Chapter 8

Robot Development Case Examples — The Intelligential and Functional Approaches

In this chapter, I will survey the current situation of robots and then introduce concrete case studies of robot development from a functional perspective and an intelligential one as well. While there is no need to emphasize the importance of industrial robots, which are exemplary of the type of robot technology that pursues functional excellence, it should be noted that the market for robots such as AIBO that appeal to human emotions is expected to grow large as well in the future. In the final part of this chapter, I will discuss the development of Honda's ASIMO and contemplate how a globally leading-edge robot came to be created.

8.1 The Current Situation of Robots

8.1.1 *What is a robot?*

Upon hearing the word "robot", we Japanese are apt to be reminded of robot characters that appear in comics and animation films of the Astro Boy variety. The robots appearing in comics and animations can be like Astro Boy on the one hand and have superior abilities that let them do things humans can only dream of doing, or they can be like Doraemon on the other hand and have abilities that are equal to or even less than those of humans. However, what they all share in common, I believe, is that they are all humankind's best friend and partner. Compared with Westerners, it is generally said that the Japanese have a more tolerant view regarding the impact of robot technology on society and one reason for this can be attributed to the fact that Japan has been having a love affair with the robots of the comic and animation lore. Perhaps it is due to this reason that Japanese robot technology is considered to be top-class in the world.

However, it is clear that robots being currently developed are not reaching the technologically advanced levels of a robot like Astro Boy. Astro Boy can walk and run through various environments using his two feet and can even fly across the sky. In addition, he is conscious like humans and seems to feel all the emotions such as joy, anger, sadness and humor. With the current state of our technology, we certainly are not able to create sentient robots and we can only have them walk in restricted surroundings.

However, it is rash to become pessimistic about robot technology for just these reasons. If we look at the manufacturing industry, we can see that industrial robots are continuing to work days and nights at factories around the world to engage in such tasks as assembling cars. The manufacturing industry will not stay viable without these industrial robots today.

In this way, robots can be seen to be very diverse and therefore it is difficult to clearly define the word "robot" to begin with. In the "Terminology for Industrial-Use Robots" contained in the Japanese Industrial Standard JIS B 0l34, there are entries for the word with modifiers such as "industrial robot" and "intelligent robot," but there is no entry for the word "robot" itself.[1]

One reason why it is difficult to define this word is the fact that the word is not really a technical term, but instead is a term that has anthropomorphic connotations. For example, we do not call the crane used in an arcade game called UFO Catcher (a claw vending machine) a robot. However, a machine that automatically grasps parts in a factory is called an "industrial" robot. Why is it that we do not refer to the crane in the game as a robot?

Incidentally, the word "robot" was coined by the Czech writer Karel Capek and was used for the first time in his stage play titled *R.U.R.* The word "robot" is said to come from the Czech word *robota*, which means labor or drudgery. Judging from this derivation, it seems appropriate to define a robot as a machine that frees humans from labor and drudgery. However, nobody calls an automobile — a machine that helps people with the labor of transportation — a robot. (However, the movement to take advantage of the fruits of robot research for automobile development has become conspicuous in recent years.[2])

8.1.2 *The history of the robot*

The premiere of Karel Capek's play, *R.U.R.*, took place in 1920, but the first industrial robot, which was called the playback robot, was created in 1960. This means that it had taken 40 years from the time the word robot was coined to the time an actual robot was put into practical use, and also that only 50 years has passed since an industrial robot had been put to practical use (see Figure 8-1).

In addition, it was in 1942 that Isaac Asimov had described the famous Three Laws of Robotics in the short story titled *Runaround*, which means that these laws actually precedes the practical use of industrial robots by nearly 20 years.

This playback robot was introduced into Japan in 1967, after which industrial robots began to spread remarkably throughout the nation. The output of domestic robot production overtook the output of American and European robot production in the 1970s, and by the latter half of the 1980s, more than half of robot installations around the world were made in Japan.

Year	Event
1920	Karel Capek's stage drama, *R.U.R. (Rossum's Universal Robots)*
1942	Isaac Asimov's Three Laws of Robotics
1960	The first industrial robot (the Playback Robot)
1967	The industrial robot is introduced into Japan
1967–	Development of the WABOT at Waseda University
1972	Successful mass installations in an automotive factory (GM in the US)
1980–1990	Project for developing "Robotics for Extremely Dangerous Work Environments" initiated by the former Ministry of International Trade and Industry
1982	Establishment of the Robotics Society of Japan
1991–2000	"The Micro-Machine Project" initiated by the former Ministry of International Trade and Industry
1996	Honda's ASIMO
1998–2002	"The Humanoid Robotics Project" initiated by the Ministry of Economy, Trade and Industry
1999	Sony's AIBO
1999–2000	The Ministry of Economy, Trade and Industry initiates the project for the "development of robotics that supports the Prevention of Nuclear Energy-Related Disasters"
2002–2004	The project for "forming the foundation of robotic development through software preparations" is initiated

Figure 8-1: Robot-Related Milestones
Source: Ministry of Economy, Trade and Industry's Society for the Study of Robotic Policies, *The Society for the Study of Robotic Policies' Report*, May 2006.

The backdrop to this achievement was the large amounts of investment put into research and development for robot-related national projects and the active R&D carried out through an industry-university collaboration, which was made possible through the investment. The representative robot-related national projects of Japan that have been completed as of 2007 are "Robotics for Extremely Dangerous Work Environments," which began in 1980, "Robot Systems for Collaborating and Coexisting with Humans," which began in 1998, "Robot Development for Supporting the Prevention of Nuclear Energy-Related Disasters," which began in 1999, "Software Preparation for Forming the Foundation of Robot Development," which began in 2002, "The Initiative for Reinforcing

Development of Robotics for Extremely Dangerous Work Environments	1983-1990	Development of robots to be used in hazardous environments in the nuclear energy, oceanology, and disaster prevention fields.
Micro-Machine Project	1991-2000	R&D for micro-machine systems that bring about the miniaturization of production equipment and also carry out inspections, repairs, and diagnosis in narrow places such as inside pipes of power plant facilities and inside the human body.
The Humanoid Robot Project	1998-2002	R&D for robots that can be manipulated through remote control via the use of communication networks to assist human beings where they work and live by carrying out complex tasks and moving through divergent terrains.
Robotics Development for Supporting the Prevention of Nuclear Energy-Related Disasters	1999-2000	Development of robots that are resistant to high levels of radiation, robots that support work supervision, miniature robots for light work, work robots for opening and closing valves, and robots for heavy-weight transportation.
Software Preparations for Forming the Foundation of Robotic Development	2002-2004	The development of middleware that make the construction of diverse robots possible by combining various robotic elements through communication networks. This development aimed to realize the limited production of diversified products.
The Initiative for Reinforcing the Foundation of Strategic Technologies (including the field of Robot Components)	2003-2005	Support for the development of robotic components carried out by small and medium sized companies. This project aimed to help improve the technological development of such companies.
The Next-Generation Robotic Applications Project	2004-2005	Development, experimentation, and demonstration of the prototypes of robots expected to carry out tasks such as cleaning and policing in the near future. The project was featured at the World Exposition in Aichi.
The Human-Assistive Robot Applications Project	2005-2007	Development of nursing robots that support patients and caregivers. From the start, this project was carried out through partnerships between users (facilities, hospitals, etc.) and robot makers.
Common Foundation Development Project	2005-2007	R&D for the modularization of robots that took into account the fruits of the RT Middleware Development Project (The project for making software preparations for forming the foundation of robotic development).

Figure 8-2: Robot-Related Large-Scale Projects

Source: Ministry of Economy, Trade and Industry's Society for the Study of Robotic Policies, *The Society for the Study of Robotic Policies' Report*, May 2006.

the Foundation of Strategic Technologies (including the Robot Parts field)," which began in 2003, and "The Next-Generation Robotic Applications Project," which began in 2004. In addition, projects that are ongoing as of 2007 are "Human-Assistive Robot Applications Project," which began in 2005, and the "Common Foundation Development Project," which also began in 2005 (see Figure 8-2).

8.1.3 *Robot development in Japan and future challenges that should be heeded*

When regarding the robot from a market-oriented perspective, it can be seen that industrial robots account for a large portion of the robot market in Japan.

According to the statistics provided by the Japan Robot Association, the shipment of industrial robots in 2005 amounted to 689 billion yen. Most of these industrial robots are in operation at factories of manufacturing industries. While nearly 40 years have passed since industrial robots were introduced into Japan, its market is in no way an old one that has become saturated. As long as unprecedented new products continue to be developed in the manufacturing industry, the development of new robots will be carried out for the production of those products. With the rapid spread of thin-screen TVs in recent years, the market for clean-room robots, which are used in the transportation of glass substrates for liquid crystal televisions, has seen sudden expansion.[3] Along with industrial progress, new needs for robots promise to arise from now on as well.

Meanwhile, the market size for robots other than those for industrial use is believed to be of a scale that approximately exceeds 7 billion yen as of 2005. A robot that is currently drawing attention as a non-industrial type of robot is the so-called "partner robot." Specifically, the partner robot is a next-generation robot that assists people in making their lives more pleasant by assuming tasks for the purpose of realizing entertainment and security for the general household, and supporting daily living in general. I will present more details on partner robots at a later point, but for now I would like to point out that according to the "Report on the Round Table Conference on the Vision for Next-Generation Robots"[4] released by the Ministry of Economy, Trade and Industry in April 2004, the market size for next generation robots is projected to be worth about 7.2 trillion yen in 2025. Considering that the current robot market size is around

700 billion yen, this would mean that a considerably large increase is anticipated to occur in the next 20 years.

In addition, in the same report, "the three issues that next-generation robots could help resolve" were stated to be as follows; low-birth rates and the aging of society (retention of the labor force), security (security countermeasures to protect against disasters), and convenience and leisure (creation of free time). When a researcher involved in robot development searches for a possible direction a research program could take, they will necessarily run into relevant scholarly papers. However, referring to reports that are published by public offices such as the one mentioned above will also prove resourceful.

In the 2006 report issued by the Ministry of Economy, Trade and Industry's Society for the Study of Robotic Policies,[3] you can find points that reflect on robot-related projects that had been carried out to date. Specifically, the report states that it was regrettable that conventional robot-related projects to date had been focused on R&D without linking themselves to market needs in any meaningful way. It goes on to further state that a balance must be struck between market preparation and technological development. Interestingly, the same report also points out that industrial robots had formerly had the same problems as the ones faced by the current service-oriented robots. These problems are as follows:

1) As is often the case with seed-type products, development geared toward the realization of an application was necessary.
2) Application-specific development of features and performance enhancements were necessary.
3) A great deal of time and effort was required for reducing the time between failures and for enhancing durability.

The industrial robot projects have overcome these problems to evolve into an extremely large market, and the lessons that can be learned from their successes are certainly to be indispensable for the development of next-generation robots. Naturally, it goes without saying that the lessons to be learned from successful precedents are vital for not only robots, but for all other products as well.

8.1.4 *Technology and Japan's competitive advantage required for the development of robots*

If you regard the robot as a "computer capable of motion," the technical expertise necessary for its development will need to cover the subjects of mechanical engineering and computer science. In *The Society for the Study of Robotic Policies Report*,[3] drive-related technology, sensor technology, battery technology, materials technology, communications technology, and software technology are mentioned as elemental technologies that are necessary for developing robots (see Figure 8-3). It can be said that we have to combine these wide-ranging technologies to develop robots.

Strategies for the Creation of New Industries,[5] which was released by the Ministry of Economy, Trade and Industry in 2004, states that the existence of this country's advanced components industrial clusters is a large advantage for realizing the progress of the robotics industry.

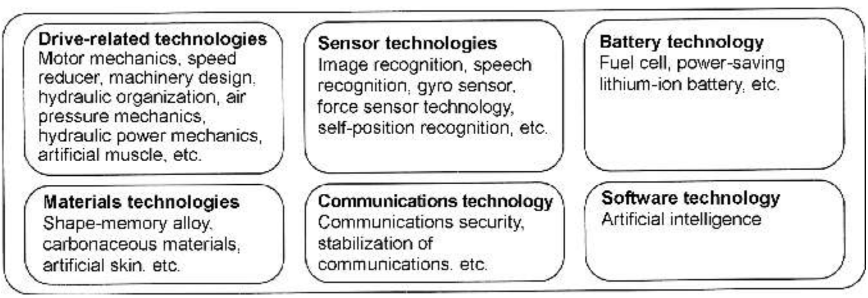

Figure 8-3: Elemental Technologies Necessary for the Development of Robots
Source: Ministry of Economy, Trade and Industry's Society for the Study of Robotic Policies, *The Society for the Study of Robotic Policies Report*, May 2006.

In the same report, it is also stated that the reason why the liquid-crystal display industry can be found to be concentrated in Japan, Korea, and Taiwan is because the industry is strongly dependent on Japan's manufacturing industry, such as the materials industry, which excels in synthesizing special materials, and the functional components industry, which excels in precision microprocessing. Similarly, Japan is expected to play a pivotal role in the robotics industry with its superior manufacturing technology.

8.2 Robots That Pursue Function

As mentioned previously, historically speaking, the industrial robot is the original robot (see Figure 8-4). In the 1960s, robot operations became popular in automotive assembly processes and largely contributed to improving productivity. Even as of today, industrial robots still account for a principal part of all robots and were developed and improved by robot makers such as Kawasaki Unimate, Yaskawa Electric Corporation, and FANUC. However, their origin lies in Joseph F. Engelberger's Unimation.

Engelberger created a robot called the Unimate by essentially using a method known as "playback." The playback method established the teaching process, which instructed the manipulator to

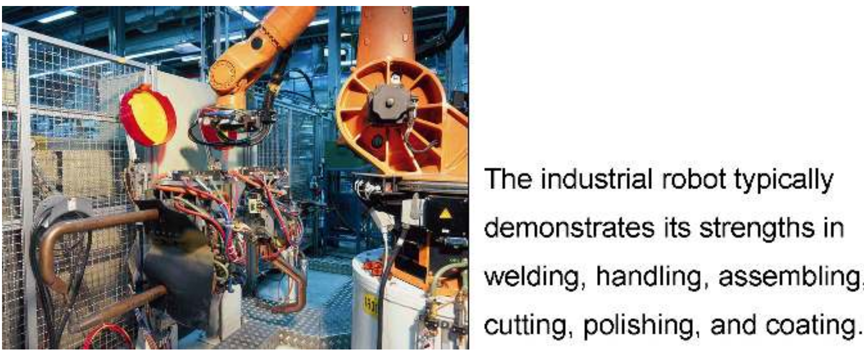

Figure 8-4: Industrial Robot

assume the position and posture it should take beforehand and then make it reproduce them (playback) subsequently. To make a manipulator assume various postures, it was necessary to specify the three-dimensional positions and posture angles of the fingers and find out what angle each joint of the manipulator should take to assume the specified positions and postures. In other words, it was necessary to resolve the issue of inverse kinematics in real time. While this is not difficult to accomplish at present, at the time, they were not able to formularize and had no procedures to solve the problem. So, at a time when computers were not developed, the playback process, in effect, had made it possible to carry out minimum calculations and thereby make practical application a reality.

In the case of Japan, success was assured by not only realizing technological progress for the robot alone, but by attaching much importance to the environmental arrangement of use and thereby technically improving the usability of robots. One consequence of this policy was the fact that hydraulic robots became electric robots.

In the following section, I will introduce robots that are intended for demonstrating superhuman functions within certain specialized environments.

8.2.1 *Significance of maintaining the external environment*

Figure 8-5 shows the roles of industrial robots in society.

All of them are robots that specialize in restricted environments. While robots are used in various sectors, general-purpose robots that can be adopted for two fields, such as agriculture and construction, are currently rare.

For example, if we examine disaster-relief robots (see Figure 8-6), we can see that its form is designed to allow infiltration into small and narrow spaces. It moves not with wheels, but with a caterpillar track, making it possible to move over unstable grounds as well. It is also equipped with a camera to detect people and a communication

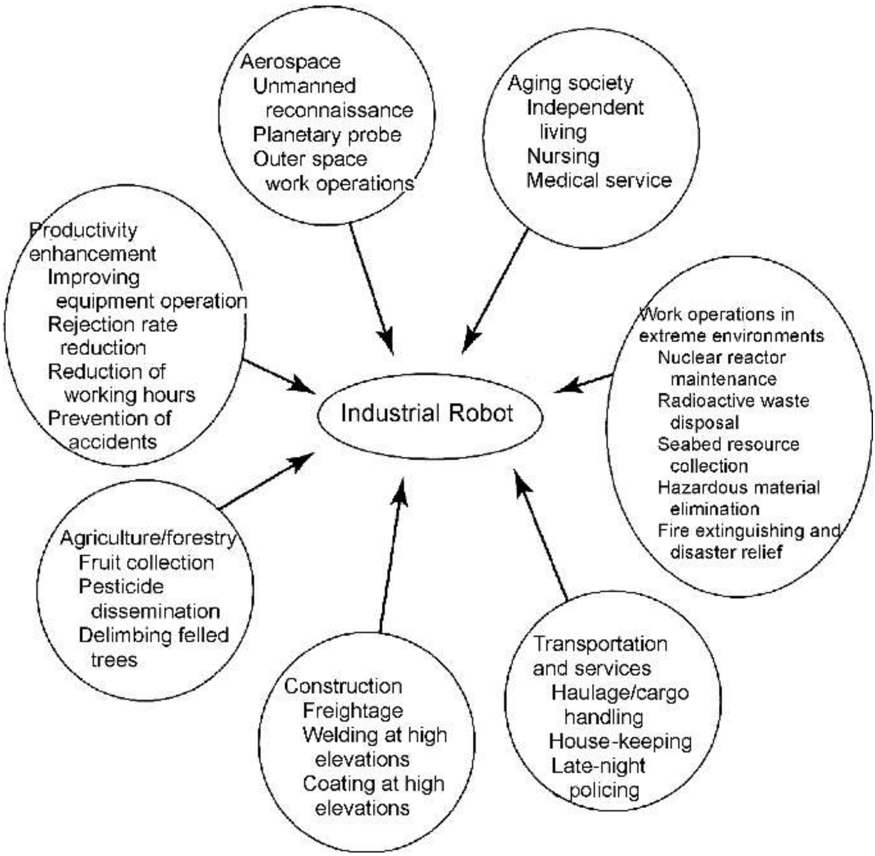

Figure 8-5: The Roles of the Industrial Robot in Society

facility to instantly report on the results of its detection. You can clearly see that these functions are geared towards fulfilling the purpose of disaster relief. By defining the intended tasks, robots that have appeared in recent years have started to become capable of carrying out those difficult tasks that are beyond the capability of humans to carry out.

Then what is the difference between the current robot and the playback robot, which was the first robot to be created? From a technical standpoint, it can be seen that the playback robot had extremely limited functions. For example, the playback robot made use of only

Figure 8-6: Disaster-Relief Robot

internal information. Internal information refers to information such as the robot's position, posture, speed, and acceleration. In other words the playback robot did not possess sensors that could let it obtain information on its surrounding environment and physical objects found in it. For this reason, even when there actually were no physical objects to be found, it carried out its tasks under the assumption that physical objects existed. Therefore, to use a playback robot, the external environment needs to be properly designed as well. The structure of an environment and the robot's sensor configuration need to be predetermined in accordance with the applicable external environment. To this day, the playback robot continues to be a major force in the manufacturing process and developing robots with designs that take the environment into consideration remains important today as well.

8.2.2 *Second-generation robots that recognize environments*

Figure 8-7 shows the process of developing robots. While the playback robot only had internal sensors, the production line around 1980 began to see the appearance of robots equipped with power and visual sensors. In other words, they were second-generation robots,

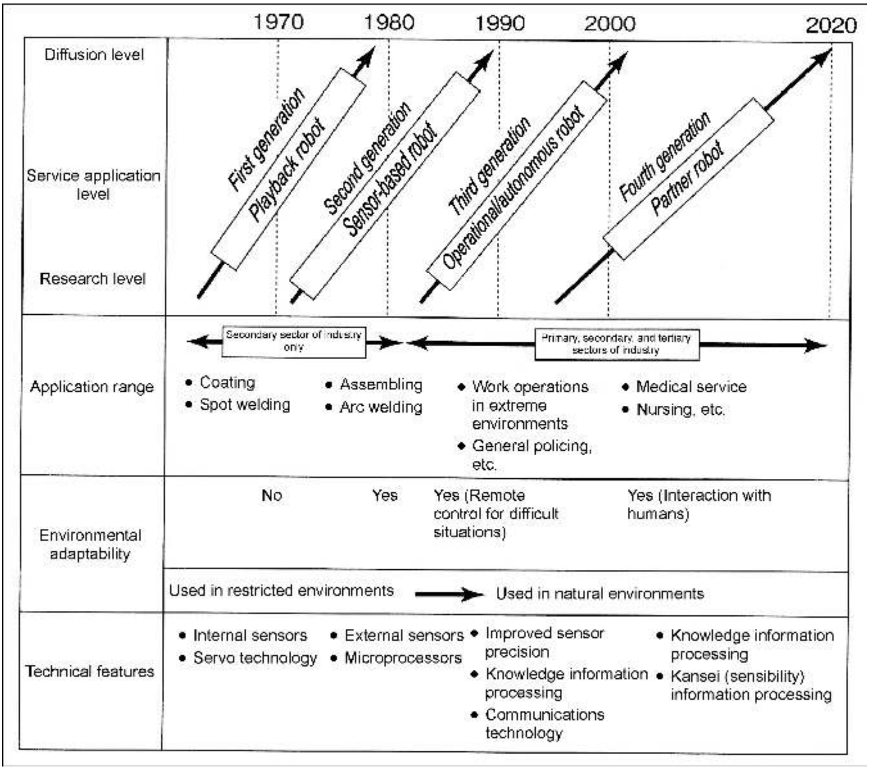

Figure 8-7: The Progress of Robot Development

which were robots that could judge their surrounding environment and determine how best to move the body. In effect, they made use of knowledge databases, and they could be given instructions that used a robot language, and dynamic position control was made possible with these models as well. Dynamic position control takes robot dynamics into consideration and realizes the control of the arm. For example, in the case of spot welding, it would be appropriate to specify the place precisely beforehand, but in the case of arc welding, since physical objects could slip out of position or become deformed by heat, if the robot only carried out movements that had been specified beforehand, then it will fail in its task. When a second-generation robot carries out arc welding, it can detect weld lines and make fine adjustments accordingly. In effect, it is able to adapt to its circumstances, or in other words, it can recognize its surrounding environment and then adaptively make decisions and carry out operations.

What have made such things possible are the component technology of sensors for environmental recognition, recognition technology for extracting only necessary information from what are provided by the sensors, control technology for decision making and carrying out operations based on recognition results, and advances in computer processors for realizing movement in real time.

The QR codes that have been appearing on such items as cellular phones in recent years (see Figure 8-8) are two-dimensional bar codes, so to speak. A QR code is embedded with a URL and is intended to be read by a camera configured in a cellular phone, whereupon it becomes possible for a user to access the intended website. It was conceived by the company Denso Wave in 1994 and was originally used for managing the products in a production line.

Within the four corners of the QR Code, there are marks located in three places. Such marks are necessary due to the

The QR code has come into widespread, everyday use in recent years. It conveys encoded information to devices, which read the information by detecting marks located in its corners.

Figure 8-8: QR Code

limitations of current recognition technology. For example, humans can understand that a whole apple and a partially eaten apple are both apples, but such a grasp is not easy for the robot. However, if the robot is presented with marks such as those found in a QR code, it will be able to recognize the apple like a human with some level of precision, even if the placement of the apple is positionally askew. Within such a prepared environment, robots have become capable of recognizing their surroundings and subsequently carrying out tasks.

8.2.3 *From pre-arranged environments to natural environments*

The first-generation playback robots were merely repetitive machines whose movements were made possible by internal sensors and a servomechanism. While these robots demonstrated redundancy and flexibility to a certain extent, they did not change the fact that they were merely being repetitive. As for second-generation sensor-based robots, it should be noted that they could be effectively used in pre-arranged environments such as those found in factories, but they become useless when customized environmental arrangements are not made for them. However, when the scope of robot usage goes beyond manufacturing industries, the demand arises for them to carry out tasks under relatively inferior circumstances, which are not pre-arranged. For example, since it is dangerous for humans to enter inside the furnace of a nuclear power station, it is favorable for robots to carry out tasks there. But even though its interior structure may be roughly known in advance, it is an area whose environment cannot be designed and optimized for a robot. Therefore the development of robots that could play an active role in not only pre-arranged environments but also in natural environments is necessary.

Third-generation robots fall into either of the following two categories; those that understand the environment and operate autonomously and those that receive commands from humans.

1) *Autonomous robots*

NASA's Mars exploration robot, Rover, used lasers to recognize its periphery and secure a map of the environment within a probabilistic framework. Consequently, it moved with the aid of visual sensors based on this map. In other words, by modeling the outside world with a peripheral environmental map, the robot could carry out proper judgments even in natural environments.

The "grand challenge" for the US's Defense Advanced Research Projects Agency (DARPA) is the unmanned robotic automobile race. In 2005, the race was carried out in the Mojave Desert in the US, and Stanford University's robotic car, Stanley, won the championship by covering a distance of 131.6 miles in 6 hours and 53 minutes (see Figure 8-9). Stanley detects passable roads using cameras and lasers and plans a model route. The relative positional relationships with obstacles found in the periphery are determined through cameras and lasers, while its own position is recognized through GPS use.

2) *Operational robots*

The Hybrid Assistive Limb (HAL) is a robot that functions as a robotic suit and was developed by Sankai Group of the University of Tsukuba. A person who wears this robotic suit could augment their physical capabilities. Since humans manipulate HAL's movements, it can operate in environments that are not pre-arranged. This type of robotic suit is expected to be used in the nursing sector, which will become increasingly vital from now on.

The surgery robot, Da Vinci, is a robot that is operated by a surgeon through remote control. The placement of a human organ varies

Stanford University's unmanned car robot.

Figure 8-9: DARPA Grand Challenge

subtly by the person, making it difficult for a robot to autonomously carry out surgical tasks. However, if we can accurately communicate images of a patient and the tactile feedback of inserting a scalpel, surgical tasks can be carried out from remote locations. Tactile feedback refers to such elements as the weight and the feel a person perceives when holding a cup and is also known as haptic information. The doctor operates the robot based on the communicated images and haptic information. To realize actual use, accurate detection of haptic information and real-time communication are necessary.

To operate robots in natural environments, technology that allows accurate recognition of the environment is crucial. For environmental recognition, superior sensors are necessary and there are sensors available today that surpass the capabilities of the fives senses such as cameras equipped with the telephoto lens. However, for the moment, there are apparently no sensors that can surpass the subtle sense of touch of humans.

Let us now compare robots with humans (Figure 8-10). While sensors that surpass human capabilities exist, knowledge information processing technology and sensory information processing technology are still in need of a breakthrough to match the level of the

Humans	Robots
Intelligence	Intelligent information processing/Sensibility information processing
Arms/hands	Manipulators/robotic hands
Muscles	Motors
Feet	Wheels/crawlers/4 footed/2 footed
Senses	External sensors (sense of sight, sense of touch, sense of force, sense of hearing) Internal sensors (gyros)
Energy	Battery

Figure 8-10: Comparisons between Humans and Robots

human brain. Third-generation robots that operate autonomously in natural environments will be demanded to not only process information from sensors accurately, but also to carry out complex decision-making based on the inputs of information obtained through the sensors. In other words, they will be demanded to demonstrate a level of intelligence that is on par with the level of intelligence of humans. It may be said that the deepening of the knowledge information processing technology and sensory information processing technology will tie into the further progress of third-generation robots.

8.2.4 *The role of information search in robot development*

The robot has evolved into an agent for carrying out human work. To search for information that can prove useful in developing such robots, observing humans is advisable.

Norbert Wiener carried out thorough observations of human actions and proposed the concept of "feedback" in a theory of motion he had deduced from his observations. Having noted the way humans and machines take action by acquiring information from the environment, he realized that there have to be underlying principles common to both entities or that both organisms and machines could be thought to share common principles. One such principle he proposed was the principle of feedback.

For example, let us consider the act of driving a car. All drivers gauge the distance between their car and the one ahead of them and step on the accelerator or brake pedal accordingly. If the distance between the cars shortens, the driver will step on the brake pedal, and if applying too much brake leads to the lengthening of the distance between the cars, the driver will step on the accelerator pedal. In effect, a flow of cause and effect is creating a loop — as a result of the output of a system, the environment changes, and when the environment changes, the input into the system changes, and when the input into the system changes, the system's output changes. This is the phenomenon known as feedback.

Wiener emphasized the fact that humans are constantly acting in response to their observations of the world around them, which are, in essence, information that are fed back to them from the world around them. Additionally, he asserted that it was the same for machines as well. In his book titled *Cybernetics*, it is written that you can examine principles of organisms through machine analogies and that if you acquire principles of organisms, then you will also be able to design machines, which will have functions of organisms based on those principles.

The act of observing and studying humans, and applying their mechanisms to the field of engineering for the purpose of realizing practical use can yield more fruits than just feedback. For example, the senses of sight and hearing are cases in point. If you register letters or faces into a knowledge base, a machine will be able to distinguish them, although not to the advanced degree of humans. Specifically, the machine is making comparisons with data stored in the knowledge database and humans are thought to be carrying out a similar form of information processing.

8.3 Robots That Take Intelligence into Consideration

Thus far, I have introduced robots that pursue functionality. For such robots, there has been progress made toward turning them into autonomous machines that would allow them to adapt to their surrounding environments. Along with this progress, there has been progress made in recognition and artificial intelligence technologies. The inheritors of this direction will be partner robots that will be able to interact with humans. Here, I would like to introduce the subject of these partner robots, which are fourth-generation robots, and R&D cases concerning the robotic brain.

8.3.1 *The brain and the computer*

It is said that the human brain carries out the following three mental activities; intellect, emotion, and volition.[6] Most of the research to date has been aimed at the intellect part of mental activities. The intellect is further classified roughly into knowledge and intelligence. Regarding knowledge, there is knowledge that is postnatal and deliberately learned and there is knowledge that is not deliberately studied but nevertheless acquired without one's knowing. The former can be procured for computers as a knowledge database, and with the progress of knowledge engineering, there are databases with an abundant amount of embedded knowledge in them at present. The form of knowledge most suitable for a computer is simple memory, and this will last almost indefinitely, once the computer stores it. In these present times when computers have made significant progress, the faculty of memory is viewed as a mechanical faculty and its value is beginning to wane.

As for understanding how knowledge is acquired naturally, there is still much work to be done. Common-sense knowledge, such as the fact that "an apple is something you eat," cannot be configured into a conventional database because of the need to understand the statement at a conceptual level and because of the fact that there are many exceptions. These matters are presently at the R&D stage. For example, let us consider human speech. Children aged three to four have a limited vocabulary but can nevertheless talk in their own special way. On the other hand, a robot can have a stored memory of a much larger vocabulary than a child's vocabulary, but making it converse will prove to be difficult, even if it is made to converse at the level of a child's proficiency.

In recent years, an approach that carries out natural speech patterns is being studied as a possible solution to this problem. This is based on a probabilistic approach called the Bayesian network approach and it is also a technique used in searches conducted by the Internet search engine, Google. Specifically, it involves expressing connections between words in terms of probability and learning them from past experiences.

Additionally, even if a computer were in possession of much knowledge, the computer would be receiving that knowledge from humans. In other words, the knowledge would not be something that the computer would actively secure on its own. With regard to actively acquiring knowledge, most of the current machines do not have such a faculty. In the fields of machine learning such as artificial intelligence, knowledge engineering, and neurocomputing, the concept of self-learning is discussed. However, I believe it could be said that as far as the process of humans teaching machines is concerned, it is still in a developing phase essentially.

Then how about intelligence? Among the different types of intelligence, the computer is adept in the area of handling logical reasoning. For example, humans pale in comparison to the computing power of current computers when carrying out such tasks as factorization, but when it comes to giving computers the faculty to consider or create new ideas, we are at present clueless, not even having a clear methodology to address the issue.

In recent years, in addition to researching the concept of "intellect" in robots, research into the concept of "emotions" in robots has also started. For example, Sony's robot, AIBO, expresses joy through its movements. But it cannot be said that the robot itself is actually experiencing this emotion. Strictly speaking, it is humans who perceive that to be the case. While I would be very hard pressed to reply to the question of whether there would be any sense in reproducing emotions themselves in a machine, to make a robot naturally interact with humans, it would be necessary to have the robot experience emotions, as that would make humans have an emotional response as well.

Additionally, there is the field of Kansei engineering (sense engineering), where experts are attempting to have computers and robots understand the fuzzy, "somehow or other" line of human reasoning. For example, images evoked by the name of the actor "Takuya Kimura" will vary by the person perceiving the name. Some people may think he is cool, while others may associate the name with music and among these people, there may be those who associate the name with outdoor sports, such as surfing and fishing. Similarly, the interpretation of quantity indicated in the phrase "a little" found in the expression "add a little salt" would also vary by the individual. It is thought that for robots to spread through society, understanding such individualistic variations is necessary.

As for "volition," if the question of whether it is necessary for robots is also asked, I am inclined to make an argument similar to the one for "emotions." Additionally, it can be said that "volition" emerges in association with "emotion." Sony's product titled "CoCoon" pioneered a feature that can be seen in hard-disk recorders available today, and this feature is that of a machine proposing programs to users by learning what they like to watch. Although the only thing the machine is actually doing is mechanistically following the dictates of pre-programmed evaluations, it is as if the system inside the machine is exhibiting its own "volition" or intent, establishing a more intimate relationship with the human user in the process. It can be said that the times are changing from an On Demand era, when people acquire what they desire instantly, to a For Demand era, when machines propose what people desire.

8.3.2 *The approach of making machines having "intellect"*

In the previous section, we made comparisons between humans and computers from the viewpoints of intellect, emotion, and volition. Here, I will discuss approaches concerned with giving computers intelligence.

The first approach is artificial intelligence. This involves the prior creation of knowledge regarding a particular world and forming behavioral models based on this knowledge. These models can be said to be patterned after the cognitive models of humans.

The second approach is an extension of object-oriented programming, which is a form of programming that is currently prevalent in software technology. This involves seeing whether more "emergent" movements can be developed by increasing the autonomy of multiple objects and promoting competitive and cooperative reactions among them. This is an approach that is related to "the complex system" concept, which was popular during the latter half of the 1980s through the first half of the 1990s.

The final third approach involves giving rise to high-level behaviors through the accumulation of low-level behaviors. When humans instinctively carry out behaviors to evade danger, such behaviors are often simple in nature and do not involve the use of the brain. For example, the action taken to avoid danger arising from sensing heat at your fingertips is not complex and does not involve the brain's faculty of making judgments. It is a rather much lower level, reflexive, cervical response. So this idea is one that proposes developing high-level behaviors that approach intelligence by promoting the accumulation of the kind of low-level behaviors just described.

Since the second and third approaches are believed to closely resemble each other in that one is dependent on the cooperation between agents while the other is dependent on the cooperation between low-level behaviors, they can be considered to be one and the same. However, since the types of contextual knowledge they use differ, I have treated them as distinctively different from each other. The knowledge of the former can be defined as a set of rules that a person can arrange in the mind and write down, but the knowledge of the latter is information that comes more from hardware.

As an example of the third approach, there is what is known as "Subsumption Architecture," which was proposed by Rodney Brooks, a professor at the Massachusetts Institute of Technology (MIT) in the US. This concept involved the attempt of creating a robot that successfully moved through spaces strewn with many obstacles. With the AI approach, movement begins after forming an action plan through inputting data such as the positions of all obstacles. However, this would cause accidents whenever the positions of the obstacles changed after formulating the plan. In response to this situation, Professor Brooks created "Genghis," a walking robot. Specifically, this robot was able to avoid obstacles with a relatively simple set of rules, such as "if the place where the forefoot is placed is angled in an X sort of way, then move the other foot in a Y sort of way."

The fact that the creation of an intelligently behaving robot was made possible through the application of a simple set of rules made waves at the time. Currently, this architecture is apparently adopted as basic technology for autonomous robots, such as Sony's "AIBO."

Now let us turn to the second approach's competition and collaboration between agents, which is the extension of object-oriented programming. Object-orientation in software development does not focus attention on the procedures of a program, but takes up the challenge of creating proper orders through placing a key emphasis on objects, which are units that contain procedures within themselves.

In this concept, the object was formerly viewed as something static, but the agent model is a model that views the object as something dynamic with a higher level of autonomy. The concept of the agent became topical after the US firm, General Magic, introduced the programming language known as "Telescript" along with the concept of "mobile communication." The agent supports human activities by acting autonomously and coordinately over a network. For example, a travel-agency agent can be created and a user can convey to this agent what type of trip they would like to have under a certain budget range. This travel agent will then compete against, cooperate with, or exchange information with agents of other travel agencies or airline companies and bring the results of those interactions to the user. This can be considered to be an approach for creating a software robot.

8.3.3 *Partner robots*

In recent years, the need has been rising for robots that could play an active role in assisting humans in their day-to-day living. Such robots include nursing and housemaid robots, but their practical application is not simple by any means. For example, let us consider the creation of a robot that could fetch the remote controller for a television set found in a household. How will it know the place where the remote controller can be found? How should it proceed to this place while avoiding obstacles along the way?

Sony's QRIO, Honda's ASIMO, and NEC's PaPeRo were intended to be such a robot and even Mitsubishi Heavy Industries and Toyota were involved in their development. PaPeRo can distinguish the faces of up to ten people through image recognition and also recognize approximately 650 words through voice recognition (see Figure 8-11). Additionally, its level of intimacy varies by the individual and its way of interacting changes accordingly. Additionally, it autonomously takes walks across a room and connects to the Internet to obtain information and convey the news and weather reports.

In the case of partner robots, friendliness with humans is a point of concern. This includes technical elements such as the ability to naturally interact, but such elements as gestures and outward appearance can also be considered to be vital factors. Additionally, the fact that these robots have names is indicative of the importance of realizing a sense of familiarity.

Sony's AIBO pursues this familiarity or friendliness by being "a robot that learns movements." While the AIBO can carry out adorable movements with its preloaded basic movement program, by having it learn new movements, it can be made to carry out movements with even further variations. This learning feature is helping to make the interaction between robots and humans pleasurable. AIBO's version of the Three Laws of Robotics is slightly humorous:[7]

1) A robot must not harm a human being. Fleeing from a human who is attempting to harm it is permitted, but it must not launch a counterattack.
2) A robot as a rule must direct care and love to a human, but it may also occasionally assume a defiant attitude.
3) A robot as a rule must patiently listen to the idle complaints of humans, but it may also turn nasty sometimes.

While safety is obviously important, the apparent trait of a defiant attitude and the tendency to "turn nasty" make the robot seem alive. Essentially, with partner robots, not only are their level of

Switch for detecting pats on the head	Recognizes its head being patted
CCD cameras	Using the CCD cameras embedded in each of its two eyes, PaPeRo walks while avoiding objects, spots a person and approaches them by measuring the distance to them, chases people, and registers and distinguishes faces.
LED	The LED configured in the mouth and cheeks gives PaPeRo facial expressions. The LED in the ear indicates that the robot is listening to a person's voice and the LED in the eyes indicates that the robot is seeing a person. The LED in the eyes flash green when the robot is searching for someone, stays green when the robot finds the person, and turns orange when it finds the face of the person.
Microphones that detect the direction of a sound source	There are a total of three microphones installed. One at the front, and one each to the sides. The robot estimates the direction of a sound by figuring out the differences in the times it takes the sound to reach each of the microphones. In so doing, the robot faces the direction from where the sound came.
Microphone for voice recognition	One directional microphone is installed in the head. Since PaPeRo speaks to a person by facing the person through image recognition, the microphone is naturally pointed toward the person as well. For voice recognition, the robot uses NEC's Smart Voice technology.
Speaker	PaPeRo plays words and music through stereo speakers.
Ultrasonic sensors	There are a total of five of these installed. Three at the front and two at the back. While PaPeRo moves, it avoids objects by processing the images captured by the CCD cameras. However, to avoid colliding into objects that are located in the robot's blind spot or those that jump into view suddenly, the robot uses ultrasonic sensors as well to measure the distance to objects.
Bump sensor	This sensor helps the robot to detect bumps in its path ahead to avoid falling.
Hoist sensor	This sensor detects the act of being lifted.
Wireless modem	PaPeRo can wirelessly access the Internet and wirelessly receive commands for actions and behaviors from an external PC, on which those commands can be created.
Wheels	A total of three wheels. Two front wheels and one rear wheel. Two motors drive the two front wheels. The maximum traveling speed is 20 cm per second.

		Action			
		Detection of a figure's orientation	Planning the path to reach targeted person	Obstacle evasion/ locomotion	Interaction with targeted person
Hardware	CCD cameras	○	○	○	
	Ultrasonic sensors		○	○	
	Microphones that detect the direction of a sound source	○			
	Bump sensor			○	
	Wheels			○	
	LDE				○
	Speakers				○
	Head pat/swat switch				○
	Voice recognition microphone				○
	Head (motor-activated)				○

Figure 8-11: PaPeRo's Hardware Configuration (top) and Examples of the Hardware Used in a Single Motion

Source: NEC Robot Research Website.

functionality considered to be important, but also their level of affability. This is their defining characteristic.

To realize widespread use of partner robots that can help human beings lead richer lives, it would be necessary to improve their performance. Toward this end, it would be necessary to make strides in all the technological elements raised in Figure 8-10. Japan's all-encompassing and highly advanced technological capabilities can prove to be extremely fruitful in the development of partner robots.

8.4 Development of a Robot at the Global Cutting Edge

In this last section of the chapter, I would like to discuss the development of Honda's ASIMO, which is a world-class, state-of-the-art robot.

ASIMO is a humanoid robot developed by Honda and it stands approximately 130 cm tall and weighs approximately 54 kg. ASIMO has the physical appearance of an astronaut clad in a space suit worn when carrying out outboard activities.

Walking just like a human being by using two feet, its gait is extremely smooth. Naturally, it gives the impression that its gait is somewhat more or less different from a human being's normal gait, but for the most part, it does not strike you as being odd. With the new ASIMO model released in 2005, the normal walking speed was 2.7 km per hour and the straight-line running speed reached 6.0 km per hour. Considering that by 2004 the straight line running speed was 3.0 km per hour, you can see that a drastic evolution had taken place (see Figure 8-12).

Honda began the development of a humanoid robot in 1986 and began developing ASIMO only after undergoing R&D for ten types of robots. The early seven types (the E-Series: models ranging from E0 through E6) aimed to realize smooth bipedal motion and did not have a head and arms. While the early E0 models succeeded in walking by having their two feet step forward in turns, every step had taken about five seconds to complete. In effect, they were carrying out what is known as static locomotion, which involves placing the center of gravity at the sole of the foot. Subsequently, with the E2 model, the robot succeeded in achieving a speed of 1.2 km per hour,

Height	130 cm
Width	45 cm
Weight	54 kg
Walking speed	When walking normally: 0~2.7 km/h When running in a straight line: 6.0 km/h
Grip force	0.3 kg (using one hand) 1.0 kg (using both hands)
Actuator	Servo-motor+harmonic decelerator+electric unit
Control unit	Walk/motion control unit Wireless communication unit Image processing unit
Head sensor	Vision sensor IC communications card used in combination with the optical sensor
Hand sensor	Force sensor
Body sensors	Floor surface sensor Ultrasonic sensor Gyro accelerator sensor
Foot sensor	Torque sensor
Operation unit	Notebook PC Handheld unit

Figure 8-12: Major Specifications of ASIMO
Source: Honda Motor Website.

and then with the E5 model, the robot went on to succeed in realizing a steady bipedal motion across stairs and even slopes.

The development of robots with legs only ended with the E6 model, and from 1993 onwards the focus shifted to the P Series, which was comprised of models that had a head and arms. With the release of the P2 model in 1996, the world's first autonomous bipedal humanoid robot was realized, and with the P3 model released in September 1997, miniaturization was attempted and the height had shrunken down to 160 cm.

Subsequently, ASIMO debuted in 2000. While its outward appearance has not changed that much since this time, as mentioned previously, in terms of walking speed, smoothness of motion, and collaborative attitude toward humans, the robot has shown considerable progress.

There may be those who question why Honda, an automobile maker, had begun development of a humanoid robot in the first place. Apparently, this is because Honda currently claims itself to be "*a mobility company* that is interested in anything that moves." In actuality, Honda is not only carrying out R&D for cars and motorcycles, but also for such means of transportation as small aircrafts. However, among the innumerable "things that move" in this world, why did the company choose to undertake the R&D for a humanoid robot capable of carrying out bipedal motion?

At the keynote lecture of the "Exhibition of Virtual Reality for Industrial Use" held in 2002, the company's representative Mr. Kazuo Hirai spoke on the particulars of how robot development began. In his explanation he used the example of "dimensions" and pointed out that second-dimension mobility was about developing cars equipped with a high-level of intelligence so as to be able to carry out unmanned and unattended operations. Second-dimension mobility was also about developing the power fuel cell, which could become the next-generation powerplant. Third-dimension mobility was about developing the "small aircraft" for the purpose of carrying out fundamental research for the "flying car." Finally, fourth-dimension mobility for Honda was about the development of an entity that could make movements on behalf of humans — in other words, the humanoid bipedal walking robot.

Apparently, this fourth-dimension alludes to the daily living circumstances of human beings. In other words, in such circumstances, there may be staircases that are difficult to access with existing means of mobility and what Honda is aiming to realize is the development of an entity that has human or even superhuman capabilities that can be applied in such daily living circumstances.

When the second dimension is correlated with automobiles and the third dimension with aircrafts, the correlation of the fourth dimension with the daily living circumstances of human beings seems to be a considerable leap, especially for engineers, who may be uncomfortable with the use of the concept of dimensions in this way to begin with, since they are aware of the fact that it has a fixed definition in the field of natural science.

The concept of dimensions may just be an afterthought and it may be just that the company was simply considering the circumstances or environments in which Honda's products were not applied or were not moving, as it were. However, in any case, in the present day and age when humanoid robots are being actively developed, the idea of benefiting from smooth mobility within daily living circumstances is extremely common. However, in light of the fact that not many other corporations were pursuing the full-fledged development of a humanoid robot at the time, Honda's conception can be considered to be truly wonderful.

To realize bipedal walking, it has been said that the developers of ASIMO made observations of the movements of actual pedestrians as well as of animals at the zoo. For example, the placement of the leg joint seems to have been modeled after the configuration of the human skeleton.

During his keynote lecture at the "SEMICON Japan 2002" exhibition, Mr. Masato Hirose of Honda R&D's Fundamental Technology Research Center commented, "When we were busy developing, the management used to make frequent visits to the research laboratory to scold us. They used to say, 'If you shut yourselves in the laboratory, you won't be able to create anything. Get active!' When we were observing pedestrians (for the purpose of researching bipedal motion), we were questioned by the police and when we inquired a doctor on where anesthesia could be injected to disable walking in order to further our understanding of the mechanism of the foot's movement, we were scolded again. But thanks to such deeds, we were able to come up with 'turnaround ideas,' such as the application of rubber, which was thought to be too soft to be stable, and controls that took advantage of the act of actively falling to realize walking." It can certainly be said that this was exemplary of Honda's traditional attitude toward development, which comprises the following three principles — scene, object, and reality.

It should be noted here that referring to the movements of people and animals for the purpose of technological development is not limited to ASIMO. There are many other developments that do the same. This type of technology that is modeled after living things is known as biomimetics and is evident in various fields. For example, neural networks, which are applied in the field of machine learning, are modeled after the human brain.

As for ASIMO, since quality targets for its movement capabilities had been achieved with the model released in December 2005, Honda is now concentrating on the aspect of intelligence that can help realize natural communication with humans.

Akihito Sudo

Acknowledgments

In the course of writing this chapter, I received considerable support and encouragement from Mr. Norimasa Kobori, who conducts robot-related research at a Japanese company. I herewith extend my deep gratitude to him.

References

1. Japanese Industrial Standard JIS B 0134-1998.
2. Seiichi Shin, *Illustrations — Cutting Edge Car Electronics — The Robotization of High-Tech Automobiles*, Kogyo Chousa Kai (transl. Industrial Fact-Finding Committee), March 2006.

3. Ministry of Economy, Trade and Industry's Society for the Study of Robotic Policies, *The Society for the Study of Robotic Policies Report*, May 2006.
4. Ministry of Economy, Trade and Industry's Round Table Conference on the Vision for Next-Generation Robots, *Report on the Round Table Conference on the Vision for Next-Generation Robots*, April 2004.
5. Ministry of Economy, Trade and Industry, *Strategies for the Creation of New Industries*, May 2004.
6. Susumu Tachi, *Introduction to Robots*, Chikuma New Book, 2002.
7. Kazuhiro Fujiwara, Kazuko Tojima, Kazuo Kadota, *Life Textbook — Living with Robots,* Chikuma Shobo Publishing, July 2003.