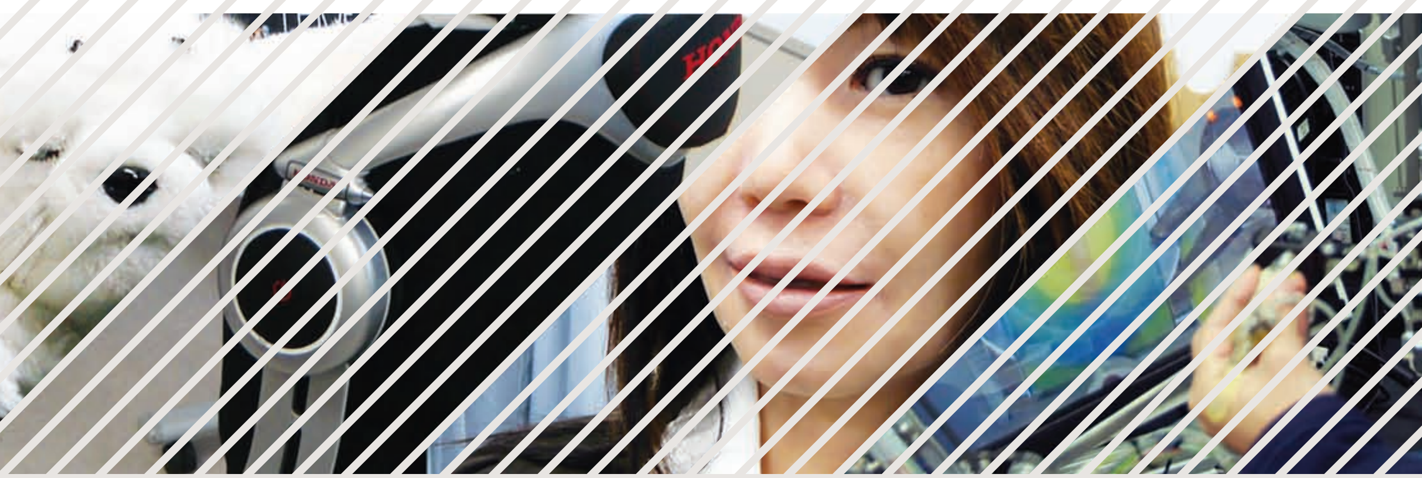
Technology Assessment

Beyond the Surface

An Exploration in Healthcare Robotics in Japan



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Rathenau Instituut

NOST NETWORK
Trendwatchers for Innovation and Technology

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Publisher: Rathenau Instituut

Preferred citation:
Lau, Ying Ying, Christian van 't Hof and Rinie van Est. Beyond the Surface – An Exploration in Healthcare Robotics in Japan. the Netherlands: The Hague, Rathenau Instituut TA report

Preface

Like many developed Asian countries, Western nations are facing an aging society. This places huge burdens on current healthcare systems. How can we cope with the rapidly increasing demand for healthcare? A wider use of technology is one possible solution. Japan is at the forefront of attempts to develop robotic technology in the service of its citizens, in particular the older members of its population. To learn from the Japanese experience, we visited the country to assess the current state of healthcare robotics there.

The present report is intended as a contribution to the debate on the future of our healthcare system. We hope it will bridge the gap between the healthcare providers and the developers of robotics systems, and provide a basis for further discussion and practical collaboration.

This study is a joint enterprise of the Rathenau Instituut in The Hague and the Science and Technology section of the Dutch Embassy in Tokyo. Ying Ying Lau from the Rathenau Instituut collected information through interviews and laboratory visits in Japan in the period from September to December 2008. Her work was supervised by Daan Archer, Science and Technology Attaché at the Embassy and Technology Assessment researchers Christian van 't Hof and Rinie van Est from the Rathenau Instituut. At the end of November 2008, they visited several laboratories to talk to experts. They were accompanied during some of these visits by a delegation of Dutch healthcare managers, who provided them with feedback on their experience of Japanese robotics. The study was rounded off by an expert meeting at the Dutch Embassy in Tokyo on 27 November 2008, where the future of healthcare robotics in Japan was discussed.

This report is the beginning of a larger set of activities in the field of robotics in the Netherlands. In November 2009 an international conference on robotics will be held by SenterNovem (an innovation agency of the Dutch Ministry of Economic Affairs), the Dutch Ministry of Education, Culture and Science and the Rathenau Instituut. Various investigations will be carried out in preparation for this event. For example, the Rathenau Instituut will carry out an exploratory study on service robots. The Rathenau Instituut will also study developments in the field of healthcare robotics in the Netherlands.

We would like to thank all the robotics experts who have contributed to our understanding of the current developments in Japan. The meetings and institutes are mentioned in Appendix A. We also owe a debt of gratitude to the staff of the Dutch Embassy in Tokyo and look forward to future collaboration.

Frans Brom
Head of Technology Assessment

27 April 2009

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1 Robotics for an aging Japanese society

A glimpse of the future of robotics can be witnessed in Japan. This country has a long tradition in robotics and a culture which is supportive of the use of robots. Also, more than any other country, Japan is a rapidly aging society. People live longer, while fewer people are born. This puts increasing pressure on the workforce, especially in healthcare. Many people in Japan believe that robotics will provide the solution, or at least contribute to it. In that sense, Japan serves as a socio-technological laboratory for the rest of the world. In this section, we will explore the problems Japan is facing with regard to the care of the growing number of elderly people in its population, will briefly sketch how robots are popularly portrayed as providing a solution to these problems and will conclude by describing the structure of this report.

1.1 A rapidly aging and shrinking population

Japan is facing a major challenge as it is fast turning into the world's oldest nation. In addition, its population is starting to show signs of decline. In 2005, the country saw its first population decrease since 1899. The current Japanese population of 127 million is expected to drop to 89 million by the year 2055. The combination of a low birth rate and a low death rate is moreover expected to give the population the form of an inverted pyramid by that time.

Figure 1

Changes in population structure

Source: Statistics Bureau, MIC; Ministry of Health, Labour and Welfare Japan

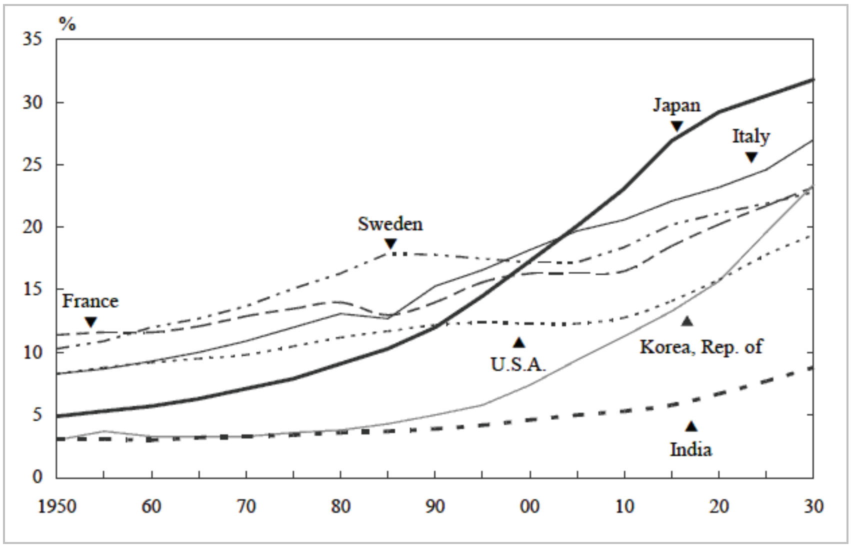


Figure 2

Proportion of elderly population (aged 65 years and over) by country

Source: Statistics Bureau, MIC: United Nations; Ministry of Health, Labour and Welfare Japan

The radical change in the ratio of young to elderly people will have major social consequences. First of all, the costs of care are likely to increase. Elderly people will need more and different kinds of medication to support their longer lives and to treat the diseases of old age. But the demand for labour seems to be the biggest challenge. A reduction in the number of young people and an increase in the number of elderly people means not only that there will be fewer workers to support the economy but also that there will be fewer carers – at a time when more and more elderly people would like to go into nursing homes and hence more carers are needed. This leads to long waiting lists. It is estimated, for example, that close to 400,000 people with dementia are currently waiting to get into nursing homes in Japan.

This phenomenon is exacerbated by changes in family structure. Traditionally, Japanese children took care of their elderly parents. It was not uncommon for three generations to live together in the same household. Nowadays, most young people do not want to live with their parents. Thus, more elderly people are living on their own or move to an old people's home. In addition, since the birth rate is dropping, not all elderly people will have children or grandchildren to support them in their old age. Future generations of women are expected to have fewer children and grandchildren than the current generation (see Table 1). Consequently, those future generations will be even more dependent on external care in their old age. In short, changes in family structure imply a need for more institutional care of the elderly.

Females, 50 years old	Born in 1955	Born in 1990 (expected)
Unmarried	11.2%	24.3%
No children	17.7%	38.1%
No grandchildren	21.2%	50.2%

Table 1
Proportion of 50-year-old women, born in 1955 and 1990, without children and grandchildren
Source: Presentation of IRT, the University of Tokyo

Although the demand for carers is increasing, being a carer is not considered a very attractive job in Japan. The work is physically demanding and poorly paid. As a result, more than 20% of carers quit their job within the first year. Young people, especially from urban areas, prefer to look for better paid work. It will probably be necessary to raise the wages paid to carers. This in its turn will lead to a demand for more technological support in this sector, to make it less labour-intensive. Encouraging people from low-income countries to work in Japan might be a solution. The Japanese government recently started to recruit foreigners as carers, but the number of foreign carers still falls far below the targets set. The low wages offered is one reason for this. Another important factor is that these carers need to be able to speak Japanese, a requirement that few foreigners meet.

1.2 Service robotics as a solution for the aging society

The Japanese Ministry of Economy, Trade & Industry (METI) predicts the emergence of a “Neo-Mechatronic Society” within the next two decades. In this society, robots will routinely provide a number of services such as cleaning, guarding buildings, providing recreational facilities and caring for the elderly. Japan thus foresees a new generation of robotics, which is also positioned as a solution for its aging society. Japan played a key role in the first wave of robot applications from the nineteen-seventies to perform all kinds of repetitive tasks in factories. It aims to play a similar leading role in the field of service robotics. In the next few subsections, we will briefly review Japan’s tradition of robotics, the attitude of Japanese people towards robots and governmental policy for promotion of the development of service robotics.

1.2.1 Loving the robot

Japan has developed numerous forms of industrial robotics, and is the world leader in industrial robotic installations. Industrial robotics has contributed greatly to Japan’s prosperity. The introduction of robots into factories also helped to increase labour productivity. While most Western countries have used both industrial robotics and foreign immigration to boost output, Japan has never welcomed immigrant labour. It should be noted that the development of robots in Japan has cultural and technical roots that predate the rise of robotics in the 1970s by many centuries.

As long ago as the ninth century AD, stories were told of magicians who could make people out of paper. This cultural fascination was later translated into artefacts. The Japanese made various automata to help or entertain people in their daily life. Japanese craftsmen were fond of humanising these automata; giving them a human face. Karakuri dolls, mechanical puppets developed around the 18th and 19th centuries, are a good example of this. The karakuri dolls were beautifully crafted to resemble human servants and could perform simple tasks such as serving tea or writing Chinese characters. The tea-serving karakuri was able to bring a cup of tea to a guest and return with the empty cup.

Figure 3
Karakuri dolls
Source: Otona no Kagaku Vol. 8

Robots also play an important role - and mainly a positive one - in traditional Japanese stories and in modern manga stories. Tetsuwan Atomu (literally ‘Mighty Atom’), or ‘Atom boy’ (also known as Astro Boy in the West), created by the father of manga Osama Tezuka (1928-1989), is the world’s first robot cartoon figure with a soul and is Japan’s most famous (atomic-powered) hero. Even though he was created in the 1950s, he is still popular. The positive role robots have played in cartoons and the media suggests a positive attitude towards robots in Japan, where the use of technology such as a robot tends to be seen as an extension of the hand. This is often contrasted with Western culture, where a common theme is the fear of losing control over the machine. The story of Frankenstein by Mary Shelley (1818), the Czech theatre play RUR by Karel Capek (1921), in which robots take over the world, and a movie like The Terminator all reflect such fears. It should not be forgotten, however, that there are also many counterexamples such as R2D2 in Star

Wars and Wall-E in the 2008 film of the same name where robots help or even save mankind.

Figure 4
Tetsuwan Atomu, also known as Astro Boy

A common theme in most of these fictional narratives about robots is the human appearance of the machine. The robots are therefore often called humanoids or androids. In the Western world with its Christian basis, an essential difference is perceived between living and non-living things, as well as between humans and other living creatures. Man has consciousness and a soul. Animals have consciousness, but no soul, and inanimate objects have neither consciousness nor a soul. Japan, however, adheres to a mixture of Buddhism, Shintoism and a little Christianity. As such, it recognises millions of gods which can exist in different types; human beings, animals, trees and even stones can be gods. The Japanese believe that everything can have a soul, and a robot is no exception.

Hari-kuyo: requiem services for broken needles
According to Shinto beliefs, every object has a soul. Even small pieces of iron can have a soul inside them, which is why a requiem service for broken needles is held annually in Japan. These requiem services, called hari-kuyo, are very important for Japanese women, who used to sew their own kimonos by hand. Even nowadays, kimonos are usually sewn by hand with needle and thread. Needles are thus very important implements, and requiem services are performed every year for needles that break or wear out from long use. Kimono-makers take old, broken or blunt needles to shrines or temples on the day of hari-kuyo, where priests recite prayers or sutras. The people thank the needles and pray for repose of the needles' soul and for improvement of their own sewing skills. Similar requiem services are also held for other objects, such as combs and knives.

Kawaii!

In Japan, the cult of ‘kawaii’, meaning cuteness and prettiness, which initially developed among teenage girls in the 1970s, has since spread to many other walks of life such as government announcements, advertisements and industrial design where it would be considered inappropriate or ridiculous in many other cultures. The design of the concept car Nissan Pivo is a good example. When we asked about the reason for this specific design, the reply was that this is kawaii. It appears that adding the element of kawaii is used by the Japanese to make technology more acceptable and less frightening. The same tendency seems to be present in robotics design.

1.2.2 Service robotics

In addition to industrial robots, Japan is actively developing a wide variety of service robots. The difference between the two lies in the environment in which they are used. Industrial robotics operate within a factory: a confined space which is both physically and socially more structured through various functions and procedures. Service robots operate in day-to-day contact with many different people; their application environment is thus less structured.

METI has predicted a 40 billion Euro home market for robot technology in 2025. These high ambitions are shared by government, industry, and research institutes and are meant to steer and shape collaborations between those actors. Japan presented its latest advances in service robotics at the World Expo held in Aichi in 2005. The products on display included security robots, tasting robots and humanoid robots. Media stories spotlight humanoid robots in particular, raising the impression that they will soon embody all kinds of human traits and activities.

Service robots do at least need to be able to respond to human behaviour to some extent. While industrial robots need to be fast, accurate and predictable, a service robot is expected to be safe and to present an unobtrusive, friendly image to its users. In short, this technology does have to incorporate some human characteristics. Robotics expert Prof. Ken Tomiyama of the Chiba Institute of Technology refers to the three aspects of human behaviour distinguished by Chinese philosophy - intelligence, emotion and will – and argues that robotics has already passed the first level and is now showing developments in the second, with robots detecting human emotions and even showing emotions of their own.

Service robotics offers a wide range of possible application areas. As Japan will be coping with an increasingly aging society in the not too distant future, more and more robotics developers concentrate on facing this challenge by developing healthcare robots. Research institutions, universities and private companies are all engaged in this work. Healthcare robots will have to offer what the old karakuri dolls used to: a helping hand – but then in a much more sophisticated, intelligent way.

Many Japanese public research programmes are currently developing healthcare robotics to support the country's aging society. The Japanese Cabinet Office occupies a pivotal position in these programmes and has approved many projects for the development of new robots but also for improvement of the underlying hardware and software like intelligent recognition, decision-making and actions in robot technologies, as well as reduction of development time and costs. The next objective is the development of safe, reliable and adaptable life-support robots for use in a dynamic, country-wide environment.

Two new robotics programmes were launched in the 2009 fiscal year. METI has initiated a five-year life-support robot project to implement robotics to assist carers in their daily tasks. This programme also takes into account the safety and regulatory issues relating to the actual implementation of robots in real-world environments. Funding will be an initial 1.6 trillion JPY (12 billion Euro) for the first year, decreasing incrementally year on year. In addition, the Ministry of Internal Affairs and Communications (MIC) has just launched a new ubiquitous robotics programme to develop robotic and telecare technologies to assist the elderly at home. Initial funding will be 550 billion JPY (4 billion Euro), decreasing incrementally over a five-year period. The combined Japanese public funding for robotics research of METI, Ministry of Internal Affairs and Communications (MIC), Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF), Ministry of Land, Infrastructure, Transport and Tourism (MLIT) in 2009 will amount to 3,9 trillion JPY (28 billion Euro).

The Japanese government supports the development of advanced skills to enable care and service robots to assist the elderly in daily chores. In addition, a workforce of robots with advanced manual skills is expected to make up almost half of the decreasing Japanese workforce in 2025. Industrial robots are expected to evolve rapidly towards flexible autonomous manufacturing systems, and increased investments from industry are crucial if this objective is to be attained. METI's robotics programmes therefore focus on the development of enhanced robotic skills to be applied in production, service, construction and disaster areas - for example, for the handling of soft materials in healthcare or the handling of wiring in factories. To provide an additional stimulus for robotics R&D in the private sector, METI launched the annual Robot Award in 2006.

The global market for industrial robots is well established, with Japan occupying a leading position. According to a spokesperson of the Japan Robot Association (JARA), 38% of all 950,000 industrial robots worldwide are based in Japan. It seems likely that when service robotics becomes established as a part of daily life, Japan will be a world leader in this field too.

1.3 Beyond the surface

Our exploration of the developments in healthcare robotics in Japan is guided by two interrelated concepts which play an important role in Japanese culture: ‘tatemae’ and ‘honne’[1]. Tatemae literally means ‘façade’ and is often used to refer to the behaviour and opinions one displays in public, what is expected by society and required according to one's position and circumstances. Honne, on the other hand, refers to one’s true feelings and desires, which lies beneath the surface and should not be shown in public.

According to Prof. Tomiyama, these concepts can also be applied to Japanese robotics. Tatemae then refers to how robots are portrayed and what they are supposed to do. This aspect should not be considered as mere window dressing, however: ambitious goals play a mobilising role and bring people and organisations together. Honne refers to the mechanical and electronic devices hidden by the smooth surface of the robots and all the complex and often frustrating adjustments made behind the scenes, to ensure that the robots live up to expectations. The underlying reality need not be dull and unvarnished, but can display a diversity and beauty all of its own.

In the rest of this report, our explorations will take us beyond the surface image of robotics portrayed in the media. We will provide a broad overview of the robotics applications being shaped in Japanese research laboratories or in the wider development world. Chapter 2 also gives an analysis of the development of robotics in the field of healthcare, while Chapter 3 surveys the social and ethical issues related to healthcare robotics. The final chapter will contain some conclusions, in particular with respect to the question of how to reconcile healthcare needs and the technological supply.

[1] In Japanese: 建前 (tatemae) and 本音 (honne).

2 R&D in healthcare robotics

This chapter provides a broad overview of healthcare robotics in Japan. Some of them are already in use, some have become famous, while some still live a laboratory life. Sections 2.1 to 2.5 describe robotic applications in five application areas, which can be seen as following a developmental pathway: (1) fundamental research, (2) education and training of medical doctors, (3) cure (e.g. surgery), (4) rehabilitation and (5) care (robotics for supporting the elderly and disabled, and/or carers). We will indicate the official objectives of and claims made for these technologies (tatemae) and contrast these with some of our own experience in the laboratories we visited (honne). In the final section of this chapter, we will explore the implications of robotics for the healthcare sector from a technological perspective. The research institutes involved in these innovations are described in the Appendix C.

2.1 Robotics for studying humans

The use of robotics to copy or rebuild (parts of) the human body is one of the most exciting fields of humanoid robotics. Some of these applications have been described by the popular media, where the main message is often how far scientists have advanced in getting machines to resemble humans. Back in the laboratory, the aim appears to be the reverse: not just building robots, but learning about humans by trying to rebuild them. This is not applied research, in which robotics serves to solve a particular problem, but rather fundamental research on what it means to be human.

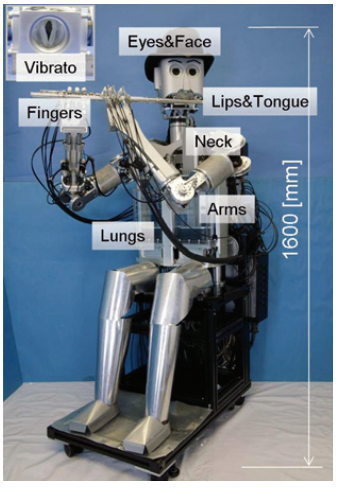


Figure 5 (Left)
Trumpet player, Toyota
Photo: Rinie van Est

Figure 6 (Right)
Flutist Robot, Waseda University
Source: Website of Takanishi Lab

Some examples are the trumpet player developed by Toyota and the anthropomorphic flute-playing robot by Waseda University (see Figure 6): a robot with rubber lips and a set of two lungs. This robot plays the flute by moving its lips and breathing in and out like a human flute player. This achievement shows how far robotics has got in understanding and mimicking the operation of the human body.

The Advanced Telecommunications Research Institute International (ATR) uses fMRI scans to mimic movements. For example, a robot hand mimics a person playing the "rock-scissor-paper" game on the basis of a fMRI scan of a person performing the relevant movements. In addition, researchers at ATR succeeded in making a humanoid robot walk in 2008 with the aid of recordings of the cortical activity of a monkey's brain sent in real time over the Internet from the USA to Japan. The same research group succeeded in 2009 in controlling the basic movements of a robot (Honda's Asimo, see section 2.6.1) through human thought.

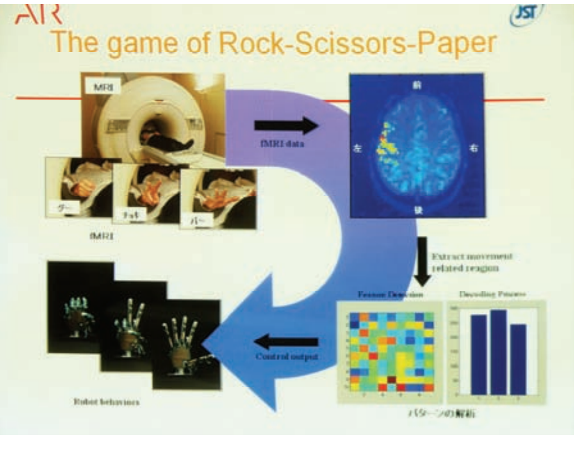


Figure 7
From fMRI to rock-scissor-paper
Photo: Rinie van Est

Figure 8
Monkey operated robot
Photo: Rinie van Est

Another area of research is aimed at elucidation of how humans respond to humanoids. The robots used for this type of research look like and are programmed to respond like humans. This may be seen as a test of the 'uncanny valley' hypothesis proposed by Masahiro Mori (Mori, 2007). He stated that there is likely to be a dip in the response curve of humans to robots over a range where the robots look and behave very much like people – but still sufficiently unlike them to seem 'strange' and uncanny, thus prompting a feeling of revulsion rather than attraction. When the robots are made even more lifelike, people will again respond positively to them. This area where the robots are experienced as like us but yet unpleasant is known as the 'uncanny valley'. Many robotic developments in Japan are assumed to be positioned before the uncanny valley, but some seem to be getting close to it.

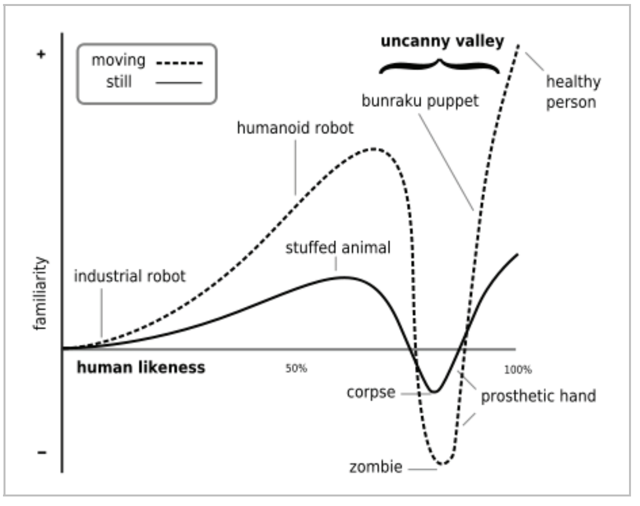


Figure 9
Uncanny Valley (simplified version)

The humanoids developed by Professor Hiroshi Ishiguro of Osaka University are an interesting example. They can move and talk by tele-operation. Professor Ishiguro has even duplicated himself in a humanoid and tested the response of his wife and daughter to it. The humanoid 'Repliee Q2' can react by movement and voice when touched in some places, such as behind the ear.

Figure 10
Humanoid copy of professor Ishiguro, Osaka University
Photo: Ying Ying Lau

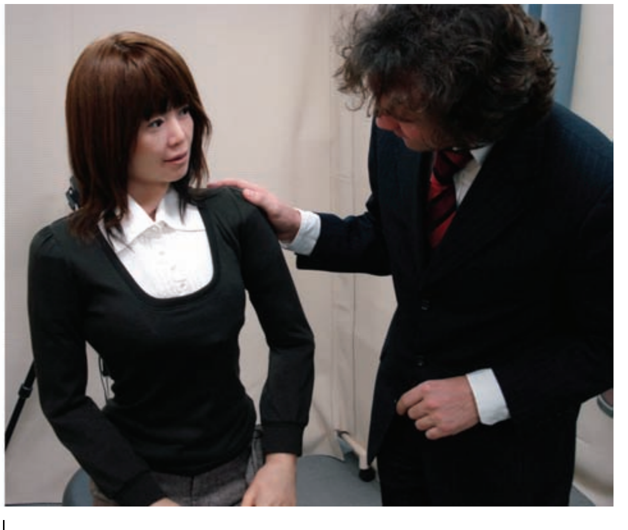


Figure 11
Trying to communicate with the Repliee Q2, Osaka University
Photo: Rinie van Est

The humanoids developed at the Intelligent Robotics Laboratory at Osaka University (see Figure 10 and 11) may be portrayed in the popular media as robots that replicate humans, but are in fact attempts to study humans through robotic technologies. When we visited the laboratory, we too were initially impressed by the lifelikeness of these humanoids but found that this effect quickly wears off at a second glance. Again, when the Ishiguro clone or Repliee Q2 responds to your presence by turning towards you, this is very impressive at first. But the feeling of lifelikeness fades away completely once you realise how many sensors, devices and people round about are needed in order to make the humanoid fully functional. With all these cameras and researchers around us, it occurred to us that this was not so much as case of our investigating a robot, but rather of the robotics engineers studying us.

2.2 Robotics in education and training

It is difficult to practice medical skills on real people. There is a lack of test patients, and people do not like to get hurt by unskilled trainees. Robotics can provide a useful alternative here. Robotics applications are being developed to help students and medical specialists practice their medical skills by providing realistic body parts and automated feedback. Sensors and software are used to evaluate the advances in their competence. The training applications often consist of a large number of sensors that measure the forces applied to a specific area, together with software designed to evaluate the performance. Synthetic materials are used to cover the devices to make them look like human body parts. A robotic training tool for practising the insertion of a tube through the mouth of a patient is being developed at Takanishi Laboratory, Waseda University. Sensors throughout the artificial throat measure the force applied and the accuracy with which the tube is inserted. The computer feeds this information back to the student.

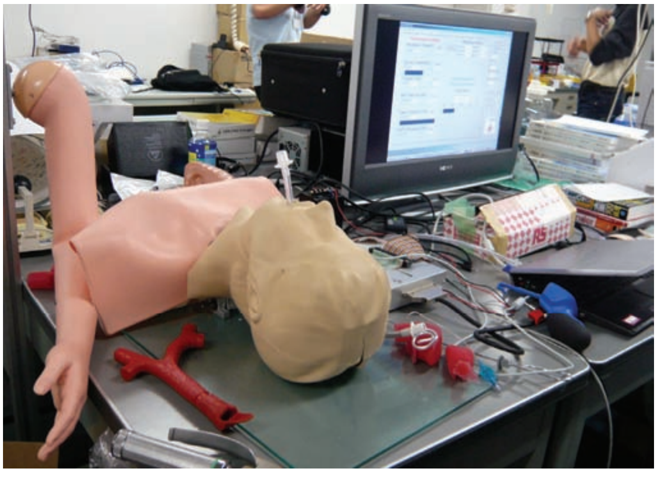


Figure 12
Robotic training tool for specialists and students, Waseda University
Photo: Ying Ying Lau

Many training tools are already commercially available. The medical and science catalogue of the company Kyoto Kagaku offers an extensive range of training tools for medical education. These tools are still relatively simple and do not give much feedback yet. The inclusion of more and more robotics will make the measurement and evaluation systems more sophisticated and able to give accurate feedback. In this way, robotics is bringing medical skills training to a higher level.

Figure 13
One page from the 2008-2009 Medical & Science Catalogue, Kyoto Kagaku Co., Ltd

The Simroid (simulator humanoid) is a robotic dental patient that can be used to train dentists. Air pressure and a silicone skin are used to make this (female) robotic patient look very lifelike. The robot reacts to commands and questions and can provide verbal and physical feedback. The Simroid has many sensors in its mouth, which allow it to react to incorrect manoeuvres performed by the trainee dentists. It can react in various ways, but most of the time it will say: “Ouch... that hurts!”, hence the nickname ‘Pain Girl’ (*Ita-gaaru*). The robot also has some sensors in its chest to deliver a warning signal if students accidentally touch inappropriate areas. Associated software evaluates student performance. The Simroid is said to have been modelled on a 28-year-old female patient who was very scared of visits to the dentist. It was developed by Nippon Dental University, Tokyo, in association with Kokoro Company, and was released in November 2007.

Figure 14
The Simroid ready for dental treatment
Source: website Pink Tentacle

2.3 Robotics in cure

Many robotics systems have been developed for use in the therapeutic field, mainly by medical professionals. Minimal invasive surgery (MIS) is one well-known example. Such robotics systems usually operate at the interface between the specialist and the patient, to permit more precise surgery.

Two examples of surgical robotics applications are a “brain-retract manipulator” and a “heart-beat canceller”, both developed in the Fujie Laboratory of Waseda University. The former is used to retract the brain to increase the limited space available during brain surgery. The latter gives the surgeon a stable endoscopic view on screen during heart surgery, with the aid of sensors that move along with the heart beat. The associated software then allows the distracting movement due to the heart beat to be cancelled out, to give a stable image. Most of these systems require a rather large working space (as may be seen in Figure 15) and high-precision measurements.

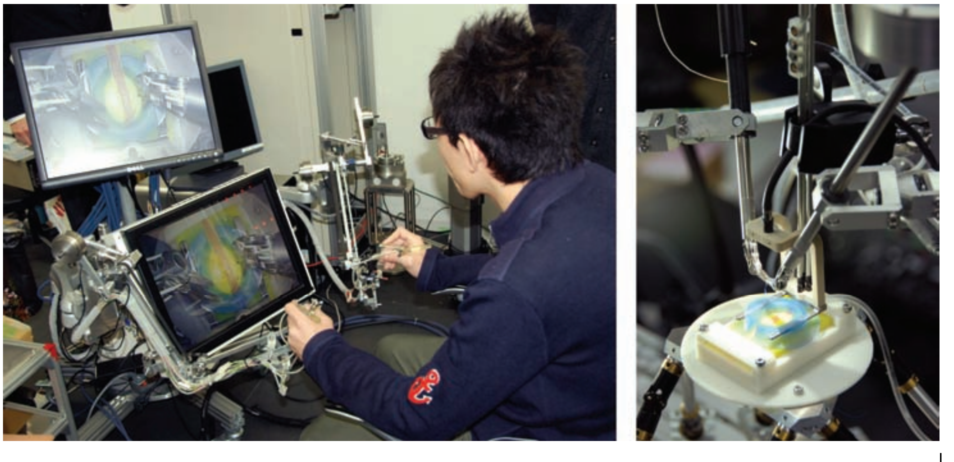


Figure 15
A master-slave system for cardiac surgeons with heart-beat canceller
Photos: Rinie van Est

Another robotics system for medical applications is a massaging robot used to treat patients with inadequate secretion of saliva, as in Sjögren’s syndrome. This robot massages the patient’s jaws, thus stimulating the natural flow of saliva. A somewhat similar application is a jaw training robot developed at Waseda University. This is intended to help patients with temporomandibular disorder (TMD) to perform exercises that may help to relieve their condition.

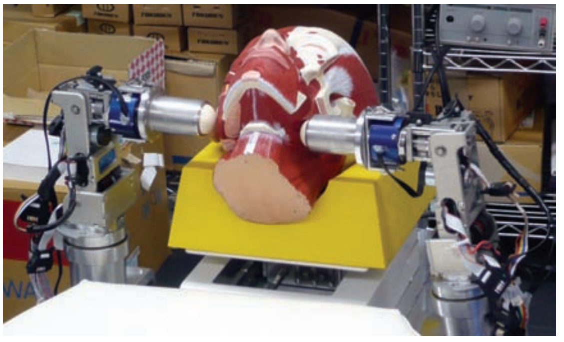


Figure 16
Massaging robot to stimulate saliva production, Waseda University
Photo: Ying Ying Lau

These examples illustrate the many promising developments in this field. There are however still many risks and other potential drawbacks associated with such applications. The prime concern here is safety. These devices operate in close proximity to or even inside the human body, and the medical specialist using them has to rely on them performing their prescribed tasks with the required sensitivity and force. The surgeon using the hearth-beat canceller or brain-retract manipulator really needs to be able to trust the software and mechanics involved. The massaging robot needs to be monitored to ensure that it does not injure the patient by using too much force. A second important issue is whether there are enough patients requiring this specific treatment to justify the huge investments involved. And thirdly, it should be borne in mind that the full development and commercialisation of a medical robot can easily take up to 10 or 20 years due to the stringent requirements that have to be met before it can be officially approved for medical use.

2.4 Robotics in rehabilitation

Robotic systems can be used either by the patient for self-rehabilitation or by a rehabilitation physician or paramedic as a treatment aid. Several applications provide support for specific parts of the patient's body or even the whole body with the aid of an exoskeleton. The best-known example of this type is the Robot Suit HAL (Hybrid Assistive Limb), developed by a spin-off company of the University of Tsukuba called Cyberdyne. The suit is activated by EMG-signals from the user's muscles. The HAL suit is expected to be applied not only for relief with certain diseases and disabilities, rehabilitation and physical training but in the future also to provide support and more strength during heavy physical labour (see e.g. section 2.5.2).

Another example of rehabilitation robotics is the "Walking Assist Device" developed by Honda, which can help people with weakened leg muscles to walk. Honda engineers started work on the development of this device in 1999, and have so far succeeded in bringing its weight down to less than 3 kg. The device is still in development, and Honda hopes to be able to market it in 5 years.

Figure 17
Walking Assist Device, Honda
Source: website Honda

Figure 18
Robot Suit HAL, Cyberdyne
Source: website Cyberdyne

A final example of exoskeleton robotics is the Muscle Suit developed by Dr. Hiroshi Kobayashi at the Tokyo University of Science. Unlike the suits described above, the Muscle Suit is powered by air pressure. This approach has two main advantages: the device is much lighter (only 3 kg for full support of the upper body) and the movements are smoother and more human-like. The lifting version of the Muscle Suit allows a normal person to lift a fifty-kilogram bag of rice with ease. The biggest obstacle to wide-spread application of this device is still the need to use a source of compressed air. This may be either an external source to which the suit has to remain connected via flexible tubes (which severely limits the range), or pressure containers which need to be replaced frequently. Some of the demonstration models of the walking device used CO_2 cylinders (normally employed for pressuring beer pulls), which allow the user to walk 150 metres on a single cylinder.

Figure 19
Lifting rice bags with the Muscle Suit, Tokyo University of Science
Photo: Rinie van Est

Some of the researchers we met claim that one interesting side-effect of the use of robotic devices to replace parts of the human body is that the brain appears to revive patterns of neurological signals intended to move the disabled part, even though the part does not move under its own power. Nevertheless, many of these applications are still too heavy or energy-consuming to be feasible in practice.

2.5 Robotics in care

Many robotics developments aim to contribute to the care of people in an old people's home. Such systems may be regarded as a sub-discipline of domotics, originally designed for use in private homes. However, they can also support a more independent life-style for the elderly no matter where they live. Many of these technologies are also useful for younger people with disabilities. When such individuals are living at home, a (professional) carer usually comes by on a regular basis. When they are living in residential care centre, the centre's nursing staff takes care of its residents. Robotics applications can play an important role in relieving the burden on these staff. They can be divided into two categories: robotics for care recipients and robotics designed to support the (professional) carer or nursing staff.

2.5.1 Robotics for care recipients

People who are elderly or who suffer from a physical and/or mental disability may need help in performing specific daily tasks. Robotic applications developed to this end can have two main advantages: they can give the user a greater feeling of independence, and they can relieve the burden on professional carers or nursing staff.

The University of Tokyo has recently developed a 'Robot Assistant' that helps elderly users to cope with daily tasks such as cleaning the floor, doing the laundry and finding lost items. Such applications may allow an elderly or handicapped person to live more independently, with less need of help from a carer. Another example of this type of application is "My Spoon" from Secom, a robotic arm that can be controlled by the user himself either manually or by mouth. This allows a handicapped person to feed himself without human assistance. It may be noted that the development of "My Spoon" was based on that of the Dutch robotic arm "Manus", developed by Exact Dynamics.

Such devices need to be very easy to use, especially since most users will have physical limitations. When developing robotic aids for the elderly, one must bear in mind not only the physical constraints but also limitations in the user's experience in coping with electronic products. This makes it desirable to design the devices for more intuitive use. Finally, safety is once again an important issue since these products will be in close contact with the user.

Figure 20
Robot Assistant, University of Tokyo
Photo: Ying Ying Lau

2.5.2 Robotics for carers

There are many ways in which robotics can support carers in their daily activities. Lifting people who cannot get up themselves, for example, is a very demanding task for carers, which may in future be performed by a robot. One robot designed to this end is Ri-man from the Riken Bio-mimetic Control Research Center (BMC). Figure 21 shows the official version, completed in 2006: a humanoid robot carrying a ‘patient’ – in fact, an 18 kg dummy. This robot has very limited capabilities: it cannot interact adequately with the environment, and moves quite slowly. The BMC is currently working on a series of improvements to this product, such as the ability to lift weights of up to 60 kg.

The limits on Ri-man’s power and speed are not just determined by hardware and software considerations, but by safety concerns. If it were made stronger and faster, it might hurt patients who do not behave in the way it is programmed to handle. Although Ri-man is fully covered with sensors to deal with this possibility, there is still the risk that it might crush patients with its powerful arms in the worst-case scenario. The developers are therefore considering a stronger robot controlled by a nurse rather than a stand-alone version.

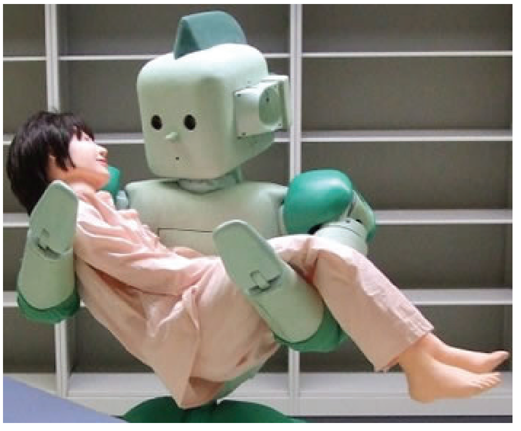


Figure 21
Ri-man, developed by Riken BMC
Source: website Riken BMC

Another product developed to assist carers is the "Toilet Assist" system from the Intelligent Systems Research Institute of the National Institute of Advanced Industrial Science and Technology (AIST). The aim of this project is to develop a total support robot toilet system for elderly and/or disabled people and relieve the lifting burden for carers. The functions of the Toilet Assist are (1) to assist the transfer of the care recipient from a wheelchair to the toilet seat and back, and to help him to stand up and sit down; (2) to ensure that the care recipient is held safely in a standing or sitting position and (3) to help the carer clean the care recipient. The robotics technology allows the wheelchair to be removed by a wheelchair shuttle carrier and to be replaced by a movable toilet. The carer only needs to support the elderly or disabled person while the latter is standing and waiting for the chairs to switch – and, as mentioned in point 2 above, the Toilet Assist can provide backup here. The system is still under development; the main problem to be resolved at the moment is that it takes a long time to switch chairs because of the need to comply with the stringent safety regulations.

Figure 22
Toilet Assist System, AIST
Photo: Ying Ying Lau

Exoskeleton robotic suits, whose use in rehabilitation has been described in section 2.4, can also be used to strengthen carers when they have to perform physically demanding tasks. This is an example of temporary external human enhancement using robotics.

2.5.3 Socialising and therapeutic robotics

Healthcare is not only about meeting physical needs but also about personal attention. This is another field where robots can play an increasingly important role. Many projects have been devoted to the development of guide and receptionist robots in hospitals of recent years. The first Japanese hospital to 'employ' robots was the Aidu Chuo Hospital of Aizu-wakamatsu city in Fukushima prefecture north of Tokyo on the island of Honshu. The robots are developed by Tsmuk and were first installed in the hospital at the end of 2006. More advanced robots are currently under development, such as the hospital transportation robot, the fruit of a joint project between Keio University and Muratec. This robot does not need a pre-programmed digital map of the hospital, as it can scan its surroundings with the aid of a wide variety of built-in sensors such as a camera, laser rangefinder, ultrasonic distance sensor and bumper sensor. It can move in any direction and can independently deliver an attached unit.

Figure 23 (Left) Receptionist and guide robot at Aidu Chuo hospital *Source:* website Aidu Chuo hospital

Figure 24 (Right) Hospital transportation robot by Muratec and Keio University *Source:* website Muratec

The application of robots of this kind is not necessarily restricted to hospitals and other medical centres. It would seem that the commercial and academic organisations developing them have their eyes on a much wider target group. Simple robots of this type may already be found in such environments as shopping malls, where they perform uncomplicated tasks such as providing information, guiding people or carrying bags. Similar applications might be envisaged in large offices, railway and bus stations, airports etc.

Perhaps more than providing information, personal attention is about physical presence and touch. One of the most successful robotic applications currently being tested in nursing homes in Japan and Sweden and on autistic and handicapped children is Paro, the therapeutic robot seal. Paro - the name is derived from the abbreviation for "personal robot" – was developed by AIST and is modelled on a baby harp seal. It provides a robotic form of animal therapy, which investigations have shown can have three different kinds of effects: psychological (e.g. helping patients to be more relaxed and improving their motivation); physiological (e.g. actually improving their vital signs); and social (e.g. encouraging communication between patients and their carers). In essence, Paro does not help patients directly in the performance of daily tasks but evokes positive feelings and other subjective reactions that can stimulate brain activity and contribute to the quality of life in this and similar ways. It is well known that real live animals can have similar effects, but robots like Paro are easier to look after and though not inexpensive are probably cheaper in the long run. While Paro was originally developed for use by elderly residents of nursing homes, investigation has shown that it also has a positive effect on the carers who showed lower levels of stress and took fewer sick leaves when they worked in environments where Paro is used.

Figure 25
Paro and patients
Source: Paro information CD

In terms of the tatemae/honne dichotomy introduced in section 1.3, Paro may be said to have a very simple exterior (tatemae) combined with a relatively complicated interior (honne). Its price of € 4,500 may appear high for what is on the surface merely a cuddly toy, but in view of the savings in medicine consumption and the lower burden on personnel that its use brings about, some healthcare professionals consider it to be well worth the investment. Thus, interestingly, one of the most cost-effective healthcare robots seems to be one which does not replace the carer but is actually taken care of by the patients themselves.

2.6 Categorising robotics

The word “robot” originated from the Czech word “robota”, literally meaning work, labour or slavery, and figuratively “drudgery” or “hard work”. For some, a machine with a face is already a robot; looking humanlike is the essential feature. We adhere to a more technology-based definition of a robot as a machine with built-in computer power, linked to mechanical movement and sensors to detect the environment. Another important feature of service robots is that they have to operate in complex dynamic environments. Since many people associate the term robot with the idea of a humanoid, we prefer to use the generic term ‘robotic technologies’ or ‘robotics’ rather than ‘robot’.

A wide variety of robotic applications in the field of healthcare were discussed in the previous section. Their appearance ranged from very lifelike to highly mechanical. In the present section we will try to categorise robotic technologies in the healthcare sector and relate them to other trends such as domotics, ambient intelligence (AmI) or ubiquitous network society, and assistive technology. Our basic classification is based on the use of two specific dimensions or axes, the mechanical axis and the intelligence axis; see Figure 26. The former ranges from low-tech to high-tech (with special reference to developments in hardware, mechanics, and sensors) and the latter from low-intelligence to high-intelligence (with reference to computer power, software and networks).

When we position healthcare robotics with reference to these two axes, the extreme humanoid type – corresponding to most people’s image of a robot – is situated in the top right-hand corner. So far, this remains a distant ideal, which may be realised in practice in the distant future. The humanoid robots that have been developed so far are more like high-tech research instruments, serving as a beacon of innovation at which other researchers can aim. This is the tatemae, or superficial image, of robotics. Terms like “robotics” and “robotic technologies” subsume the broad diversity of robot-like technologies directed towards this goal. Study of existing robotic technologies allows us to analyse the honne, or underlying content, beneath the superficial image.

The various assistive technologies with which we are familiar are situated on the low-intelligence side of Figure 26. The aim of robotics is to incorporate intelligence into these machines, thus turning them into intelligent or smart assistive technologies. For example, a wheelchair is an assistive technology but does not normally include robotics. Nevertheless, robotics can be incorporated in the wheelchair, for instance to make it easier to manoeuvre. The technologies with a low mechanical content fit into the familiar field of information technology (IT). Incorporating mechanics will bring these technologies into the domain of robotics, for example domotics. Accordingly, the two axes of Figure 26 define (low-intelligence) assistive technologies and IT systems with little mechanical content as the two extreme forms of robotics. The following two sections elaborate on these two extreme types.

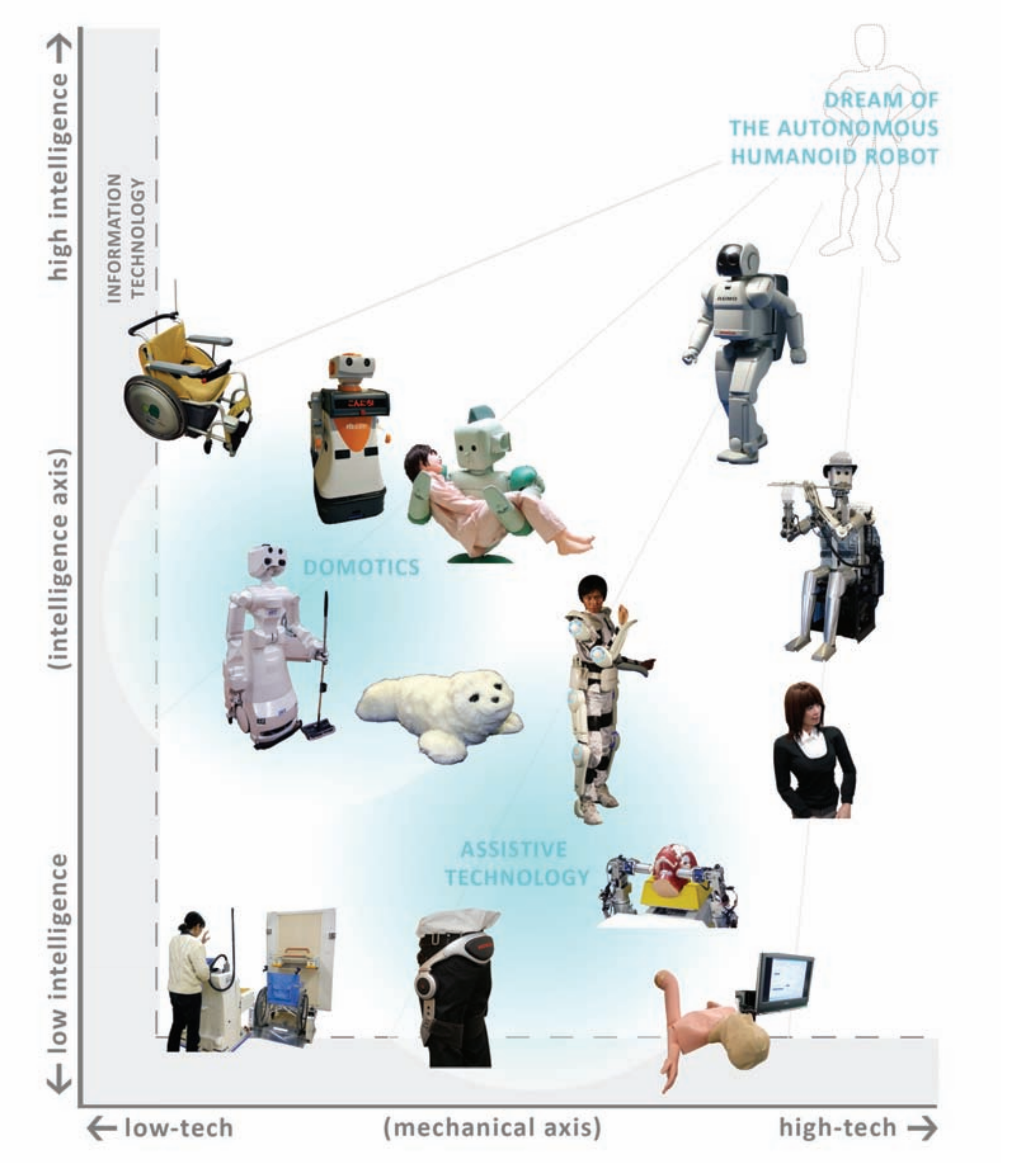


Figure 26
Classification of robotics systems in the field defined by the mechanical and intelligence axes

2.6.1 High-tech and low-tech assistive technologies

Many of the robotics applications arrayed in Figure 26 have similar goals and look similar, but each one is based on a different technological solution with its own advantages and disadvantages. The choice of solution in a given case will depend on the users' requirements and financial scope. This can be illustrated by comparing the HAL robotic suit with the two other robotic applications discussed in section 2.4.

The HAL suit can be used to strengthen both the upper body and lower body. The core technology used here is a system that detects and measures the EMG signals, allowing the user to 'naturally' operate the HAL suit. The upper part of the HAL suit enhances the wearer's arm strength. Dr. Kobayashi's Muscle Suit is also designed to enhance arm power, but uses air pressure to power the 'muscles'. Air pressure is often used to make movements smoother and more lifelike. By contrast, the HAL suit uses decentralised motors controlled by bio-signals to provide the extra strength.

The main difference between the leg unit of the HAL suit and Honda's 'Walking Assist' device is the degree of complexity involved. Both systems use motors to provide the power, but the Walking Assist device is controlled by a joint angle sensor instead of the nerve-impulse measurement system used in the HAL suit. The lower complexity of the Walking Assist device means that it is much lighter than the leg unit of the HAL suit, but also less easy to use. It weighs a mere 3 kg (as does the Muscle Suit) as compared with 10 kg for the leg unit of the HAL suit. Furthermore, the Walking Assist does not need calibration and can be put on more quickly. On the other hand it cannot support people who are unable to stand unaided, while it is claimed that the HAL suit can help even such users to walk again.

Honda's Asimo and Wabian (Waseda Bipedal humanoid) developed at Waseda University are both designed to walk much like humans do. Asimo was developed using a top-down approach in which each step and the coordination of the body parts needed to maintain balance during walking are pre-programmed (calculated in advance). Wabian on the other hand uses a bio-mimetic approach. There is no need to pre-programme each step, as it can auto-balance like humans. Another major difference between Wabian and most other humanoid types of robotics is that Wabian has a hip with three degrees of freedom, allowing it to walk more accurately and smoothly.

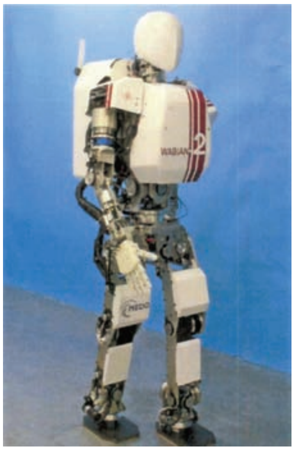


Figure 27 (Left)
Asimo, Honda
Source: website Honda

Figure 28 (Right)
Wabian, Waseda Univeristy
Source: presentation Takanishi Lab

The above are clear examples of robotics. During our research, we also found many human assistive technologies being developed at the same laboratories that are too simple to be dignified by the title ‘robotics’. For example, Prof. Noriyuki Tejima of Ritsumeikan University has been developing many devices to help the elderly and disabled such as robot arms, powered wheelchairs and simple mechanisms to help people get out of bed. Prof. Tejima claims his devices are much more effective than humanoids like Ri-man, but receive much less funding. He says that often in practice: “low-tech means low funding, high tech means high funding”.

2.6.2 Robotics in the Ubiquitous Network Society

Europe has its own vision of the future of the information society, namely ambient intelligence (AmI) (Van den Berg, 2009). The corresponding big idea in Japan is the Ubiquitous Network Society, in which all sensor, intelligence and network technologies are interconnected to form a cyberspace in which we live (Schilpzandt and van ’t Hof, 2008). It is envisioned that robotics will play a crucial part in this scenario, since robots are increasingly being equipped with a CPU and a network connection. These robots can collect or send information and communicate with one another.

We may mention two examples we encountered where robotics is being integrated into the concept of the Ubiquitous Network Society. The Advanced Telecom Research Institute (ATR) is currently developing a track-and-trace system for nursing personnel, by which nurses can keep track of each other. The system consists of an infrared identification (IR-ID) hairpin to be worn by the nurse and an IR-ID sensor system installed throughout the hospital, which receives the signals from the hairpins. Each nurse can check on her PDA where all her colleagues are.

So far, this is simply an advanced IT application, but not robotics. The researchers at ATR added a robotic dimension by giving nurses accelerometers to wear around their wrists. The Bluetooth-based sensor network then allowed specific hand movements performed by the nurses to be tracked with the aid of the accelerometers. For example, quick movements of the arms in specific directions with a specific speed and duration could indicate that a nurse was washing her hands. It proved possible to track more than a hundred specific actions performed by the nurse in this way. This application could provide the basis for a training system for nurses or a monitoring system used to check whether a nurse had performed specific required or prohibited actions.

Figure 29
IR-ID sensor system for nursing personnel: IR-ID hairpin (left) and locations of the accelerometer (right) worn by nurse.
Photos: Rinie van Est

A second example of the integration of robotics and network technologies is a wheelchair developed by the National Institute of Advanced Industrial Science and Technology (AIST). Use of a combination of guidance systems - a Global Positioning System, Radio Frequency Identification and laser sensors – all linked together would allow the wheelchair to move automatically from one location to another without bumping into objects or people. These examples demonstrate how robotic technologies are increasingly mingling with other technological developments such as ubiquitous computing.

Figure 30
Intelligent wheelchair, AIST
Photo: Christian van ‘t Hof

3 Social and innovation issues

Many social, ethical and legal and innovation policy issues need to be addressed before robotics technology can become generally accepted as a standard solution to the growing problems currently encountered in the healthcare sector. How do people relate to machines? What are their actual needs? What do they expect? What kinds of tasks are they willing to delegate to robotic technologies? Where is regulation needed in order to handle safety issues effectively, and where would (too much) regulation actually hamper desirable developments? In this section we will briefly touch on the following four key issues in this field: safety, robo-ethics, innovation culture and related issues, and finally user involvement and the need for multi-disciplinarily.

3.1 Safety of robotic systems

In Japan, safety is currently seen as the most pressing social issue with regard to healthcare robotics. As robotic systems of this type will interact with people and will operate in very close physical proximity to people, great care must be taken to ensure that they are safe before they are authorised for commercial use. Most of the applications we have seen in Japan are still in the developmental stage, and only a few are commercially available.

A clear sign of the need for safety and control over robotics applications is the big emergency cut-off button prominently placed on many of these devices. This also indicates that the safety issue has not yet been fully resolved. In addition, most if not all of these applications are not yet considered safe enough to run at high speed. In fact, many operate remarkably slowly. This is certainly the case with Ri-man and the Toilet Assist system, which take so long to do their job that the observer involuntarily wonders whether such applications are actually any use at all.

There is a need for standardisation of production systems and (safety) regulations to cut the costs of robotics and to facilitate their introduction on to the market. It is very difficult to predict at present when a product that is currently in development will actually be marketed, according to Professor Masakatsu Fujie of Waseda University. For example, the heart-beat canceller mentioned in section 2.3 could be implemented in five years, with favourable input from political and other relevant systems such as healthcare insurance. The requirements to be met before new medical devices can be approved for use are currently very stringent. It might be appropriate to relax them to a certain extent – without compromising safety – to allow useful products to be introduced on the market more quickly.

In addition, clear, comprehensive regulations governing the field of healthcare robotics, especially with reference to safety issues, need to be drawn up. We were informed at a meeting with the Ministry of Economy, Trade and Industry (METI) that discussions involving JARA, the Japanese representative of ISO, among others regarding the drafting of safety standards are ongoing. It is hoped to publish the first standards by 2011, but in view of the complexity of this issue these initial standards will probably only contain definitions without accurately quantified requirements.

3.2 Ethical issues

The main ethical issue associated with robotics concerns the autonomy of the devices: what should they be allowed to do? Although a robot should not be allowed to overrule human decisions, it should have a certain level of autonomy in order to enable it to go beyond the level of a simple machine. In Japanese robo-ethics, a distinction is made between three levels of consciousness, based on the ancient Chinese distinction between intelligence, emotion and willpower.

Robotic technologies are currently still at the level of “intelligence”: the robot can make decisions according to pre-programmed logical algorithms. Significant progress towards the emotional level may however already be distinguished. Prof. Ken Tomiyama of the Chiba Institute of Technology makes a distinction between ‘virtual’ emotions and real emotions at this level. When he speaks of virtual emotions in a robot he means that the robot behaves in such a way that it gives the observer the impression of having emotions, not that it is truly emotional in itself. According to Prof. Tomiyama, there is no need to create real emotions in robots: evoking real emotions in humans through virtual emotion is sufficient.

The above Japanese term for emotions, pronounced ‘kansei’, is already widely used in Japan to refer to the widespread efforts being made to introduce emotion into robotic systems and has made its way into the English-language literature on these activities. There is a Japanese Society of Kansei Engineering, and terms such as ‘kansei sensing’ and ‘kansei robotics’ are widely encountered. In this context, kansei has been defined as ‘the technology of emotion’. At Prof. Tomiyama’s Department of Advanced Robotics, a ‘kansei expressive modulator’ for robotics has been defined in which kansei is being applied in the following four steps: (1) The robot must detect and in a certain sense ‘understand’ human feelings (kansei detection); (2) the robot generates (virtual) feelings (kansei generation); (3) the robot conveys these feelings to the user (kansei expression); and finally (4) the robot adapts the feelings it conveys to fit the user's emotional world (kansei modulation). The first two steps are part of 'kansei engineering'. Once a 'kansei generator' is available, the robot can build its own "personality". This personality will however have to be continuously modified to ensure emotional bonding of the user with the robot (Miyaji and Tomiyama, 2003).

The final level of robotics would be to build willpower into robotic systems. The basic notion of willpower is the instinct for survival; even a germ has a will. If a robot has willpower, it will strive to maintain itself in good working condition. This could be an advantage, and some developments are already going on in this direction. For example, Honda's Asimo and Mitsubishi's Wakamaru robots will automatically charge themselves by going back to the docking station when their power gets low. This reduces the workload of the human maintenance staff slightly.

When this behaviour is derived from built-in willpower, how much and at what cost will a robot want to recharge itself? This raises complex issues, and brings us to the heart of the problem of giving a robot willpower. It seems clear that great care must be taken in drawing the line beyond which a robot should not be allowed to develop. Prof. Tomiyama has strong views on this subject: "We don't want to create Terminators, so we shouldn't build willpower into robots," he said during an interview. Yet some workers in this field believe that it may one day be possible to create virtual willpower in robotic systems.

This possibility leads to a discussion of whether there is a need for laws to govern the behaviour of robotic devices, like the 'three laws of robotics' introduced by Isaac Asimov in the 1940s as the conceptual basis for many of his science fiction stories. These laws are so well known that they are often used as a basis for discussions on the ethical aspects of robotics in the real world – a topic that has so far not been widely addressed in Japan, and certainly not by the general public: such discussions tend to be restricted to the engineers responsible for the development of robotic systems. An exception to this rule is Takeshi Kimura, an Assistant Professor from the Graduate School of Humanities and Social Studies at Tsukuba University who specialises in the study of religions and comparative philosophy, and who has developed an interest in robo-ethics from this perspective. He believes more discussions on robo-ethical issues including psychological and cultural issues are necessary, especially on when robotics should be introduced into a society and who should bear the responsibilities when something goes wrong. It is likely that the engineers will tend to disclaim the (main) responsibility in such cases, even though at present it is the decision of the engineers and researchers what kind of robotics are developed. The society on the other hand is still wondering what sorts of new robotics development it should implement.

An early example of robo-ethics: Isaac Asimov's three laws of robotics

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

Source: Asimov, 1950

Kimura holds that existing military robots have already broken Asimov's laws. Robotics in Japan is not directed towards military applications. This is in line with the strong anti-war tradition that has developed in Japan after the end of World War II, and which pervades all aspects of Japanese culture. Nevertheless, some of the robotic applications developed in Japan could be used by the military. Kimura has heard of such a case. The discussion was sparked by the fact that Prof. Sankai, the developer of the HAL suit, was approached by the American military concerning the possible application of the HAL technology for army purposes. Prof. Sankai declined it, as he believes that technology should be only used for the sake of helping humans, not hurting them. He wants the HAL suit to be solely used for peaceful purposes.

3.3 Innovation culture and related issues

It has often been claimed that the Japanese excel in creating new applications and incremental improvements but are not so good at coming up with new concepts and basic innovation. This also seems to apply in the field of robotics. Since the Aichi Expo of 2005, few new robotic systems have been developed by the major Japanese companies. They have tended to limit themselves to improving existing systems. Wakamaru, Asimo and Paro still exist, and are undergoing further development. New concepts developed after 2005 do not seem as impressive as the older ones. An exception to this rule can be found in the field of rehabilitation robotics, where many promising developments have arisen in the past few years.

During a discussion at the expert meeting held at the Dutch Embassy in Tokyo on how fast robotic applications may be expected to develop in the near future and what form the new developments will take, Professor Takashi Maeno from Keio University explained why robotics developments normally fail to meet expectations:"IT developments have led the public to expect great things of new technologies. For example, computer processing power has increased a hundred-fold in the past decade, giving rise to new, affordable applications. In robotics, however, specialised fields like actuator technology have only advanced by a factor two or three in the same period.” [The actuators are the motors which enable robots to move.] Hence, not all technologies are expected to advance as quickly as computer technology. Simple robotic appliances will probably enter the market In the near future, but not autonomous robots. They are still too complicated, and involve many technical issues that cannot be resolved within a couple of years.

Also, much robotics research is fundamental and there is no guarantee that useful applications will ever be derived from its results. Researchers working on the development of autonomous robots do not seem to be motivated by a wish to contribute directly to society. Many are probably fascinated by the challenge of making humanoids that resemble human beings as much as possible. Another widely heard reason for such research is the wish to make robots that ‘understand’ how human beings work and think. The idea is that if we can get a robot to learn, we will gain a better understanding of how human brains work. Prof. Tomiyama concluded that most of the work on robotics in Japan is pure research and not development. This seems to be borne out by the examples given in this report.

3.4 User involvement and multi-disciplinarity

It was stated in Chapter 1 that Japanese people generally like high-tech devices in general and robotics in particular. Nevertheless, even the Japanese are quite reluctant to let robots take over a wide variety of tasks. This was shown by a survey conducted by the UFJ Institute among Japanese people. People were asked which chores they would like robotic systems to perform and which not. Most of the jobs people would be quite happy for robots to do involved tedious repetitive work: clearing up after meals, cleaning and tidying up, doing the laundry, vehicle maintenance and repair, assembling and mending furniture and fetching things. Two tasks which people clearly stated they wanted to do themselves were cooking and taking care of their children – both closely related to personal care and responsibility. Clearly, the future of healthcare robotics as preferred by the Japanese citizen will not be one in which humanoids will replace humans, but rather one in which a shrinking labour force is increasingly supported by robotics.

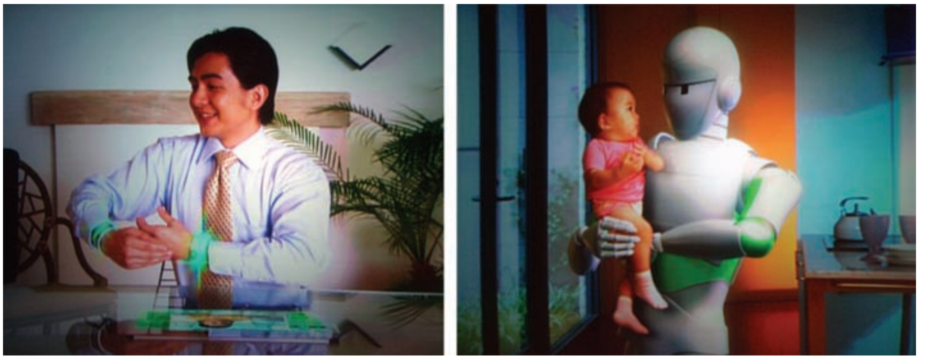


Figure 31
In the future vision of NTT DoCoMo, a networked household robot performs traditional parental tasks
Photos: Christian van 't Hof

Not only future visions portrayed by researchers are out of line with user needs. Little user involvement is to be found in the current development of robotics either. Most developments are driven by (mechanical) engineers, who concentrate on the technical challenges and possibilities. It follows that progress in this field is mainly driven by technology push rather than by market or social pull. For example, only engineers worked on the development of Ri-man: no representatives of other disciplines, such as social scientists and designers, were involved in this project.

There are exceptions to this rule, however. The robotics department of Waseda University works closely with the Women's Medical Hospital University to develop suitable medical robotics, while brain scientists and mechanical engineers work together on robotics developments at the Advanced Telecommunications Research Institute International (ATR). The Global Robot Academia of Waseda University presents another promising example. Their PhD programme addresses legal, ethical and cultural issues alongside the strictly technical issues. Although still in its infancy, this programme promises to deliver many multi-disciplinary robotics experts.

Besides involving other scientific disciplines, it is also important to approach a problem from the user's perspective. Studying users' needs and problems during the development of a product can lead to a very different outcome. The development of Paro, the therapeutic seal robot, is a good example of this. This robot was initially designed to resemble a cat. The problem here was that most people are well acquainted with the appearance and behaviour of cats, and the cat robot would have to give a very close approximation to the real thing before it could be considered acceptable. The prototype cat robot did not meet these high expectations, and was consequently not a success. These initial results led the developers to model the therapeutic robot on another attractive little animal that would be well known to users but of which they would have little or no first-hand experience: a baby seal.

A brief note on the economic feasibility of robotics from a Dutch perspective

The Dutch introduced surgery to Japan in the 19th century. This was the first time the Japanese encountered Western medicine. Since then the Japanese have improved their medical techniques enormously, and now produce surgical instruments of superb quality for hospitals. In the field of robotics, the roles are reversed: Japan is the world leader here, and the Dutch are learning from them. During our stay in Japan we met a group of Dutch healthcare managers who were there on a study tour. Most of them agreed that both Japan and the Netherlands are facing the same demographic trends (see section 1.1), the consequences of which could be alleviated by the use of healthcare robotics. But there are many differences as well; apart from those concerning the perception of robotics alluded to in section 1.2.1. Jan Cooijmans, chairman of the Ommelander Hospital Group located in the north of the Dutch province of Groningen, noted striking differences in hospital efficiency. For example, one task that would require 33 radiologists for its performance in Japan could be carried out by 5 radiologists with less highly qualified support staff in the Netherlands. He also observed that wages in the Netherlands were considerably higher than in Japan, leading to higher operating costs but perhaps also making the work more attractive. Since the price of healthcare is much lower in Japan, even though the price of the technology used might be the same in both countries, the introduction of robotics technology would not save as much money in Japan as it would in the Netherlands. On the other hand, of course, as indicated above public acceptance of robotics may be much higher in Japan due to long-standing cultural differences.

4 Conclusions

In this study we have analysed both the more superficial aspects (tatemae) and the underlying content (honne) of healthcare robotics in Japan: the official promises and popular media images, and the hardware and software behind the façade that make the systems work. Our initial premise was that in Japan, as in many other countries, people are living longer and fewer babies are being born. This will lead both to a rise in the demand for healthcare and a drop in the number of people providing this care. We have investigated the extent to which robotic technologies will be able to provide a solution to this upcoming challenge.

We found a wide range of different robotics technologies in use in healthcare. These ranged for example from humanoid robots mimicking human behaviour that played a role in fundamental research on the workings of the human body and people's reaction to robots to simpler robotic systems mimicking body parts to help students and researchers to learn more about the function of the human body. We also encountered high-tech mechanical systems which can help surgeons to perform more precise operations, alongside a range of robotic systems for rehabilitation and care. These included for example, sensitive devices with wheels or joints to take some of the load off carers, to support disabled people during the rehabilitation process and to help older people to live more independently and to enhance their quality of life.

Despite this broad variety of robotics applications in healthcare, we noted that most research efforts and funding seem to be focused on the very high-tech end of the robotics scale. Popular media and the scientists and engineers working on these systems combined to project the image of multifunctional humanoid robots, which may one day replace carers.
Such ambitious goals are successful in unleashing public funds for fundamental research in the field of robotics. However, such advanced humanoids are not likely to enter the healthcare sector in the foreseeable future. This makes it important to look beyond the surface of the media hype and focus on the wide range of robotic technologies that do stand a realistic chance of supporting healthcare workers in their daily activities and care recipients in their daily life. A paradoxical example is the therapeutic robot seal Paro, which has been shown in trials to be reasonably cost-effective and well accepted. This achieves its therapeutic effect by being taken care of by patients instead of caring for them. It seems to empower the patients.

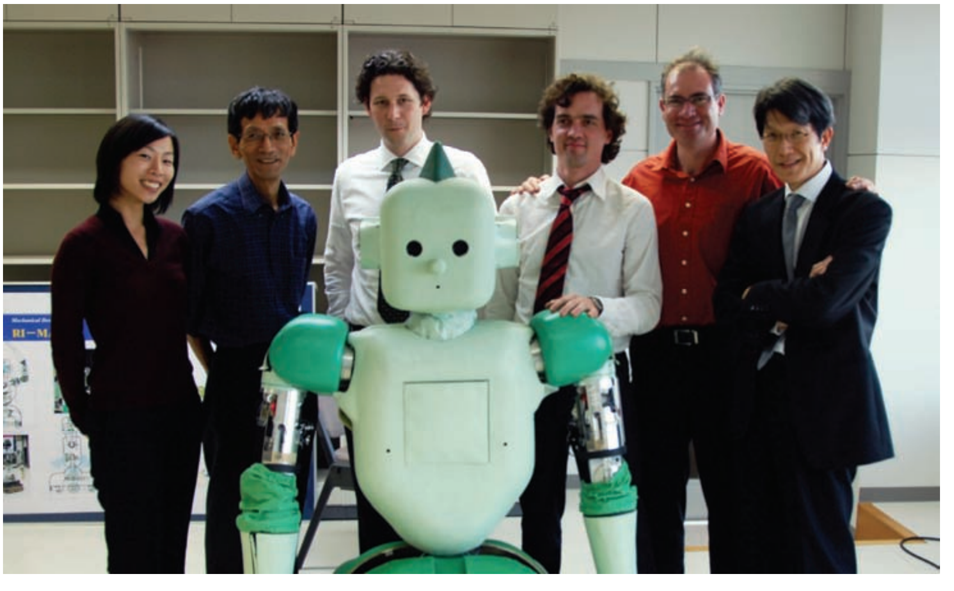
We may conclude that while robotics applications may not be the final solution in facing the challenge of an aging society, they are certainly worth considering. And in order to develop technologies that can be used in society and not just in the laboratory, a shift in policy focus is needed towards robotic technologies that address real needs in the healthcare sector. A more user-oriented, multi-disciplinary approach is required. Engineers may already find it difficult to exchange some of their knowledge with colleagues, since hands-on experience is less easy to transfer than words. Still, in the end, they will only be able to continue their work if there is a public demand for it.

The successful development of new robotic technologies will demand close attention to a range of ethical, social, legal and innovation issues now. The need to address safety issues is commonly agreed upon in Japan. Unfortunately, much less attention is paid to ethical issues, and privacy issues are generally ignored. Engineers should realise that a more socially sensitive approach would not hamper the development of robotics, but would actually help them to formulate common concrete challenges. What should robotic applications look like? What kind of tasks and decisions can be delegated to the machine? Do we need high-tech solutions, or will low-tech ones suffice? There are important lessons to be learnt in this field for Japan but also for the Netherlands. Moreover, these are matters of concern not just to engineers, but to society as a whole.

Acknowledgement

We would like to thank all the robotics experts who have contributed to our understanding of the current developments in Japan. We also owe a debt of gratitude to the staff of the Dutch Embassy in Tokyo, in particular to Kikuo Hayakawa and Daan Archer who arranged numerous valuable contacts. Also, we are very thankful to Daan Archer for providing the research team with important information for this report and for making our stay in Japan very pleasant.

Ying Ying Lau, Christian van ‘t Hof and Rinie van Est



The research delegation at their visit to Dr. Eng. Hosoe (second from left) of the BMC Riken Researchers (from left to right): Ying Ying Lau, Daan Archer, Christian van ‘t Hof, Rinie van Est and Kikuo Hayakawa

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[Note: most of the information has been obtained during interviews (see Appendix A for list of visits) and the expert meeting held on 27 November 2008 at the Dutch embassy in Tokyo.]

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Appendix A: Meetings and visits

The following table shows the meetings and visits in Japan that has been completed in the period of September 2008 till January 2009.

Date	Type	Institution/department	Person
10 Oct 2008	Seminar	"Present and future of domestic robots", Robo Japan 2008	Helen Greiner Chairman iRobot
12 Oct 2008	Exhibition	Robo Japan 2008	Pacifico Yokohama
17 Oct 2008	Meeting	Waseda University Fujie Laboratory	Masakatsu Fujie Professor
20 Oct 2008	Meeting	Keio University School of System Design and Management	Takashi Maeno Professor
21 Oct 2008	Workshop	"Service robots and applications", German Cultural Center	Organised by Fraunhofer Institute
22 Oct 2008	Lab visit	Waseda University Takanishi Laboratory	Atsuo Takanishi Professor
23 Oct 2008	Meeting	Chiba Institute of Technology Department of Advanced Robotics	Ken Tomiyama Professor
31 Oct 2008	Lab visit	Osaka University Intelligent Robotics Laboratory	Several researchers
5 Nov 2008	Tour	Kansai Science City Tour: ATR & Seksui house	Organised by Kansai Economic Federation
6 Nov 2008	Meeting	Nissan Motor Nissan Research Center	Dr. Norimasa Kishi Research Director
7 Nov 2008	Lab visit	Tokyo Institute of Technology Hirose Laboratory	Shigeo Hirose Professor
9 Nov 2008	Tour	Panasonic Eco & Ud house	Panasonic Center
12 Nov 2008	Briefing	Council for Science & Technology Policy (CSTP) briefing, Royal Norwegian Embassy	Dr. Masuo Aizawa
12 Nov 2008	Visit	Honda R&D Fundamental Technology Research Center - Walking Assist	Kiyoshi Oikawa (chief engineer) & Ken Yasuhara

13 Nov 2008	Demo	Honda Asimo demonstration	Honda headquarters
15 Nov 2008	Visit	Museum for emerging science and innovation (Miraikan)	Tokyo
25 Nov 2008	Visit	Advanced Telecommunications Research Institute International	Several researchers
25 Nov 2008	Lab visit	Ritsumeikan University Tejima Laboratory	Noriyuki Tejima Professor
25 Nov 2008	Lab visit	Osaka University IRL: Repliee Q2	Researcher
26 Nov 2008	Tour	Toyota Motors Showroom & engineering plant	Ron Haigh
26 Nov 2008	Lab visit	Riken-Tri Collaboration Center for Human-Interactive Robot Research	Dr. Eng. Shigeyuki Hosoe and other researchers
27 Nov 2008	Expert meeting	"The future of healthcare robotics"	Organised by TWA-Tokio & Rathenau Institute
27 Nov 2008	Lab visit	Tokyo University of Science Kobalab	Hiroshi Kobayashi Professor
28 Nov 2008	Lab visit	Waseda University Fujie & Takanishi Laboratories	Prof. Fujie, Prof. Takanishi & researchers
28 Nov 2008	Visit	AIST Paro	Dr. Takanori Shibata
28 Nov 2008	Visit	Toilet Assist Device & Robotic Wheelchair	Researchers
28 Nov 2008	Visit	Cyberdyne HAL suit	Philip Wijers
10 Dec 2008	Meeting	Ministry of Economy Trade and Industry, Industry Machinery Division	Dr. Motoki Korenaga
10 Dec 2008	Meeting	Ministry of Economy Trade and Industry, Medical and Assistive Device Industries Office	Hiroshi Kato & Hiroya Hirose
19 Dec 2008	Meeting	The University of Tokyo IRT Foundation	Dr. Isao Shimoyama Dean
16 Jan 2009	Meeting	Ministry of Economy Trade and Industry, CRDS	Dr. Kunihiko Niwa

Appendix B: Expert meeting

An expert meeting has been held on 27 November 2008 at the Embassy of the Kingdom of the Netherlands, Tokyo.

Attendees

Rathenau Institute

- Dr.ir. Rinie van Est, coordinator technology assessment
- Christian van 't Hof, senior researcher

Japanese experts

- Prof. Takashi Maeno, Keio University
- Prof. Ken Tomiyama, Chiba Institute of Technology
- Dr. Takanori Shibata, National Institute of Advanced Industrial Science and Technology (AIST)
- Dr. Takeshi Kimura, University of Tsukuba
- Mr. Yusuke Yasukawa, project coordinator, New Energy and Industrial Technology Development Organization (NEDO)

Dutch Health Care Delegation

- Jan Cooijmans, chairman board of directors, Ommelander Ziekenhuis Groep

Netherlands Office for Science and Technology

- Thomas Bleeker, counsellor for Science and Technology
- Daan Archer, attaché for Science and Technology
- Kikuo Hayakawa, project officer
- Ying Ying Lau, researcher

Programme

10.00h	Welcome
10.05h	Introduction of the expert meeting "The Future of Healthcare Robotics"
10.10h	Introduction round of experts and organisation
10.40h	Future visions on healthcare needs: What can we expect in 2025 and what do we have to do now?
11.20h	Break
11.40h	Future visions in healthcare robotics: What will be the technological options, and which tasks in daily life may be automated?
12.20h	Final discussion: Where do visions in healthcare and robotics complement, where do they collide?
13.00h	Lunch

Appendix C: List of institutions

Brief explanations of institutions that are mentioned in the report are provided below.

Institution	Brief description
National Institute of Advanced Industrial Science and Technology (AIST)	AIST, established in 2001, is a research organisation, funded by Japanese government to a large extend. Its headquarters are located in Tsukuba and Tokyo. AIST has over 50 autonomous research units in various research fields related to science and technology. About 2500 research scientists and more than 3000 visiting scientists, post-doctoral fellows and students work at AIST. The most well-know robotics development from AIST is the seal-robot Paro, by dr. Shibata.
Advanced Telecommunications Research Institute International (ATR)	ATR, founded in 1986, aims to promote basic and creative research activities in telecommunications. Its core institution is currently located in “Keihanna”, a major science city created in the Kansai region.
Intelligent Robotics Laboratory (IRL), Osaka University	The IRL is lead by professor Ishiguro, famous for his twin-humanoid and android. These robots are tele-operated and studies regarding humanlike presence are done amongst others.
Bio-mimetic Control Research Center (BMC), RIKEN	RIKEN carries out experimental and research work in a wide range of fields, including physics, medical science, and engineering. It covers mostly basic research, but also some practical applications, such as the Ri-man, a development by the BMC. Currently the BMC has finished it work, and further development on the Ri-man is taken over by Riken-Tri Collaboration Center for Human-Interactive Robot Research, lead by professor Hosoe.
Kobalab, Tokyo University of Science	Kobalab, lead by Dr. Kobayashi, has developed the robotic muscle-suit amongst others. Dr. Kobayashi claims that this suit is much better than the HAL-suit by Cyberdyne.
IRT Foundation, The University of Tokyo	The IRT Foundation to Support Man and Aging Society merges information technology (IT) and robot technology (RT) into a multi-disciplinary research area. IRT innovation that combines IT and RT aims to support society and life and to bring social transformations by focussing on developments in (1) humanoids (2) social and daily life support systems, and (3) personal mobility devices.

Cyberdyne Inc., University of Tsukuba	Cyberdyne Inc. is a venture firm aiming to utilise accomplishments by Prof. Sankai and his laboratory at University of Tsukuba. Cyberdyne's main product is the robot suit HAL, a wearable suit that can expand and improve physical capability. Recently the European representative office has been opened in the Netherlands.
Humanoid Robotics Institute (HRI), Waseda University	The HRI consist of many robotics laboratories of which the Takanishi laboratory and Fuije laboratory, resp. lead by professor Takanishi and professor Fujie, have been visited. Both of these laboratories focus on robotics development for cure and care.

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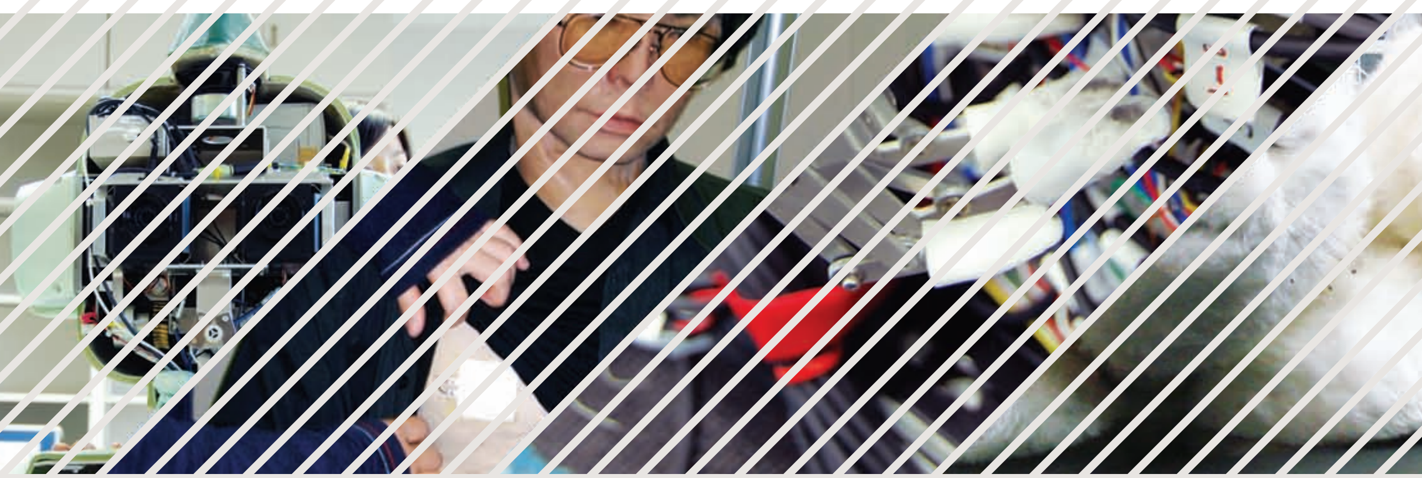

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