Humanoid Robots

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OVERVIEW: Human-oriented research on robotics is an active field. Researchers in the past tried to build robots that would mimic human beings and perform complicated tasks. Recently, they have shifted their main interest to human-symbiotic robotics in which human beings receive services from robots or are co-workers with robots in performing collaborative tasks. Hitachi began research on robotics at a very early stage and has been involved in many challenging projects since then. Its prototype intelligent robot in the 1970s and its Advanced Quadruped Robot in the 1980s are examples of Hitachi's commitment to this field and the lessons learned from these projects are reflected in our latest EMIEW humanoid robots that act as evolving hubs between the human, machine, and information worlds.

INTRODUCTION

INTERACTION with the real world is of great importance for the advance of human intelligence. Now that the Net has spread worldwide and IT (information technology) is available everywhere, a new kind of social intelligence is about to be born. We need to overhaul the technologies that will be used to connect this new intelligence to the real world. In particular robotics technologies that integrate senses, motor responses, and intelligence will be of great importance.

There have been many advances in the devices used to construct robots in recent years. The advances have expanded the fields in which robots can act. They have also presented robotics researchers with new research challenges.

In the early history of robotics, robots were confined to specific places such as factories where they were used for repetitive and tedious tasks. Precision and speed of control were important for

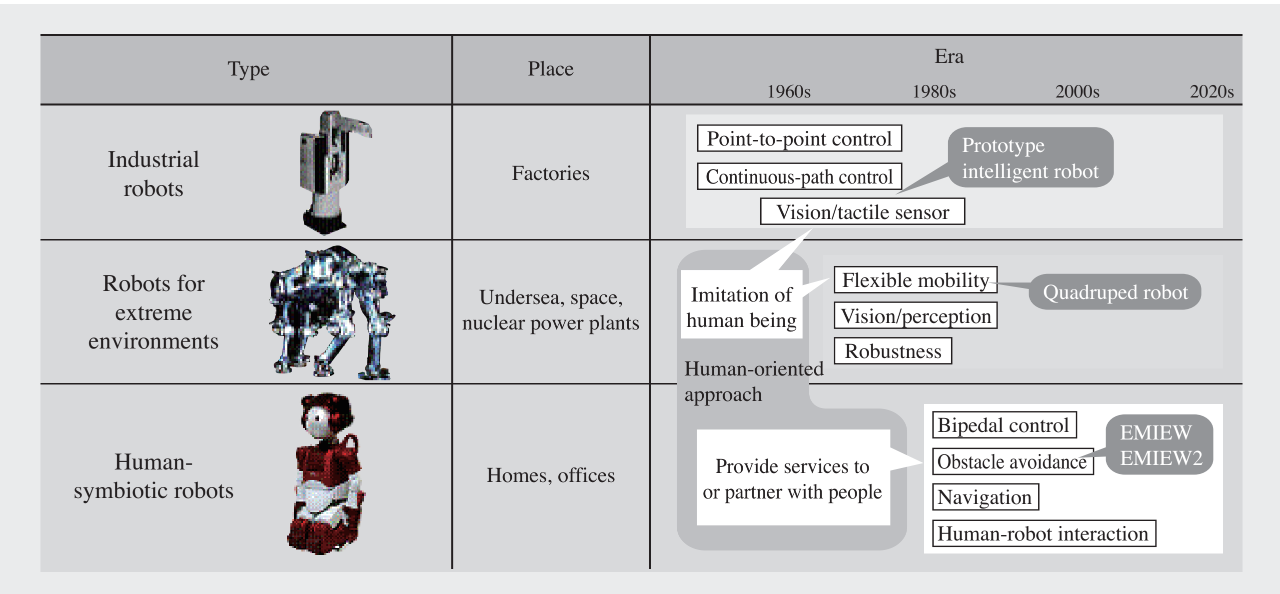

Fig. 1—Human-oriented Approach to Research on Humanoid Robots.
The places where robots can be used is expanding from factories and some extreme environments into human-symbiotic environments such as homes and offices. Hitachi research in this field is based on a human-oriented approach to robotics.

such tasks. Typical research topics in those days related to servo control and trajectory planning.

As the range of applications for robots expanded to include space, undersea, and other extreme environments such as in nuclear power plants, adaptability became an important issue. In particular, mobility mechanisms that can adapt to different terrain, sensing techniques that can capture changes in the environment, and robust control techniques were developed.

One of the most important challenges for the 21st century is human-robot symbiosis. Human-robot interaction and autonomous navigation are now very active research topics. Robot safety and reliability are also important concerns if robots are to enter practical use.

Hitachi has been researching robotics since the 1970s (see Fig. 1). In this article, we review some of Hitachi's contributions to human-oriented robotics including a prototype intelligent robot from the 1970s, the Advanced Quadruped Robot of the 1980s, and the current EMIEW.

PROTOTYPE INTELLIGENT ROBOT

Since the first industrial robots appeared in the 1960s and were put into practical use in the 1970s, many robots have been used in controlled environments like factories. Currently, 370,000 robots are in operation in Japan. Hitachi has developed commercial robots for welding, painting, and assembly. For these robots, the most important consideration was the precision of the motions that they performed. Thus, the technical challenges were related to servo control and trajectory control.

However, applications were limited because the robots were only able to perform simple repetitive tasks. When a human worker assembles a machine, they first verify the locations and orientations of the parts and then put them together in the correct way to complete the assembly. The early industrial robots did not have the ability to recognize parts or to plan the sequence of motions they would need to perform the assembly. Hitachi recognized these limitations and developed a prototype intelligent robot in 1970 called the "HIVIP Mk.1"[1] (see Fig. 2). The robot featured the following three capabilities:

(1) Ability to understand the given task from line drawings

(2) Recognition of the orientation of parts by computer vision

(3) Automatic planning of the sequence of motions required for the given task

These features meant the robot was capable of automatic assembly work that was impossible for previous conventional robots. It was a significant achievement and drove the subsequent boom in industrial robotics. Following on from this successful development, Hitachi went on to develop a series of other robotic systems in the 1970s, including an automatic bolt tightening robot and a fully automatic transistor assembly system.

Fig. 2—HIVIP Mk.1 Prototype Intelligent Robot.
Hitachi developed the first integrated intelligent robot in 1970. The robot captures video images of engineering drawings, understands the purpose of the tasks given to it, recognizes objects (building blocks) on the table, plans the sequence of motions to execute the task, and then automatically assembles the objects as shown in the drawings.

ADVANCED QUADRUPED ROBOT

Use of robots in harsh environments such as under water, inside nuclear power plants, or in space gained momentum from the 1970s to the 1980s with topics such as methods for navigating the environment and recognition techniques for understanding the physical world being key issues. During this time, Hitachi developed an undersea survey robot system in 1973 and a sensory-guided mobile crawler robot in 1983. Hitachi also participated in a large-scale project called the "Advanced Robot for Hazardous Environments" run by the Ministry of International Trade and Industry (now the Ministry of Economy, Trade and Industry) from 1983 to 1990 during which it developed the Advanced Quadruped Robot for hazardous environments (see Fig. 3).

The development of a quadrupedal walking mechanism was based on the results of previous research into the WHL-11 bipedal robot carried out in collaboration with Waseda University. The

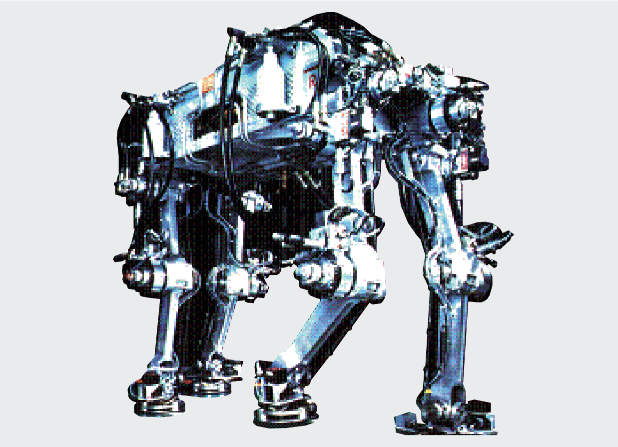

Fig. 3—Advanced Quadruped Robot.
The Advanced Robot Project was sponsored by Ministry of Economy, Trade and Industry (1983-1990). Hitachi developed this prototype mobile robot as part of this project.

objective for the Advanced Quadruped Robot was "flexible walking" that would allow the robot to move rapidly through environments full of steps, piping and other obstacles such as might be found inside a nuclear power plant. The problems to be overcome to achieve this included how to ensure the feet contacted the ground smoothly, reducing drive torque peaks, and minimizing energy consumption. Unfortunately, these problems could not be solved simply by extending the bipedal walking technique to the quadruped robot. However, this flexible walking ability is exhibited by horses and other four-legged animals. Accordingly, the researchers undertook a comprehensive analysis of gait in the form of the walking styles of animals such as horses, elephants, hippopotamuses, and rhinoceros.

The different gaits of a horse include the walk, trot, canter, gallop, pace, and jump. Of these, this research focused on the trot. This is the gait in which diagonally opposed legs move together so that the right-front and left-back legs move as a pair, as do the left-front and right-back. This analysis determined that the horse achieved a smooth gait by moving its toe with the trajectory of a trochoid curve (see Fig. 4). It was also found that apparently slow-moving animals such as elephants and hippopotamuses also have a walking motion based on a trot. An improved trotting gait for quadrupedal robots was developed incorporating these discoveries and succeeded in producing a dynamic walking motion with a maximum speed of 2.5 km/h.

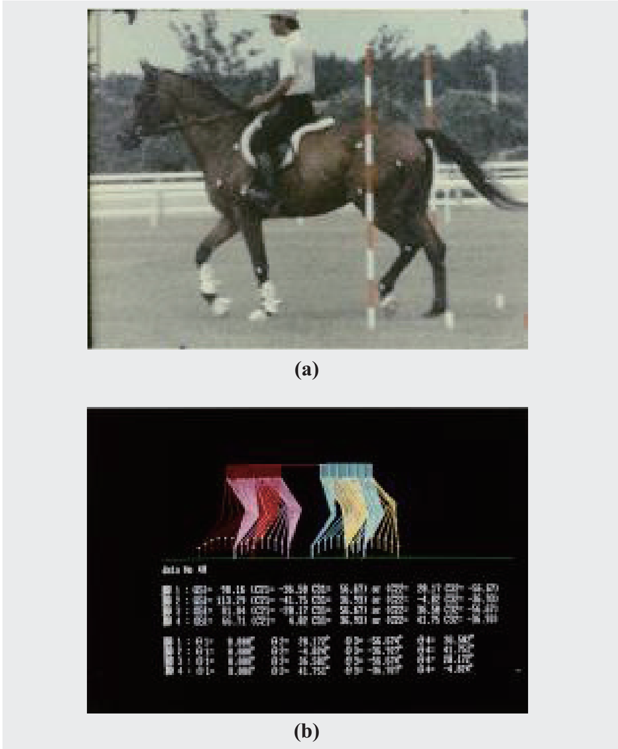

Fig. 4—Observation of Horse Gait.
A trotting horse with markers (white dots) is shown in (a).
A stick diagram of the gait reconstructed by computers from the measured position of the markers is shown in (b). The trajectories of the toes can be approximated as trochoid curves.

HUMAN-SYMBIOTIC ROBOTS: EMIEW AND EMIEW2

Human-symbiotic Robots

Since 2000, there have been many challenges in developing robots that can safely share space with ordinary people and provide them with services. The main focus has been on human robot interaction and autonomous mobility. Some issues such as safety, cost, and reliability remain a problem. Furthermore, certain human factors have proven to be problems. Examples include robots that don't give a favorable impression or make people feel uncomfortable.

Hitachi participated in the "Project for the Practical Application of Next-Generation Robots—Prototype Development Support" program (2004 to 2005) sponsored by the New Energy and Industrial Technology Development Organization (NEDO) during which it developed the prototype EMIEW human-symbiotic robot(2). Based on the knowledge gained in the development of the EMIEW, Hitachi went on to announce a successor called the EMIEW2 in 2007 with the aim of further improving safety and ease of use(3).

EMIEW

Fig. 5 shows the structure of the EMIEW. For mobility, the robot uses an inverted mechanism for balancing on two wheels that incorporates a body rocking mechanism to maintain stability when turning. The body of the robot incorporates laser radar to detect obstacles in the vicinity, a remote voice recognition micro-array used as an interactive interface, a high-quality speech synthesis system, and CCD (charge coupled device) cameras. A two-arm manipulator with six degrees of freedom combined with the freedom of rocking motion of the body and head gives the motion of the robot a rich range of expressions. The robot weighs 70 kg and has a height of 1.3 m to allow it to perform similar tasks to people.

The inverted mechanism for balancing on two wheels adopted for the robot incorporates a function for maintaining balance that lets the two wheels corner smoothly and handle sudden acceleration or deceleration. This gives the robot good maneuverability while keeping its cross-sectional area small. The slim body is an important factor because it helps prevent the robot from getting in people's way when it is used alongside people. This structure gives the robot a top speed of 6 km/h, equivalent to a fast walking pace, a maximum acceleration and deceleration of 4 m/s^2, and a minimum turning circle at top speed of 0.5 m.

Hitachi also developed dynamic obstacle avoidance technology to maintain safety when the robot is moving about. The robot uses the laser radar located in its central torso to detect any person walking within a radius of 5 m then uses this information along with the robot's own velocity vector to determine the region of high future collision risk and to plot a path that will avoid any collision. This processing is repeated every 50 ms. Testing has demonstrated the ability of the robot to make its way, without stopping, and at a speed of 4.3 km/h, around up to five pedestrians who are walking at speeds of approximately 4 km/h.

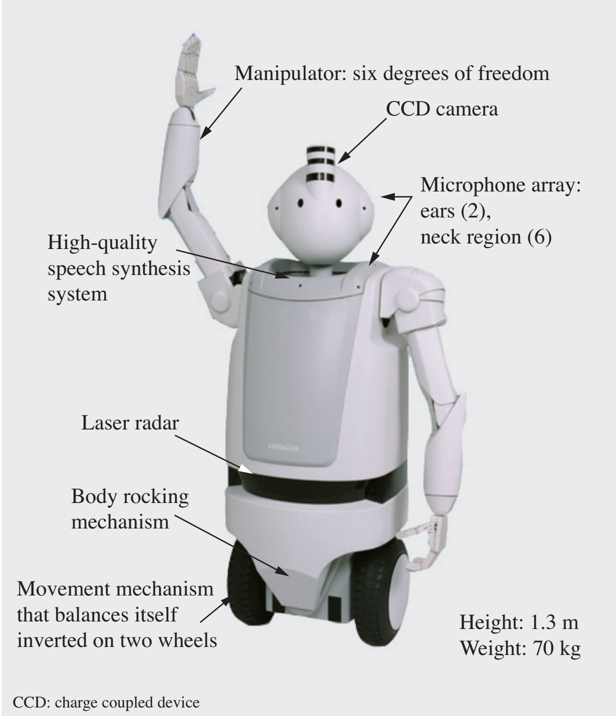

Fig. 5—Structure of EMIEW.
Features include a movement mechanism that balances itself inverted on two wheels and allows agile motion, a remote speech recognition system, and arms that can express body language.

EMIEW2

The lessons learned from the first-generation EMIEW gave us confidence in the efficacy of human-symbiotic robots that are fast and safe and can interact effectively with humans. We also obtained good results in enabling human-like motion in humanoid robots. Our latest EMIEW2 is a service robot prototype intended for practical use. EMIEW2 was revealed to the public in September 2007.

In addition to making the robot unit smaller and lighter, this development also aimed to improve the robot's stability by allowing it to switch between different modes of travel. The targets set as part of the design strategy were a weight of no more than 15 kg and a maximum speed of 4 km/h or more to ensure agility. The end result was a robot that weighed 13 kg and could travel at up to 6 km/h.

Fig. 6 shows the mechanisms used in the EMIEW2. A height of 0.8 m was chosen so that the robot could use its head-mounted CCD cameras to view the tops of office desks at a height of 0.75 m. Measures adopted to reduce weight included shrinking various dimensions, slimming down the structural chassis, and adopting servo motors with integrated drivers.

Leg-mounted wheel mechanisms are used to move the robot about, with the drive wheels being located at the ends of leg mechanisms that have five degrees of freedom. For high-speed movement, the robot balances itself inverted on the two drive wheels with the legs extended. In situations where more stability is required such as when idle or transporting an object, the robot adopts a kneeling posture and runs on four wheels consisting of the two drive wheels and two spherical casters located in the robot's knees. It is envisaged that if a power cable, step or other obstacle is present on the floor, the robot will place its claw mechanism on the floor to form a ground-contact surface with the drive wheels and use a bipedal walking motion to step over.

For the navigation control function, the robot uses an infrastructure-free autonomous mobility technology developed by Hitachi's Advanced Research Laboratory. The robot fixes its position by comparing spatial information about the surroundings obtained by the laser radar fitted in the robot's neck with a stored map that was generated separately. This function allows the robot to move safely even in cramped spaces such as rows of desks. The robot also reuses the dynamic obstacle avoidance control function from the EMIEW.

A 14-channel microphone array is mounted in the robot's head and is used for remote speech recognition in the same way as the EMIEW. The manipulators are also equipped with largely the same motion expression functions as on the EMIEW and this has been combined with the highly coordinated exterior design produced by Hitachi's Design Division to provide a powerful tool for non-verbal communication.

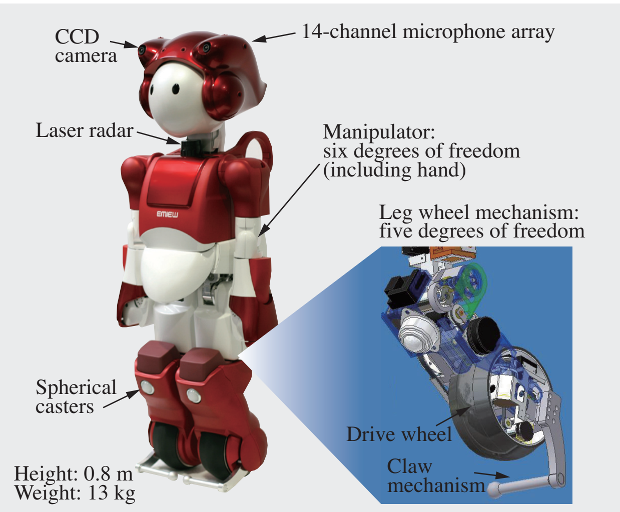

Fig. 6—Structure of EMIEW2.
Further development of the two-wheel inverted balance movement function used on the EMIEW produced a new mechanism for the EMIEW2 that integrates the drive wheels into leg mechanisms that have five degrees of freedom. The new mechanism reduces the risk of the robot falling over and allows it to step over steps and similar.

CONCLUSIONS

This article has described important contributions made by Hitachi to human-oriented robotics research.

Robotics is a technology that connects human beings, machines, and information. To keep pace with the rapid advance in information and communication technologies, we need to overhaul our robotics technologies. Moreover, the "aging of Japan" is driving demand for the use of robots to provide services for elderly and handicapped people. There remain many challenges such as lowering costs and increasing functionality and reliability before we can put these service robots into practical use. We will continue our research to overcome these challenges.

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