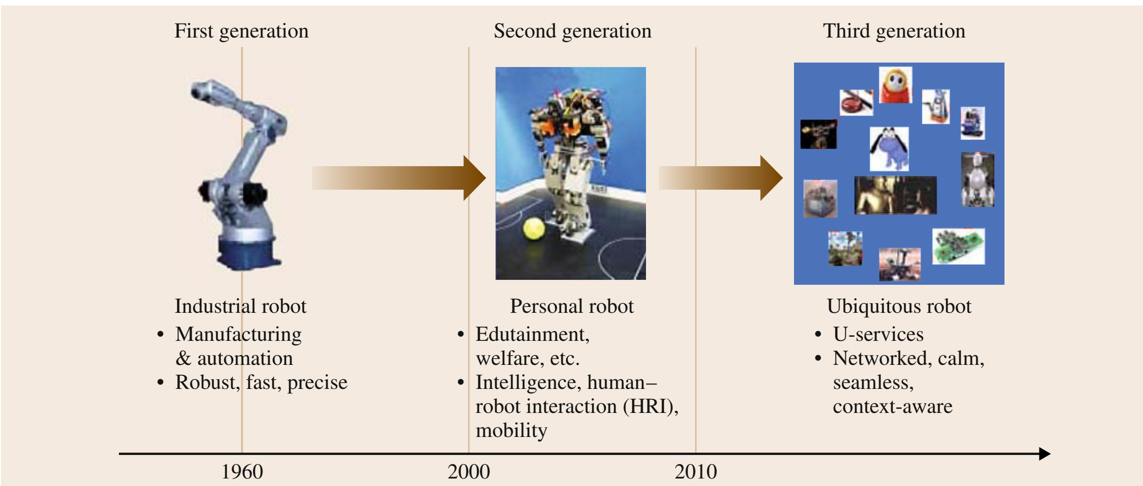

Fig. 74.2 Development trends in robotics [74.2]

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74.1 Robots in Entertainment, Leisure, and Hobby

One of the newest application areas of service robots is in the field of entertainment, leisure, and hobby, because people have more free time, and modern information technologies lead to loneliness of humans (teleworking, telebanking, teleshopping, etc.). We need robots to assist, support, and join humans. The field of *robots in entertainment, leisure, and hobby* was therefore born. The roots of such robots go back more than 20 years ago [74.3, 4]. These robots are usually mobile, intelligent, and cooperative. The idea of making modern automation transparent for a broader public goes back to the middle of the 19th century. One tool for this is playing with automation. First examples were in the field of process automation, e.g., two- and three-tank systems, model railways, model racing cars, etc. At the end of the 19th century and the beginning of the 20th century robots started to attract a broader public. One of the reasons for this is humans' long-time dream of having an intelligent machine looking and acting like us. Therefore robots are currently and will be also in the future *high-tech toys* for playing with automation.

In the past construction sets for stationary, industrial robots served for playing with robots. These model robots were a popular gift not only for children. Approximately 30 years ago the first construction kits for mobile and also humanoid robots appeared on the market. Currently and also in the future the development of entertainment robots is closely connected to the development of real, mobile, intelligent, especially humanoid robots. Most of the *advanced* theories implemented in these real robots are and will be the basis for entertainment and play robots. The main problem can be summarized under the headline *cost-oriented automation* (COA). These robots must be available on the market for a reasonable selling price.

74.1.1 Definitions

First it is certainly important to take a brief look at different definitions of the terms entertainment, leisure, and hobby. Their meanings often overlap, but nevertheless they all mean something different.

Entertainment

This can be defined as: the act or profession of entertaining, i.e., to amuse and interest, especially by public performance and keeping the attention of people watching or listening [74.5]; the act of entertaining, or something diverting or engaging as a public performance, e.g., a (usually light) comic or an adventure novel [74.6].

Leisure

This can be defined as: time when one is free from work or duties of any kind; free time [74.5]; freedom provided by the cessation of activities; especially time free from work or duties [74.6].

Hobby

This can be defined as: an activity which one enjoys doing in one's free time [74.5]; a pursuit outside one's regular occupation, engaged in especially for relaxation [74.6].

74.1.2 Categories

Due to the broad range of possible applications of robots in entertainment, leisure, and hobby, the following classification [74.3] has been made in order to give this chapter its basic structure:

- Robot construction sets
- Sports assistants
- Robots for promotion and public relations
- Robots in entertainment industry
- Personal robots
- Humanoid robots
- Competition robots.

74.1.3 Examples

In the following some *classical* examples, because of the rapid development in this field, are presented and shortly discussed.

Robot Construction Sets

These construction sets often stem from *conventional* technical construction sets that have been upgraded using sensor and microcontroller technology, paired with computer interfaces to allow the user to run self-programmed software. They are mainly for *computer enthusiasts* for testing own-developed software on a cheap hardware.

There are two main types of construction kits available:

- Sets where it is possible to construct various robots
- Sets where only one robot can be constructed

Within these main categories it is also possible to choose from a wide variety of different kits; prices range from under US$ 100 to several hundred US dollars.

The well-known system in the first category is Lego Mindstorms [74.7]. Based on the products of this company, the construction set allows a great variety of possible assemblies due to its modular structure. The only limit is the fantasy of the constructor. The system consists is of a specially developed microcomputer (the heart of Lego Mindstorms), software, 717 elements (bricks, connectors, wheels, and gears), 2 motors, 2 touch sensors, 1 light sensor, and an infrared transmitter for sending programs to the robots.

Mobile Robots is a construction set for sensor-guided robots. The included robot–personal computer (PC) interface allows one to write ones own command routines on the computer and load them into the robot's memory. So the robot can act independently and without any attached cables. Possible constructions are capable of detecting edges and stopping before falling down, are aware of obstacles, and can follow light sources or track plotted lines. As it is a totally flexible system, own creations are possible and appreciated.

Representatives of the second category are robots from a company offering a wide variety of construction kits, but all of them designed for building one robot only. Various models of robotic arms, bipeds, quadrapods, hexapods, polypods, carpet rovers, four-wheel-drive (4-WD) rovers, and sumo robots are available.

Sports Assistants

The robots introduced into this field are systems well equipped with high-tech sensors that assist humans in their favorite sport by performing routine tasks usually annoying such as collecting tennis balls or carrying golf clubs.

Tennis Ball Collector: Jeeves. Developed by a freelance designer in cooperation with a university, this robot collects tennis balls by driving towards them when detected by the onboard charge-coupled device (CCD) camera, and bringing them into a basket in the rear using a rotating brush. Ultrasound distance sensors avoid collisions with obstacles on the court while the robot generates a map of the environment based on its sensor data and stores this information for further use, thus enabling *Jeeves* to sweep an already known court effectively. Path planning is done by a sophisticated computer system running on an off-board workstation that is connected via a radio link.

Golf Caddy: InteleCaddy. This robot replaces a human caddy in a mass sport application where many golfers are not willing to pay for a caddy, currently being installed at golf courses all over the world. The InteleCaddy is a computer-controlled, electrically powered golf caddie robot that navigates around the golf course with its telecommunication skills and sensors, being connected to the golfer via a small pager-sized coded transmitter. The robot features a digital aerial map of the golf course and is programmed to stay within preset boundaries, thus following the golfer with the bags using geographical positioning system (GPS) and ultrasound sensors for navigation and obstacle avoidance. As a bonus, the computer also supplies the golfer with useful information on the course such as exact distance to predefined positions (greens, bunkers, and tees) on the map.

Robots for Promotion and Public Relations

Robots for promotion and public relations can be divided into the categories of tour guide robots and performance robots, hence having very different tasks.

Tour guide robots give information to people while interacting with them, thus attracting and entertaining prospective visitors as well. Performance robots are for performances in public places or at events, mostly with robot systems rented by specialized companies.

Tour Guide Robots. A tour guide robot has to be able to move around autonomously in the environment. It has to acquire the attention of visitors and interact with them efficiently in order to fulfil its main goal: give the visitors a predefined tour. These robots were designed to conduct guided tours in public places such as museums

Fig. 74.3 Museum tour guide *Minerva*

Fig. 74.4 Museum tour guide *Twiddling, Inciting, Instructive*

while managing autonomous sensor-based navigation as well as avoidance of collisions in a densely populated area of unpredictable moving visitors.

The tasks of a tour guide robot are:

- Traveling from one exhibit to the next during the course of the tour
- Attracting visitors to participate in a new tour between tours
- Engaging people's interest and maintaining their attention while describing a specific exhibit.

Furthermore, they are equipped with social interaction features, which range from rather simple voice output (*RHINO*) [74.10] to a combination of voice, facial expressions, and a model to express feelings as well (*Minerva*), giving the robot a *human touch*. The navigation system of both units is based on real-time processing of sensor data to generate a map of the environment.

Minerva [74.11] was developed in 1998 by Carnegie Mellon University and the University of Bonn and is working in the Smithsonian's National Museum of American History, USA.

These robots, developed by Fraunhofer IPA, Stuttgart, have been in use in the Museum für Kommunikation in Berlin, Germany since 2000.

Performance Robots. The main task of performance robots is to entertain people, often using low-tech applications with a few sensors, limited computing power, and no capabilities to act autonomously. Systems such as *Robosaurus* or *Boxerjocks* can be rented for large public events to attract visitors and thus increase the revenue of the renter.

Fig. 74.5 *Megasaurus* [74.8]

Due to the existence of a large number of companies renting or distributing performance robots, just a few applications have been included in order to give a short survey of how broad the range of entertainment robots or animatronic systems is in this field.

Megasaurus and Transaurus are modeled after a *Tyrannosaurus rex* and have hydraulically activated arms, grasping claws, and jaws, as well as flame throwers set up in the head to give the effect of breathing fire from the mouth. They both fold up into a vehicle based on a tank and when the robots perform they initially appear as a box on tracks decorated as either a military vehicle (Megasaurus) or a dinosaur (Transaurus). Each robot is roughly 30 feet tall at maximum extension. They are used primarily to destroy cars by *eating* them (ripping them apart with the claws and jaws) at motor sport events, especially monster truck competitions.

Fig. 74.6 *Transaurus* [74.9]

Fig. 74.7 Boxer Jack [74.12]

Boxer Jacks Robotic Boxing is an animatronics system that serves as an attraction in amusement parks or other places where large crowds of people can be found, such as shopping centers. The application system is fairly straightforward: Two of these robots are located within a certain area where they can move around freely. Each of the systems is controlled by a human, who tries to punch the other's robot. Technical features include:

- Construction – Tubular steel network with a rigid steel mesh surrounding the rider's upper body, providing ample safety and visibility
- Drive – Dependable Honda gasoline engine powers the hydropneumatic system for mobility and arm punching articulations
- Body – Hand-laid fiberglass with choice of color scheme; quality urethane enamel finishes used
- Seating – Designed so that riders aged 8 years through to adults can operate a Boxerjack easily
- Impact areas – Use of heavy rubber on all contact areas, bumper, gloves, and arms cushion all shock loadings during the match
- Electrical – 12 V direct-current (DC) battery system use for arm switching, scoreboard, and head horn.

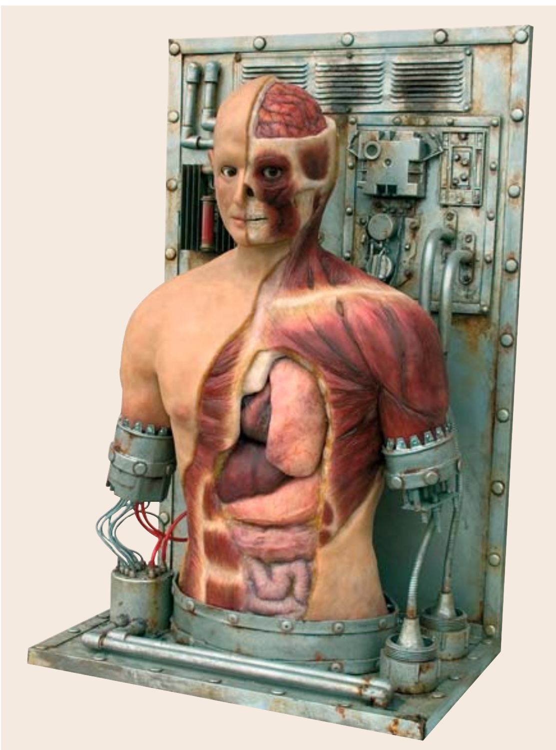

Fig. 74.8 Jekyll and Hyde animatronic (courtesy of Life Formations [74.12])

Robots in the Entertainment Industry

Robot applications in the film industry are often spectacular because of their custom-made special features. In this chapter robots as performing artists, can be found as well.

Film Industry. Starting with *Metropolis* in 1926, dealing with a futuristic city and its mechanized society with humans being replaced by a robot, through *The Day the Earth Stood Still* (1951), *Lost in Space* (1965) to *A Space Odyssey*, robots have frequently been used in films.

One of the most recent examples in movies is *I-robot*; although not based on the the book written by *Asimov*, it was based on the concepts proposed therein, such as the three laws of robotic behavior. It presents a future where robots do all manual labor. One robot is programmed and trained to understand human emotions, and commits murder due to a promise and out of love. The robots take over as they get deeper understanding of the three laws – mankind is destroying itself and has to be protected from self-destruction.

As the entertainment industry was one of the first fields to use service robots, there is a huge variety of applications in theme parks and especially movies, where robotic and animatronic creatures are often combined with animated computer graphics to realize spectacular special effects (Figs. 74.8–74.10).

Another field of robotic applications is in the performing arts, where robots can be found rather seldom, but therefore in mostly amazing performances that partly have a scientific background as well.

Robotic Snake in Anaconda. This lifelike replica of the giant *Anaconda* is a high-tensile-steel robot structure, consisting of individually controlled artificial vertebrae that are driven by hydraulic cylinders. The system is controlled by more than 70 coupled microprocessors with a special control concept that allows the underlying hydraulic system to perform the necessary quick movements of the heavy structure.

Robots in Jurassic Park. The robotic system incorporating the *Tyrannosaurus*, the largest one ever built for use in a movie, is a fiberglass frame construction covered by clay and afterwards coated with a specially painted latex skin. As the robot measured 9 m high and weighed 10 t, it had to be supported by a massive foundation usually used for flight simulators.

Other less spectacular systems such as the replica of a *Triceratops*, featuring remotely controlled motors and a mechanism to imitate breathing movements, were also used in the movie.

Robots as Performing Artists. The robot band introduced here is a pretty low-tech application for entertainment purposes that plays digital music from a computer disk while the animated robotic figures pretend to move to the sound and play their instruments.

Although the *Ullanta Performance Robots* seem at first sight to exist solely for entertainment, these fully autonomous robots are used for research in cooperative robot group behavior and multiagent systems as well, both employed in a dynamic environment. These robots are, within certain boundaries, allowed to *interpret* the script based on their own software.

Personal Robots

Pet Robot: Furby. Being the ancestor of all pet robots, this popular animatronic pet is equipped with a computer chip, various sensors, and a small motor. It responds to its environment in *Furbish*, a nonsense lan-

Fig. 74.9 Lincoln library (Springfield, IL) animatronics (courtesy of Life Formations)

Fig. 74.10 Rolling Hills, Kansas Museum animatronics (courtesy of Life Formations)

guage, and is able to communicate with other *Furbies* via infrared signals.

Personal Robot: R100. This prototype mobile personal robot uses a completely new voice-controlled approach, thus providing a more natural, buttonless interface in order to become a *real family member*.

With its visual and voice recognition technology and Internet connectivity, it can be used as a voice message or home security system (besides its function as a personal companion).

Catrobot: Tama. Featuring speech output and recognition, this kitten-like pet robot serves as a companion and information source for senior citizens, while being remotely accessible by health or social workers who thus can take care of the elderly without too much intrusion into their privacy.

Robodog: i-Cybie. Described as "a watered-down version of AIBO with almost the same functions without the finesse" in the press, this infrared-controllable robot dog indeed features many of AIBO's functions at a technically lower level but for a fraction of the price.

Robodog: AIBO. AIBO is an abbreviation for artificial intelligence robot. Because of its reduced instruction set computer (RISC)-processor-powered high-tech system including numerous sensors, a color camera, and 18 motors to move its extremities it is the first entertainment robot that can think, feel, and act by itself. It can walk and play, sit, and stretch like dogs and cats. AIBO's brain contains an emotion model to handle feelings and an instinct model to handle drives. The emotion model covers six feelings: happiness, sadness, anger, surprise, fear, and dislike. The instinct model has four components: love, search, movement, and hunger.

Pet Robot: My Real Baby. This interactive, animated doll features instant, sophisticated, and interactive emotion-like responses and is able to simulate a maturation and speech development process.

Humanoid Robots

Entertainment robots are expected to be one of the real frontiers of the next decade. According to latest estimations millions of such robots will be in use in the coming years. The newest developments are *friendly* robots for humans; for example, elderly people need listening and talking friends. We now have dogs, cats, and human-like robots available for reasonable prices, but not really humanoid robots walking on two legs [74.13]. First examples are described below.

Since 1986 the Japanese Company Honda has developed humanoid robots, P2, P3, and ASIMO (advanced step in innovation mobility). The basic idea is to integrate intelligence and moving capability into a robot for trivial tasks. Over the years the robot has become smaller (from 160 cm for P3 to 120 cm for ASIMO) and lighter (from 130 kg of P3 to 43 kg of ASIMO). The newest development is ASIMO. It can move at up to 1.6 km/h and has 26 degrees of freedom (DOFs). This kind of robot can easily be used in home as wheel-driven robots, because of their ability to move over an uneven surface such as stairs.

Therefore service robots will become a real *partner* of humans in the near future. One dream of the scientists is the *personal* robot. In 5, 10 or 15 years everybody should have at least one such robot. Because the term personal robot is derived from personal computer the prices should be equal. Some new ideas in automation, especially in robotics, are realized very quickly while others disappear.

Honda is trying to build the ASIMO robot to be a partner for people. So far it is merely a study about how to imitate humans' movements and make it able to help people somehow. It is 120 cm high, which is enough to reach most gadgets designed for humans. The latest model, introduced in December 2004, can even run at 3 km/h like a human.

QRIO is Sony's [74.14] next step after the robodog AIBO in entertainment robots. It's a bipedal humanoid robot that is able to:

- Walk on uneven and sloppy surfaces
- Run
- Jump
- Perceive depth through its two CCD cameras
- Create a three-dimensional (3-D) map of its surroundings
- Recognize people from their faces and voices
- Learn
- Connect to the Internet via a wireless home network
- Download and read information it thinks you're interested in
- Sing
- Dance
- Survive a fall unscathed and get back up again by itself.

In order for QRIO (Fig. 74.11) to walk and dance so skillfully, an actuator was needed with the ability to produce varying levels of torque at varying RPM speeds and respond with quickness and agility.

The robot moves with *dynamic walking*. *Static walking* means that the robot keeps its center of gravity within the zone of stability – when the robot is standing on one foot, its center of gravity falls within the sole of that foot, and when it is standing on two feet it falls within a multisided shape created by those two feet – causing it to walk relatively slowly. In *dynamic walking*, on the other hand, the center of gravity is not limited to the zone of stability – in fact it often moves outside of it as the robot walks. People move using *dynamic walking*.

If pushed by someone, QRIO will take a step in the direction in which it was pushed to keep from falling over. When it determines that its actions will not prevent a fall, it instinctively sticks out its arms and assumes an impact position. After a fall, it turns itself face up, and recovers from a variety of positions. It is equipped with a camera and the ability to analyze the images it sees. It detects faces and identifies who they are. Moreover QRIO can determine who is speaking by analyzing the sounds it hears with its built-in microphones.

An example of a reasonable cheap entertainment robot is the humanoid robot of Robonova [74.15]. This robot offers educators, students, and robotic hobbyists a complete robot package. It is a fully customizable and programmable aluminum robot (Fig. 74.12). Sixteen digital servos and joints give complete control of torque, speed, and position. The programming software is simple, so advanced knowledge of programming is not needed. It can walk, run, do flips, cartwheels, and dance. The robot is available as a kit – assembly time approximately 8 h – or preassembled, ready to walk robot. In addition to the typical robot talent of walking until it senses a wall using ultrasound, Robonova can be instructed to do cartwheels, take a bow, and even do one-handed pushups.

The simplest way for programming is with the *catch-and-play* function. With RoboScript or RoboBasic the robot is moved to any position and by mouse click that position is *captured*. The software then links these *captured* positions and, once activated, smoothly transitions the robot's movements through these programmed positions.

For beginners in robot programming two software packages are available. With these the users can create operational subroutines without knowing any programming language at all. The computer screen displays sliders for every individual servo (joint). Moving the sliders changes the position of the servos. Simple movements can then be assembled to produce complex movements simply by clicking the mouse. These movements can then be called up on a graphical user interface.

For more advanced users a programming tool based on the Basic programming language is available. This enables the users to create complex applications de-

Fig. 74.11 QRIO

Fig. 74.12 Robonova

signed to accomplish their own individual tasks. The independent development environment includes an editor and compiler. Commands for synchronous servo movements, servo point-to-point movements, and servo motion feedback are also available. The robot can be extended with several accessory modules and items: additional servos and brackets, gyros, acceleration sensors, speech functions, remote control (RC) accessories, and more can also be added as they become available.

The RoboSapien (Fig. 74.13a) is a toy-like robot [74.16] preprogrammed with moves, which can also be controlled by an infrared remote control included with the toy, or by either a personal computer equipped with an infrared transmitter, or an infrared-transmitter-equipped personal digital assistant (PDA). The toy is capable of walking motion without recourse to wheels within its feet. It is also able to grasp objects with either of its hands, and is also able to throw grasped objects with mild force. It has a small loudspeaker unit, which can broadcast several different vocalizations, all of which appear to be recordings of a human male pretending to be a great ape, such as a gorilla.

The toy's remote control unit (Fig. 74.13b) has a total of 21 different buttons. With the help of two shift buttons, a total of 67 different robot-executable commands are accessible.

The remote controller is equipped with a basic level of programmability. Users can string together movement commands to form what the toy's manual describes as either macros or mini-programs, but which are more correctly described as robotic instructions sets. It is also possible to produce a sensor-keyed instruction set.

Fig. 74.14 RoboSapien V2

The original robot was developed in the year 2000 and was a brilliant achievement of breakthrough design. It could walk, grasp, and respond – in human-like ways.

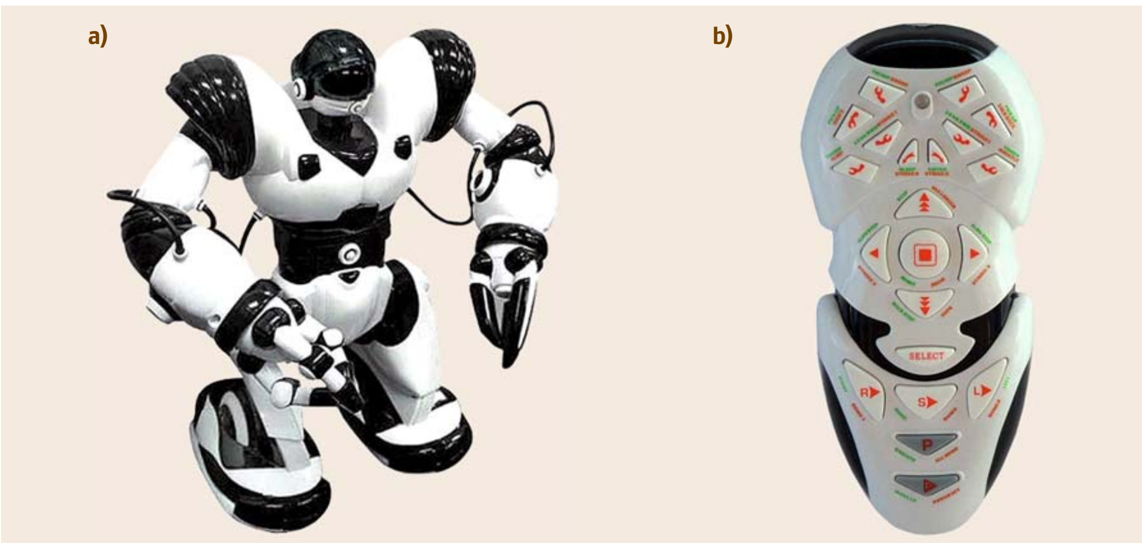

Fig. 74.13 **(a)** RoboSapien, **(b)** remote control

Fig. 74.15 RS Media

The next generation (Fig. 74.14) was released in 2003 and is nearly twice the size of the original robot. Instead of the original caveman grunts the V2 can speak a reasonably large list of prerecorded phrases. It has infrared and basic color recognition sensors, grip sensors in its hands, touch- or contact-activated hand and foot sensors, and sonic sensors. For movement the V2 has an articulated waist, shoulders, and hands, giving it a wide variety of impressive body animations.

The latest model, the RS Media (Fig. 74.15), which was released in October 2006, uses basically the same body as V2, but a different brain based on a Linux kernel. As the name implies, RS Media's focus is on multimedia capabilities, including the ability to record and playback audio, pictures, and video.

Another example of a reasonable cheap entertainment robot is a 12 inch-high robot that can walk, run, and do flips, cartwheels, and dance moves, and that, once programmed, is ready to compete in distinct competitions. This fully articulating humanoid is controlled by a control board, which can operate up to 24 servos and 16 accessory modules with 16 digital servos.

Optional devices will eventually include gyros, acceleration sensors, speech synthesis modules, and operational devices such as Bluetooth controllers and R/C transmitters and receivers. The operation time with a five-cell rechargeable battery pack is approximately 1 h.

The main problem with such robots consists in the preprogrammed movements and that it is not easy to add some software modules.

Competition Robots

A very popular group of entertainment robots are those for competitions. A robot competition is an event where robots have to accomplish a given task. Usually they have to beat other robots in order to be judged the best. Most competitions are for schools but, as time goes by, several professional competitions are arising. There is a wide variety of competitions [74.17] for robots of various types. The following examples describe a few of the higher-profile events.

The idea of a robot competition is not new; they have been held for several years at, for example, the Massachusetts Institute of Technology (MIT) in Boston and Eidgenössische Technische Hochschule (ETH) in Zurich. Having a robot competition in an academic curriculum is highly beneficial, as it gives students open-ended problem spaces, teaches them to work in groups (of two or three persons), and stimulates creativity [74.18].

Classical examples are:

- Robot outdoor tournaments
- Robot soccer
- Ping-pong-playing robots
- Robot wrestling
- Sumo wrestling robots
- Billiard robots.

Table 74.1 gives some examples of robot games.

RoboGames. RoboGames [74.19] (previously ROBOlympics) is an annual robot contest held in San Francisco, California. RoboGames is the world's largest

Table 74.1 Examples of robot games

Beam robot games/olympics		Robofesta official games
Solarroller	High/long jump	Robocup
Photovore	Legged race	Robot grand prix
Aquavore	Innovation machine	All Japan sumo tournament
Rope climbing	Robot-art	All Japan micromouse contest
Robot sumo	Micromouse	
Nanomouse	Aerobot compet.	

open robot competition. They invite the best minds from around the world to compete in over 70 different events. About two-thirds of the robot events are autonomous, while the remaining one-third are remotely operated.

The first goal is to bring builders from combat robotics (mechanical engineering), soccer robotics (computer programming), sumo robotics (sensors), androids (motion control), and art robots (aesthetics) together for exchange experiences. The second goal is to offer recognition to engineers from around the world in varying disciplines with consistent rule sets and low cost or without contestant fees. There are no prerequisites for contests; the event is open to anyone, regardless of age or affiliation. Twenty-eight countries competed with more than 800 robots in 2007.

Competition categories:

- Combat:
  - Categories from 1 to 340 lbs (454 g–154.5 kg)
  - RC and autonomous
- Robot soccer:
  - MiroSot 5:5/11:11 (autonomous)
  - Biped soccer 3:3 (R/C)
  - AIBO soccer 4:4 (autonomous)
- Autonomous humanoid challenges:
  - Basketball
  - Weight lifting
  - Obstacle run
- Autonomous autos
- Sumo
- Bot hockey
- R/C humanoid competition
- Tetsujin (exoskeletons)
- Art bots
- Junior league (< 18 years old)
- Open.

DARPA Grand Challenge. The Defense Advance Research Projects Agency (DARPA) Grand Challenge [74.20] is a prize competition for driverless cars, sponsored by DARPA, the central research organization of the US Department of Defense. Congress has authorized DARPA to award cash prizes to further DARPA missions to sponsor revolutionary, high-payoff research that bridges the gap between fundamental discoveries and their use for national security.

Fully autonomous vehicles have been an international pursuit for many years and the Grand Challenge was the first long-distance competition for robot cars in the world; the main goal is to make one-third of cars autonomous by 2015.

The first competition of the DARPA Grand Challenge was held in 2004 in the Mojave Desert region of the USA along a 150 mile to just past the California–Nevada border in Primm. None of the robot vehicles finished the route. Carnegie Mellon University's Red Team traveled the farthest distance, completing 11.78 km (7.36 mile) of the course.

All but one of the 23 finalists in the 2005 race surpassed the 11.78 km (7.36 mile) distance completed by the best vehicle in the 2004 race. Five vehicles successfully completed the race.

Vehicles in the 2005 race passed through three narrow tunnels and negotiated more than 100 sharp left and right turns. The race concluded through Beer Bottle Pass, a winding mountain pass with sheer drops on both sides. Although the 2004 course required more elevation gain and some very sharp switchbacks (Daggett Ridge) were required near the beginning of the route, the course had far fewer curves and generally wider roads than the 2005 course.

The third competition of the DARPA Grand Challenge (2007) was named the *Urban Challenge*. The course involved a 96 km (60 mile) urban area course, to be completed in less than 6 h. Rules included obeying all traffic regulations while negotiating with other traffic and obstacles and merging into traffic. While the 2004 and 2005 events were more physically challenging for the vehicles, the robots operated in isolation and did not encounter other vehicles on the course. The Urban Challenge required designers to build vehicles able to obey all traffic laws while they detected and avoided other robots on the course. This is a particular challenge for vehicle software, as vehicles must make *intelligent* decisions in real time based on the actions of other vehicles. In contrast to previous autonomous vehicle efforts that focused on structured situations such as highway driving with little interaction between the vehicles, this competition operated in a more cluttered urban environment and required the cars to perform sophisticated interactions with each other, such as maintaining precedence at a four-way stop intersection. Four teams completed successfully the course.

The cars are usually equipped with laser measurement systems, laser sensors, global positioning systems (GPS), and cameras. The teams employed a variety of different software and hardware combinations for interpreting sensor data, planning, and execution. Some examples included C++ and C# running on Windows hosts with planning involving Bayesian mathematics;

and Mac Minis running Linux because it can run on DC power at relatively low wattage and produce less heat. Examples of the latter included Mac Minis running on Windows and an embedded version of Windows XP.

Annual Fire-Fighting Home Robot Contest. The main challenge of this contest [74.21] is to build an autonomous, computer-controlled robot that can find its way through an arena that represents a model house, find a lit candle that represents a fire in the house, and extinguish the fire in the shortest time. This task simulates the real-world operation of an autonomous robot performing a fire protection function in a real house. The goal of the contest is to make a robot that can operate successfully in the real world, not just in the laboratory. Such a robot must be able to operate successfully where there is uncertainty and imprecision. Therefore, the dimensions and specifications listed in the rules are not exactly what will be encountered at the contest and are provided as general aids. However, the size limits on robots are absolute and are enforced by the judges.

Once turned on, the robot must be autonomous, i. e., self-controlled without any human intervention. Fire-fighting robots are to be computer controlled and not manually controlled devices.

A robot may bump into or touch the walls of the arena as it travels, but it cannot mark, dislodge or damage the walls in doing so. There will not be a penalty for touching a wall, but there is a penalty for moving along the wall while in contact with it. The robot cannot leave anything behind as it travels through the arena. It cannot make any marks on the floor of the arena that aid in navigation as it travels. Any robot that deliberately, in the judges' opinion, damages the contest arena (including the walls) will be disqualified. This does not include any accidental marks or scratches made in moving around.

The robot must, in the opinion of the judges, have found the candle before it attempts to put it out; for example, the robot cannot just flood the arena structure with CO_2, thereby putting the candle out by accident.

Early competitions include the following:

Robot Golf Open. An example of a robot competition is the 1996 robot contest called the Robot Golf Open. The contest arena was a rectangular square of 2×2 m, surrounded by a 15 cm high wall. The green was located in the middle of the arena and was a 7 cm high disc with a diameter of about 40 cm. Seven golf balls were randomly placed on the arena. It was the task of the robot to locate the balls, pick them up, and put them in some way into the hole, with two points being given for each ball. One point was given if the ball was only placed on the green. It is emphasized here that the robots performed the task autonomously, i. e., they made decisions as to how to control themselves according to the software running on the onboard computer based on sensory information. Two robots *played golf* against each other for a period of 2 min.

Environmental Control Robot Competition. The latest contest with a vision system, held in the spring of 2001, was called *environmental control*; the robot task was to locate three different kinds of garbage in an arena and bring them to the correct container. The arena was 2×2 m and contained *containers* at one side, three for each robot. The garbage was either a bottle, a battery or a pack of newspapers.

Other currently well-known competitions are:

Aerial Robotic Vehicle Competitions. The International Aerial Robotics Competition [74.22] is the longest running aerial robotic event, held annually since 1991. This competition involves fully autonomous flying robots performing tasks that, at the time posed, are undemonstrated anywhere worldwide. The competition is open to universities and has had missions involving ground object capture and transfer, hazardous waste location and identification, disaster scene search and rescue, and remote surveillance of building interiors by fully autonomous robots launched from 3 km. A series of micro air vehicle (MAV) events have been sponsored by various organizations. Typically, these competitions involve capability demonstrations rather than missions, and may or may not involve full autonomy.

Ground Robotic Vehicle Competitions. In addition to the DARPA Grand Challenge [74.23] there is also the *Intelligent Ground Vehicle Competition* (IGVC) for autonomous ground vehicles. The robots must traverse outdoor obstacle courses without any human interaction. This is an international student design competition at university level and has held annual competitions since 1992.

Underwater Robotic Vehicle Competitions. This is a spin-off of the International Aerial Robotics Competition [74.24], and as such, carries through the theme of full autonomy of operation, albeit in a subsurface robotic vehicle. This is, since 1997, a collegiate competition.

International METU Robotics Days. The Middle East Technical University (METU) Robotics Days [74.25] are organized in Ankara, Turkey. There are robot competitions from various categories in which original and creative ideas take their part, while innovation is honored. Participants are always encouraged to share their knowledge. International METU Robotics Days, apart from holding competitions for those who would like to challenge their skilled robots, also host professionals and academics interested in the field of robotics to come together in lectures and workshop studies with younger amateurs, giving them the opportunity to take a closer look at this continuously developing technology.

IEEE Micromouse competition. In the classical Micromouse competitions [74.26], small robots try to solve a maze in the fastest time. Micromouse competitions were held first in Tampere Finland Technical University around 1983–1985.

Botball Educational Robotics. Botball [74.27] is a robotics competition for middle- and high-school students. Organized by the KISS Institute for Practical Robotics, Botball encourages participants to work constructively within their team, building basic communication, problem solving, design, and programming skills. Each team builds one or more (up to four) robots that will autonomously move scoring objects into scoring positions.

Mobile Autonomous Systems Laboratory Competition. The Mobile Autonomous Systems Laboratory [74.28] is one of the few college-level vision-based autonomous robotics competition in the world. Conducted by and for MIT undergraduates, this competition requires multithreaded applications of image processing, robotic movements, and target ball deposition. The robots are run with Debian Linux and run on an independent OrcBoard platform that facilitates sensor-hardware additions and recognition.

Wall-Climbing Competitions. There are two worldwide known events. The Duke Annual Robo-Climb Competition (DARC) [74.29] in the USA and the Climbing and Walking Autonomous Robot (CLAWAR) [74.30] competition in Europe. The task is to create innovative wall-climbing robots that can autonomously ascend vertical surfaces of different materials with obstacles.

AAAI Grand Challenges. The two Association for the Advancement of Artificial Intelligence (AAAI) Grand Challenges [74.31] focus on human–robot interaction, with one being a robot attending and delivering a conference talk, the other being operator-interaction challenges in rescue robotics.

This is only a selection – there are a lot of other robot competitions worldwide, mainly dedicated to BSc students.

As an example, robot soccer will be described in more detail below.

Robot Soccer

The fascinating idea of using small robot cubicles to play soccer was born just a decade ago in Korea and Japan and has since spread all over the world. Yearly championships are even organized in different countries. From the scientific point of view, robot soccer is one of the first applications of a MAS. The players – robots or agents – have to solve a common task, i. e., to win the game.

Robot soccer was introduced to develop intelligent cooperative multirobot (agents) systems (MAS) and to educate the young generation in these difficult scientific and engineering subjects by playing. From the scientific viewpoint the soccer robot is an intelligent autonomous agent which carries out tasks with other agents in a cooperative, coordinated, and communicative way. Generally robot soccer is a good test bed for the development of MAS. Furthermore it is also a good tool for spending leisure time and for education [74.32].

In the future, production systems will become more complex. Several independently working autonomous mobile robots are working together, and therefore conflict situations in certain areas could appear, e.g., where several robots gather at an intersection. In order to avoid conflict situations and delays, and guarantee smooth movement, robots should have the capability to communicate and cooperate in order to coordinate their actions.

Soccer is one of the best known sports worldwide. It is exciting to watch how robots play the game. It is also possible not only to watch the game but also to play the game – human against computer, human against human – using a joystick as well as a keyboard. The big question for common use is the price of the whole system. With the development of electronic devices and peripheries the cost is going down. For the realization of interdisciplinary research, work should be done in areas such as robotics, image processing, sensors, mechatronics, communication, etc.

At the moment there are two robot soccer organizations in the world: the Federation of International Robot-Soccer Associations (FIRA) [74.33] and RoboCup [74.34]. The objects and scope of both organizations are similar. The size, speed, acceleration of the robots, the sizes of the playgrounds, and the numbers of robots playing are different.

RoboCup. RoboCup is an international research and education initiative. Its goal is to foster artificial intelligence and robotics research by providing a standard problem for which a wide range of technologies can be examined and integrated.

The main focus of RoboCup activities is competitive football. The games are important opportunities for researchers to exchange technical information. They also serve as a great opportunity to educate and entertain the public. RoboCup soccer is divided into the following leagues:

Simulation League. Independently moving software players (agents) play soccer on a virtual field inside a computer.

Small-Size Robot League (f-180). Small robots of no more than 18 cm in diameter play soccer with an orange golf ball in teams of up to five robots on a field with size bigger than a ping-pong table.

Middle-Size Robot League (f-2000). Middle-sized robots of no more than 50 cm diameter play soccer in teams of up to four robots with an orange soccer ball on a field the size of 12 × 8 m.

Four-Legged Robot League. Teams of four four-legged entertainment robots (Sony's AIBO) play soccer on a 3 × 5 m field. The robots use wireless networking to communicate with each other and with the game referee. Challenges include vision, self-localization, planning, and multiagent coordination.

Humanoid League. Biped autonomous humanoid robots play in *penalty kick* and *2 versus 2* matches, and *technical challenges*. This league has two subcategories: kid-size and teen-size.

RoboCupRescue. The intention of the RoboCupRescue project is to promote research and development in this significant domain by involving multiagent teamwork coordination, physical robotic agents for search and rescue, information infrastructures, personal digital assistants, standard simulator and decision support systems, evaluation benchmarks for rescue strategies, and robotic systems, which will all be integrated into a comprehensive system in the future.

Federation of International Robot-Soccer Associations (FIRA). Similar to RoboCup there are also different categories in this *Robotsoccer World*.

Micro Robot World Cup Soccer Tournament (MiroSot). A match shall be played by two teams, each consisting of 5 or 11 robots on a dark playground 220 cm × 180 cm for the middle league, 400 cm × 280 cm for the large league, with an orange golf ball (Fig. 74.16). Only three human team members, a *manager*, a *coach*, and a *trainer*, are allowed on the stage. One host computer per team, mainly dedicated to vision processing and other location identification, is used. The size of each robot is limited to 7.5 cm × 7.5 cm × 7.5 cm. The height of the antenna is not considered in deciding a robot's size.

Nano Robot World Cup Soccer Tournament (NaroSot). Similar to MiroSot, but the size of the five robots is limited to 4 cm × 4 cm × 5 cm. They play with an orange ping-pong ball on a playground 130 cm × 90 cm (Fig. 74.17).

Kheperasot. The Kheperasot game is played by two teams, each consisting of one robot player and up two human team members. The robot is fully autonomous with an onboard vision system. The human team members are only allowed to place their robot on the field, start their robot at the beginning of each round at the position indicated by the referee before each round, start

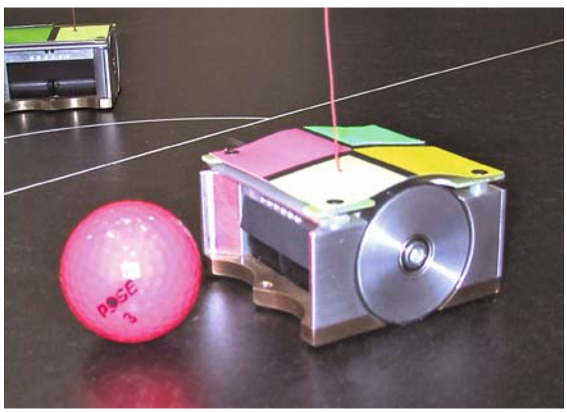

Fig. 74.16 MiroSot robot [74.31]

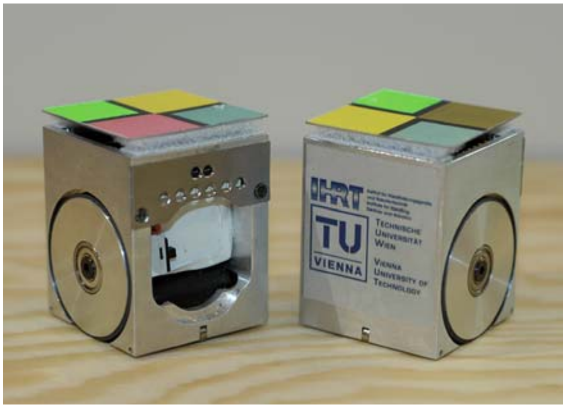

Fig. 74.17 NaroSot robot [74.31]

their robot when indicated by the referee, and remove the robot from the field at the conclusion of the match. They play with a yellow tennis ball on a playground 130 cm × 90 cm.

Humanoid Robot World Cup Soccer Tournament (HuroSotCup). In this competition, the humanoid robot has two legs (biped robot). The game is played using humanoid robots on a playground 340–430 cm × 250–350 cm. The maximum size of the robots is 150 cm, and the maximum weight is 30 kg. The robots have remote or auto control.

RoboSot. A match is played by two teams, each consisting of one to three robots with maximum size 20 cm × 20 cm × (no limit in height) on a playground 260 cm × 220 cm with a yellow with light green tennis ball. Only three human team members, a *manager*, a *coach*, and

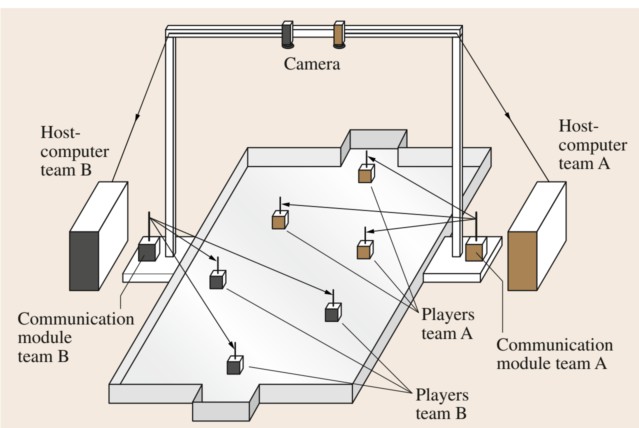

Fig. 74.18 Overall system of robot soccer

a *trainer*, are allowed on the stage. The robots can be fully or semiautonomous. In the semiautonomous case, a host computer can be used to process the vision information from the cameras onboard the robots.

Simulation Robot World Cup Soccer Tournament (SimuroSot). SimuroSot consists of a server, which has the soccer game environments (playground, robots, score board, etc.) and two client programs with the game strategies. A 3-D color graphic screen displays the match. Teams can make their own strategies and compete with each other without hardware. The 3-D simulation platform for 5 versus 5 and 11 versus 11 games are available at the FIRA web site [74.33].

MiroSot and NaroSot. The FIRA Mirosot and NaroSot systems work as follow: A camera approximately 2 m over the playground delivers 60 pictures/s to the host computer. With information from color patches on top of the robots, the vision software calculates the position and orientation of the robots and the ball. Using this, the host computer generates motion commands according to the implemented game strategy and sends motion commands wirelessly to the robots.

A soccer robot is an excellent example of mechatronics. Its main parts are wheels, drives, a power source, a microprocessor, and a communication module. All these parts have to be included in a very small volume: a cube 7.5 × 7.5 × 7.5 cm or a cuboid 4.0 × 4.0 × 5.0 cm. The soccer robots of a team (5–11 players) are controlled by the team computer.

The robot itself has a drive mechanism, power supply, electronic parts to control robot behavior, and communication. Mostly digital proportional–integral–differential (PID) controllers are used. The problem is the setting of the controller parameters. Therefore fuzzy control and neural networks are applied to adapt the parameters.

The main problems are the power sources of such robots. Usually batteries are approximately 50% of the weight of the robot and have a lifetime of only 2 h.

Worldwide there are already more than 150 teams competing in regional and world championships.

As pointed out earlier, a soccer robot is an excellent example of multidisciplinarity. For the construction and manufacturing of the body, knowledge of mechanical and, because of the small dimensions, precision engineering is required. Electrical as well as control engineering is necessary for the drives and the power source. The control and communication board of the robot is more or less applied electronics. A microprocessor serves as an internal controller and is also responsible for wireless communication with the host computer. For these tasks and for the software of the host computer fundamental knowledge in computer science is necessary. The software of the host computer includes online image processing, game strategies, control of the team's own players, communication with and between these, and the user interface.

Development of a robot soccer team therefore requires the teamwork of specialists from various disciplines, having different thinking and talking a different language. The project leader has to harmonize such a team and must have at least basic knowledge of all these necessary subjects.

One possibility to go into a broader market is to replace conventional games in amusement parks and restaurants. Therefore, as a first step in this direction, the software had to be adopted to use also a joystick to control each robot player. This offers the following possibilities for playing:

- Humans against humans (both teams controlled by joysticks)
- Humans against computer (only one team controlled by joysticks)
- Computer against computer (state of the art).

In contrast to soccer video games this new technology offers a *real-life* feeling similar to that in a soccer stadium.

A special application is robot dancing. Mirosot robots are programmed for dancing and are judged on criteria such as creativity and costumes. With a user-friendly programming interface a 2 min dance can be created in half a day without any pre knowledge. As an example Fig. 74.20 shows two Mirosot robots from the soccer team of *Vienna University of Technology* dressed in tuxedo and white robe ready for dancing the worldwide well-known Blue Danube Waltz.

Until now the robots are completely unintelligent; they have no sensors and are controlled by the host computer. In the future robots will be more and more intelligent and will be equipped with different sensors (ultrasonic, infrared, laser, etc.). This offers the possibility for robots to adapt the commands of the host computer.

Future developments will be towards humanoid soccer players. A humanoid soccer playing robot has to:

Fig. 74.19 Overall view of robot soccer

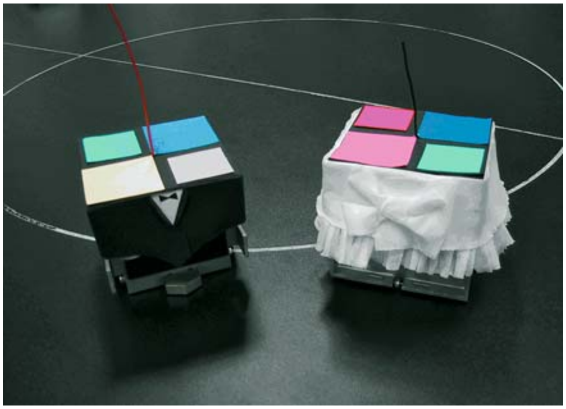

Fig. 74.20 Dancing couple for a Vienna waltz

- Be able to accelerate and slow down as fast as possible
- Keep its balance all the time, even after a crash with another robot
- Localize itself on the field
- Localize the ball
- Localize the opponents
- Make autonomous decisions regarding which actions to take.

As a first step some producers are offering robots with four or six legs at a high price. In some years players with two legs will probably be available – then we can start the first soccer games with humans against robots.

74.2 Market

Consumers showed an astonishingly quick appreciation of the new products in this field, especially of *Furby*, the first animatronic pet marketed on a larger scale, in February 1998. This pet's popularity is on the one hand due to the well-prepared marketing campaign that was organized for its introduction and on the other hand to market mechanisms outside the company's control that made these little creatures a must-have item in practically every child's room.

As this product proved to be nearly perfect for the manufacturer, combining low production costs with extremely high customer demands, many other companies copied the product or designed other robotic pets based on the successful concept in the subsequent years to participate in this expanding market as well.

By far the most famous of these *personal companion robots* is AIBO, which sold out over the Internet within minutes, regardless of the fairly high price. For the second generation, introduced in the market at the end of 2000, a large number will be sold.

It is safe to assume that this market will continue to expand, with newly developed and technically even more refined products entering the market. Thus other companies in this market will have to keep pace and develop further products themselves.

Even in related fields such as robot soccer, robots are likely to find their way to the toy market as soon as these systems can be produced in larger quantities and at a lower price than today.

74.3 Summary and Forecast

Mobile, intelligent robots are now available on the market. The number of these robots in use will dramatically increase in the next year. One of the main application areas will be the field of *entertainment, leisure, and hobby* and robot competitions.

Well-known scientists engaged in robotic research, and who dare to make forecasts not only for the immediate future of service robotics but for the more distant future, also believe that the evolution of service robots will basically happen in several stages, being closely linked to progress in computer technology.

The semiconductor market has seen a series of market-driving waves, from the analog wave to the first digital wave, in which the PC was central, to the second digital wave, in which the digital consumer and network were central. After these waves, scientists expect a robotics wave to occur. So the personal robot market will become more important than the PC market. An estimation of one scientist is that a humanoid robot-soccer team will win against the world champions by 2050.

We are talking about entertainment robots in general, beyond QRIO. It would be desirable to develop is a robot companion for human beings. For instance, a robot can hold things in its memory indefinitely. The hardware might break down over the course of many years, but by taking the memory stick and putting it into a new robot, you could transfer those memories to it. In so doing, one can share with it a short time's worth of memories and knowledge and visions. In some ways, a robot could be the ultimate companion. Yet another idea would be a robot that listens to you. The basis for this is the active listening method of counseling, wherein the counselor gives no information but simply listens. A robot can do that too. A robot can listen to complaints, share information, and be a counselor anytime, day or night.

Therefore we will probably see the following generations:

First Companion Robot Generation – 2010

Mobile, human-sized universal service robots, being as intelligent as a lizard, will be able to perform everyday routine work such as cleaning floors, remove garbage or dust furniture. The required computing power for such a robot would be approximately 5 Mips (5 million instructions per second).

Second Companion Robot Generation – 2020

The subsequent robot generation, also designed to assist humans in their everyday activities, performs janitorial services, or simply entertains them, features an advanced processor capable of computing about 100 000 Mips, thus boosting the intelligence level of the system to that of a mouse. These robots can already be trained using praise and censure.

Third Companion Robot Generation – 2030

With computing power advancing further to 5×10^6 Mips, the robotic system reaches the intellect of a monkey.

Forth Companion Robot Generation – 2040

Within 40 years from now, the forth generation of service robots should be capable of abstracting and generalizing problems like a human, thus performing not only routine tasks, but tasks that require preparation and planning as well. Therefore the existence of companies that do not employ a single human worker any more, besides their autonomous robots, might be well conceivable. We are looking forward to what will be realized.

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