Lab Tour to Asia
Japan, South Korea and China

Alois Knoll, Geoff Pegman, Rolf Pfeifer, Marie-Luise Neitz, Andreas Müller, Jianwei Zhang, Fabio Bonsignorio

ECHORD European Clearing House for Open Robotics Development

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„Globalization has changed us into a company that searches the world, not just to sell or to source, but to find intellectual capital – the world's best talents and greatest ideas."

Jack Welch, Chairman and CEO of General Electric (1981–2001)

To look beyond the borders of Europe to find the greatest ideas and most successful methods to transform scientific knowledge into products and services that create added value for the customer are the missions of ECHORD's structured dialogue. After consulting robotic experts in North America on how to organize academia-industry collaboration, ECHORD visited about 30 labs in three Asian countries to investigate their best practice of academia-industry collaboration. The results are presented in this report.

The ECHORD team would like to express its sincere gratitude to our European travelling experts for sharing their expertise with us. They did this entirely free of charge and very generously dedicated their time to the tour and to this report. We would also like to sincerely thank the Asian labs and their professors, managers, senior researchers and young professionals for hosting our expert group. They openly shared their best practice with us and allowed us to integrate their success stories on knowledge transfer into this report. My special thanks to the members of the ECHORD team who made a significant contribution to the organization of the tour and the literature research for this report: Laura Voss and Anna Marcos Nickol. Last but not least, I would like to explicitly acknowledge the work of Amy Beth Bücherl for proofreading this report and for her contributions to the excellent coordination of the entire tour.

Munich, September, 2012

Alois Knoll, ECHORD Coordinator

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1. Introduction

In October 2011, ECHORD – the European Clearing House for Open Robotics Development – the largest EU-funded project in robotics to date, accompanied a group of renowned robotics experts to a total of 30 labs in the USA and Canada. The mission of the group was to summarize their recommendations on best practice for academia-industry collaboration and the most successful methods of technology transfer.

Their major findings on the tour include the statement that the window of opportunity for service robotics in industry is now open. Professional service robotics is seen as a market, but domestic service robotics is not yet perceived as an opportunity. In addition, the 'classical' areas (elderly care, medical robotics, exo-skeletons, etc.) may not be perceived as spectacular any more, but they are still being very actively pursued. The experts found few programs for encouraging spin-offs to promote the transfer of technology developed by academic labs to the commercial market place. Industry-academia collaboration was mostly restricted to the local area and based on trust and long-term relationships. The degree of application-orientation versus research-orientation of academic labs varied widely among the institutions visited.

Another purpose of the trip was to explore the funding schemes in the U.S. and to get some inspiration for Horizon 2020.

In the summer of 2012, the same group of experts visited three Asian countries – Japan, Korea and China – to make a comparison with the insights gained in the USA and Canada. In all three countries, we found an industrial structure which was totally different from the one in North America. However, the similarities between the three Asian countries were striking. They are also uniform in recognizing the one huge challenge that will affect their prosperity, competitiveness and economic growth: the shrinkage and ageing of their populations, which has been unprecedented in history to date. Both the industrial structure and this monumental societal challenge have had a massive impact on robotics. Thus, medical and assistive robotics and elderly care service robotics have a different significance in Asia than they have in the US. They have influenced the funding schemes, the approach in robotics and the R&D in government and companies alike.

The strengthening of academia-industry cooperation is the primary goal of the ECHORD project. Two initiatives achieve this: first of all, 15 Mio Euro (of 19 Mio Euro total project funding) are invested in 51 experiments, in which target-oriented research focused on specific problems is done by small consortia in which academic partners and industrial users join forces. Secondly, via the 'structured dialogue', investigating academia-industry cooperation and using tools including targeted group interviews, Delphi studies, online questionnaires, conferences, workshops and extensive literature research. The purpose is to establish the best practice of academic-industrial cooperation in Europe and to identify its weak areas.

The two international lab tours are also initiatives undertaken under the umbrella of the structured dialogue. The purpose is to look beyond the frontiers of Europe and to identify excellent approaches which are worth duplicating to further improve our industry-academia collaboration without re-inventing the wheel.

The findings of both tours – USA/Canada and Asia – will be compared with the data on Europe, collected via ECHORD's structured dialogue, culminating in a three-continent comparison on the trends and best practice of successful knowledge transfer from the lab to the market place.

2. Trip Overview

The ECHORD expert group in Korea

Like last year on the trip to North America, the group consisted of experts from academia and European robotics industry. The tour's kick-off dinner took place in Tokyo, Japan. The first day, June 18th, was spent in Tsukuba at the National Institute of Advanced Industrial Science and Technology (AIST), followed by various lab visits at the University of Tokyo the next day. From there, the experts took a train to Sendai City to visit Tohoku University on June 20th. The group then flew to Fukuoka to visit the last lab in Japan, namely the YASKAWA Corporate Research and Development Centre in Fukuoka.

Trip Overview

On the evening of June 21st, the experts left Japan and took a flight to Seoul, Republic of South Korea. In the capital area, the group had the opportunity to see several labs, both industrial and academic. They got invited by the Korea Institute of Industrial Technology (KITECH), LG, SungKyunKwan University, the Korea Institute of Science and Technology (KIST) and Yujin Robot Co. Ltd.. In addition to the lab visits, a workshop with the Korean Ministry of Knowledge and Economy was held at KIST, as well as a round table with Hyundai, Samsung and the Korean Association of Robot Industry (KAR). The Seoul visit included a free weekend during which a part of the group went to the EXPO 2012 at Yeosu. Moreover, a short trip to Daejon was undertaken on June 25th in order to see the Korea Advanced Institute of Science and Technology (KAIST) and the Electronics and Telecommunication Research Institute (ETRI).

On June 27th the group took a plane from Seoul to Beijing, China. Besides the visits at the research institutions Beijing Institute of Technology (BIT), Beihang Uiversity and

Tsinghua University, the experts had the opportunity to explore the possibilities of European-Chinese cooperations at a meeting with the Chinese Ministry of Science and Technology. On June 30th, the group flew to Shanghai, the tour's last stop. They saw labs at Shanghai Jiao Tong University and visited the Kunshan Industrial Technology Research Institute (KSITRI), a new research center which was established in order to foster the region's academia-industry collaboration.

After these intensive but very informative two weeks, the group broke up in Shanghai and the experts flew back to Europe on July 1st.

2.1. Sites on the tour

Site	Labs visited
Tsukuba, Japan	▪ National Institute of Advanced Industrial Science and Technology – AIST
Tokio, Japan	▪ University of Tokyo
Sendai City, Japan	▪ Tohoku University
Fukuoka, Japan	▪ YASKAWA – Corporate Research and Development Centre
Seoul, South Korea	▪ Korea Institute of Industrial Technology – KITECH ▪ LG ▪ SungKyunKwan University – SKKU ▪ Korea Institute of Science and Technology – KIST ▪ Yujin Robot Co. Ltd. ▪ Hyundai, Samsung and Korean Association of Robot Industry (KAR)
Yeosu, South Korea	▪ EXPO 2012
Daejon, South Korea	▪ Korea Advanced Institute of Science and Technology – KAIST ▪ Electronics and Telecommunication Research Institute – ETRI
Beijing, China	▪ Ministry of Science and Technology China – MOST ▪ Beijing Institute of Technology ▪ Beihang University ▪ Tsinghua University
Shanghai, China	▪ Shanghai Jiao Tong University ▪ Kunshan Industrial Technology Research Institute – KSITRI

Note: at most of the universities, the group visited several individual labs which are not all listed in detail here.

3. Analysis

This chapter will provide a profound basis of data and objective background information on the following topics: the triggers of Asian robotics, the Asian robot markets, the funding of research and development, the most important characteristics of the technology transfer in Asia and an overview of academic education with respect to technology transfer. To some extent, this information is the result of extensive literature research on the respective topics. But there are also gaps in the existing literature that could only be filled with findings gathered during the lab tour.

3.1. Triggers of Robotics in Asia

As early as 2001, Gruber et al [15] identified the aging of its populations as the single most important, long term, fiscal issue facing the developed world. They predicted a steep increase in the ratio of the elderly to the working age population in nearly every developed country within the first half of the 21st century.

Although Europe has to cope with a demographic decline, low natural growth and the aging of part of its population, the challenge is much more severe in Asia. The Asian continent – mainly East Asia – will be facing population aging at an unprecedented pace over the next 50 years. The percentage of the Asian population which is 65 or older will increase by 314 percent – from 207 million in 2000 to 857 million in 2050:

Region or subregion	Number of people age 65 and above (1,000s)			Percent increase
	2000	**2025**	**2050**	**2000—2050**
Asia	206,822	456,303	857,04	314
East Asia	114,729	244,082	393,802	243
Southeast Asia	24,335	57,836	128,958	430
South Asia	67,758	154,358	334,28	393
Source: United Nations (2001) Notes: All data are based on the United Nations medium fertility variant. The analysis includes Taiwan.				

Projected growth of Asia‘s elderly population, source [53], p.83

New figures released by the Japanese government in January 2012 [14] suggest that the world's oldest country – Japan – is about to get even older. The population decline is expected to accelerate over the next few decades (14 % - 25 % decline by 2050). Thus, 50 years from now, the number of people aged 65 and older are expected to increase from 23 % to between 35 - 40 % [28].

The Japanese already have the highest life expectancy in the world. A forecast conducted by the National Institute of Population and Social Security Research every five years suggests that the life expectancy for Japanese women will increase from 86 to 91 over the next half century. The number is expected to rise from 79 to 84 for men. The aging population will result in insufficient manpower and therefore insufficient resources for elder care, increasing costs for health insurance and increased household burden, thus, driving the need for robotics in Japan. [28]

The world's most rapidly aging population, however, is to be found in South Korea. By 2050, the median age of the Korean population is projected to be 57 years (now it is 37 years). The aging population coincides with the lowest fertility of any country, as the average number of births does not exceeded 1.3 (the replacement rate is 2.1).

China is also in a dilemma. The effect of the one-child-policy on the population is amplified by China's lowered mortality rate. By 2005, citizens over 65 years of age accounted for 6.96 percent of the whole population. By 2020, over 23 percent of China's citizens will be over age 65 – hence, the only child today will have two parents and four grandparents to look after. [63]

Over the next few decades, the ratio of elderly people to those of working age will rise steeply, from 10 % now to 40 % by 2050. From about 2030 on, the country will have more elderly dependants than children, whereas in most other developing countries the opposite will remain true for the next few decades. China's one child policy lowers in the long term the supply of cheap labor. [11]

"China's pattern of aging is very similar to that in Japan, Hong Kong, Singapore, South Korea and Taiwan. The difference is that in China this is happening at a time when the country is still relatively poor." [50]

In China, however, there is another aspect that strongly promotes industrial robot installations: the push for higher wages and better quality products. The boom in industrial robotics (as outlined in the following chapter of this report) is largely driven by China's automotive industries, but also by factories making products from metal, rubber and plastics, and – to a lesser extent – producers of food, beverage and pharmaceutical goods. "But it's in electronics factories that the shift could be greatest […]." [11]

Many reasons contribute to this development – some of which are specific to Asia:

- The state has, for too long, relied on the family, including the extended family, to shoulder the cost of childrearing.
- The intense 'education fever' (mainly in Korea and China) means that parents invest their own resources in after-school tutoring and classes for children. Korea has the highest proportion of private educational expenditures of any OECD country, and spends little on public childcare.

- The one child policy in China
- The fear of young Asian women to risk their career perspectives to raise children. Part-time work is basically unknown in the formal labour market in Korea.
- The push for higher wages, a desire for better quality products (particularly in China)

However with regard to China in particular, as Gro Harlem Brundtland, former Director-General of the World Health Organization, noted: “While the developed countries became rich before they became old, the developing countries will become old before they become rich.” [23]

In the Asian countries we visited, the aging population is thus the major trigger of investments in robotics. Apart from the impact on the labor market, this development will have a major influence on the need for institutional elderly care, thus changing Asian societies – which till now relied on family care. The aging society has a massive impact on the governmental funding schemes in Japan, Korea and China. It has, for instance, shifted the emphasis in Japan from humanoids to elderly care robotics. It has even influenced the way industry and academia co-exist and interact with each other in the field of robotics research.

The first step is to replace the human workforce with robots to keep up the economic momentum despite the lack of human labor. This can be done in industrial manufacturing, but also in areas like education and service. The second area of impact will be the creation of a new market – the elderly care market.

While the need to find ways to handle the aging population is the unified factor that triggers investments into robotics in all three Asian countries, there are additional (and less strong) factors to promote R&D in robotics. Despite the financial crisis and the subsequent drying up of funding, there is still a relatively high degree of curiosity-driven research in academic labs in Japan – with amazing results in the field of android robotics. Both Korea (where robotics has been selected as one of the ten areas of technology for economic growth; the total funding for robotics is about US$80 million per year [5,6] (for more information see chapter 3.3) and – to a lesser extent in China – robotics is seen as part of the industrial growth strategy. Finally, the defense needs in Korea (due to the tensions with North Korea) are a significant driver of investments in robotics. Korea has a fairly high degree of military funding which pushes innovative research (like in the United States).

3.2. Asian Robot Markets

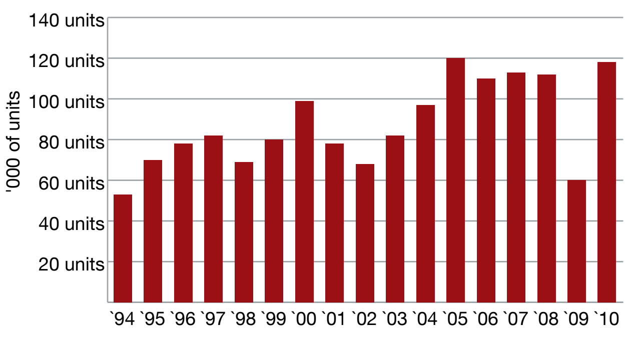
Increasing the efficiency of industrial manufacturing is the only way to cope with the shortage of labor force and the cost increases incurred by the demographic changes many countries, including those visited in Asia, have to face. In addition, aspects geared toward the big societal challenges of our century – like sustained economic growth, products manufactured in an environmentally-friendly way and measures to reduce the consumption of energy – are becoming more and more important everywhere. This means that there is a clear need for new production methods and automation (based on robotics technology) as the key to future success.

3.2.1. Industrial robots worldwide

Analyses of the International Federation of Robotics (IFR) underline that worldwide robot sales almost doubled in

2010 (market size: 118,337 units). Thus (with a growth rate of 97 %) the worldwide annual supply of industrial robots once again reached the peak attained in 2005. Due to the worldwide economic and financial crisis, 2009 was a black year for industrial robots. Compared to 2008, annual sales declined by 47 % (60,000 units) – the lowest level reported since 1994. This decline was unprecedented. [20]

Worldwide annual supply of industrial robots 1994-2010



The upsurge of robot installations continued throughout 2011: the increase – which was originally expected to reach a new peak of 139,000 units (+18 %) – exceeded all expectations. In fact, 165,000 industrial robots were sold worldwide, meaning an increase of 37 % from 2010. “The International Federation of Robotics projects the global market to reach $100 billion in 2018.” [51]

The growth was mainly driven by the automotive industry (modernization and increase of production capacities), but the exploitation of robotic technology also increased in the metal industries and engineering. Electrical engineering and the electronic industries which had already nearly tripled their robot installations in 2010, increased, albeit slightly, the use of robots in 2011. In nearly all the industrial branches mentioned, there is still a huge unexploited potential.

Robot installations in Asian countries also fell significantly in 2009. The only Asian country that disconnected its robot sales from the general market trend was Singapore, where more units were installed than in India in 2009. [36]

In 2010, the total amount of the consolidated markets in Japan, South Korea and China was 60,400 units. In Japan and South Korea it was 45,400 units, in China, 15,000.

This is a clear comeback after a severe drop in 2009, where the market – due to the financial crisis – shrunk by 50 % to a size of 30,100 units compared to 2008. The worldwide recovery in robot sales in 2010 was driven by the demand in Asia (incl. Australia and New Zealand), where sales increased by 132 % to about 70,000 units, the highest level ever recorded.

The most dynamic Asian markets were China, the Republic of Korea and the ASEAN countries. As outlined by the IFR Industrial Robot Statistics, sales to these markets almost tripled. [20] All Asian countries visited on the tour have contributed to this development, even though the level of their contribution varied significantly.

Despite only moderate growth rates, Japan (+27 % with 28,000 industrial robots sold) and South Korea (+9 %, 25,000 units) remained the largest users of industrial robot technology in 2011. In 2011 China, the US and Germany reached new peak levels. However, they still could not reach the levels of the two biggest markets, which had only a sub-average increase. The combined market of Japan and Korea remained the biggest market for industrial robots.

Japan

Japan was the first industrialized economy to fully embrace automation and robotics technology. Its percentage of world manufacturing output increased tremendously during the 1980s and reached its peak with 21.6 % in 1993. Since then, "[…] it has steadily declined to (a still comparatively large) 10.7 percent in 2010." [52]

Japan's boom was mainly driven by technology. There was a strong domestic consumer market demanding smaller electronic products (miniaturization). New manufacturing technologies based on robots provided Japanese firms with the tools to beat their international competition in price without sacrificing quality. As a result, Japan became the world's leader in electronics consumer products like cameras, calculators and stereos. [52]

At the time of the Asian economic crisis in the late 1990s, Japan hosted three of the world's biggest automotive manufacturers – Toyota, Nissan and Honda – 57 % of the world silicon wafer production and 20 percent of the world semiconductor output. The industrial structure of Japan with strong, huge companies that have been very successful for a long time is one of the major challenges for spin-offs trying to crack the market. Based on the assumption that the number of SMEs has a significant impact on the innovative power of a country, the industrial structure can be a handicap for Japan.

Due to an employment structure where employees are rarely fired, there has been little resistance to mechanization from the Japanese labor force. [28] Exposure to high technology has made Japanese citizens more acutely aware both of the benefits and shortcomings of such technology. Japanese people do appear to have a more positive attitude toward function-oriented technology, such as assembly line robotics, than U.S. citizens. Such technology is more likely to be perceived as adding efficiency to the human workforce instead of being seen as a threat to replace it [26].

Nowadays, Japan is actually experiencing its most challenging period since World War II. The country was hit by the terrible earthquake, tsunami, and nuclear reactor crisis. "Adding to Japan's economic woes has been deflation and depressed corporate income." [36]

Due to the depressed corporate income resulting from lower private consumption, company investments in robotics R&D has decreased. [36] There have been reports on a continuing decline in robot investments in Japan since 2006.

Japan is still the country with the highest robot density in the world. This phenomenon is due to the automotive industry which operates about 1,436 industrial robots per 10,000 employees. The robot density in other areas of Japanese industry is much lower (some 191 industrial robots per 10,000 employees.) [52] In total, about 36 % of all industrial robots in operation worldwide (about one million) are used in Japanese factories, as reported by the Japan Robot Association (JRA).

The robotics market has gone from earning Japanese companies $5.2 billion in 2006 to $26 billion in 2010. The Japanese government hopes to see this jump to $70 billion by 2025. [39]

This development was possible due to the long-term financial resources and strong domestic market which made Japanese companies extremely competitive. Their robots spread all over the globe. Only a few non-Japanese companies managed to survive in this market, including Adept Technology, Stäubli-Unimation, the Swedish-Swiss company ABB (ASEA Brown-Boveri), the Austrian manufacturer igm Robotersysteme AG and the German company KUKA Robotics.

The global robotics market is almost entirely dominated by Japanese manufacturers. Denso Corporation, Epsom, Kawasaki Heavy Industries, Yaskawa Electric Corp., Honda, Toyota and Toshiba are among the largest.

Investments in Japan can be expected to gain momentum again now as reconstruction and new projects are being carried out. The IFR expected Japan to return to the top of the robot market in 2011. As a consequence of the disaster in Japan, Japanese companies have been trying to diversify their production geographically. This will result in considerable investments in robot installations in Asian markets as well as in Europe and in North America. [20]

According to Tanaka [40], in 2008, Japan produced 80,000 of the 113,000 units shipped globally. This underlines the fact that a huge share of Japan's robots are exported to other countries. After the collapse of the market in 2009, robot sales to Japan recovered by 72 % in 2010 (to about 21,900 units). The total robot sales to Japan reached 28,000 units in 2011 [1].

Nevertheless, in 2010, for the first time, Japan was only the second largest robot market in the world. [52] The top position is now held by Korea. The increase in 2010 could not compensate for the slump of sales in 2009 where the Japanese market nosedived by almost 62 %. In 2010, the motor vehicle suppliers continued to reduce robot investments while the electrical/electronics industry considerably increased robot purchases. [20]

South Korea

In its annual report, the Frankfurt-based International Federation of Robotics picked Korea as the world‘s top robot buyer in 2010, with demand almost tripling in a year. This view is substantiated by statistical data supplied by the IFR suggesting that in 2010 Korea showed the most dynamic comeback of industrial robots with some 23,500 robots sold 2010 (this figure was 7,800 units in 2009). [20] This push in demand was triggered by huge investments made by the electronics industry and the motor vehicle industry. This initiative fits into the historical support of the automotive and electronics manufacturing industry, pumping huge investments into the development of robotics technology in South Korea in order to promote the rapid industrialization the country has undergone in the past 30 years.

Even in 2011, robot sales to the Republic of Korea increased slightly (by 9 %) to 25,500 units.

"According to a survey by the Korea Association of Robot Industry of 395 firms, including also service robot companies, their combined sales nearly doubled to 1.93 trillion won ($2.123 billion) in 2010 from a year earlier. Total production volume and exports shot up 75 per cent and 137 per cent to around 1.78 trillion won and 229 billion won, respectively." [51] In 2009, the Republic of Korea, at that time the second largest robot market in Asia, "[…] saw a substantial decrease of robot supplies after considerable growth in 2008, from 11,600 units to 7,800 units." [36] Moreover, a plan to pump 100 billion won into 10 pilot projects in service and industrial robotics was developed in January 2011 by seven ministries. [51]

"According to the Ministry of Knowledge Economy, Korea's robot production in 2011 reportedly doubled 2010's figure. Export in the same year also went up two times higher than its previous year 2010." [57] The Ministry's "Robot Industry Report in 2011" revealed a 20.3 % rise in overall production of robot makers in Korea (the production volume equaled KRW 2.15 trillion compared to the previous year, despite slow economic growth worldwide). "Domestic output increased 1.6 % and export went up 195.2 %." [57] Robots for service use expanded 13.4 % (mainly driven by the growth of personal service sectors: robots for home use at KRW 1701 billion, Education and Research 530 billion won, and Healthcare 65 billion won). "Following the trend, production in robot parts also jumped 86.1 % over the same quarter in 2010. Export's double increase depended heavily on manufacturing and cleaning robots at 5211 billion won, while its imports went up 21 %, to KRW 3308 billion." [57]

According to the survey, the number of active companies in the industry increased from 334 in 2010 to 346, which coincided with the number of employees, up 15.1 % to 10,509 from 9129 in 2010.

China

Even China, which has been the fastest growing market for robot technology in the past few years, was affected by the collapse of 2009. Then, robot sales in China fell by 30 % to 5,500 units. [36] In 2010, due to heavy robot investments in China, China became the fourth largest robot market after North America, with 15,000 new robots supplied to China. According to the IFR World Robotics 2011 Industrial Robots report, this effect was not only due to the increase of production capacities, but also to an increasing trend towards automation in order to meet the demand for quality. [20] In 2011, Chinese customers bought nearly 22,600 of the 165,000 industrial robots sold worldwide (meaning a share of 14 % of the total market). [1]

The automation of Chinese factories is happening at such a rapid rate that China is forecast to soon overtake Japan and South Korea as the world‘s biggest market for robots. China is the fastest growing market in robotics, and by 2014 it will top the global market, according to the International Federation of Robotics. There is consensus among market experts that China has the potential to be on the top of robot markets by 2014. At present, Japan is still leading with about 300,000 operational robots (while China has about 60,000 robots installed in their factories), but China is booming. At present, the lion's share of industrial robots still come from companies based in Europe and Japan, but this is changing. [11]

Apart from the economic growth of China, the rush for industrial automation is pushed by the rise of the wage levels of factory workers. According to China's National Bureau of Statistics, wages in China's cities rose 12.4 % in 2011, while in rural areas they were boosted by 21.9 %. This trend prompts factory owners to replace human labor with robots, which are cheaper, faster and deliver higher quality. Concerning the degree of automation, China's factories are lagging behind other countries. While, as outlined above, there are 306 robots working per 10,000 people in Japan, in China the rate was 15 robots per 10,000 people in 2011. [27]

The Foxconn Technology Group's factories in China are a good example. The company group announced plans to have 1 million more robots installed which will replace humans in assembling and welding gadgets like Apple's iPhones and iPads. This work is tedious, dull and low-paid.

"Noticeably absent from the industrial robot sector […] is the United States, which long ago lost this market to foreign competitors. In the U.S., the robotics industry starts and ends with the military […]." [37] There is strong disagreement of the ECHORD experts with this statement from the literature. Adept is strong in industrial robots and the USA are strong in service robots, particularly surgery robots. Admittedly, they are also very strong in military robots.

3.2.2. Professional service robotics

Professional service robots are robots that are used in a work setting outside of the standard industrial robot usage. Typically, these are found in applications such as surgery and healthcare, agriculture, construction, military, space and underwater. Professional service robots generally are high value, capital goods and account for over 90 % of the total sales value of service robots worldwide, despite being just 1 % of the number of units shipped (IFR 2010).

However, despite significant research funds going into the area of service robots in the countries visited (particularly healthcare), none of these countries has gained a significant share of the world market, with only 1 % of professional service robots originating from the whole of the Far East and Australasia (IFR 2011). Please note, however, that Korea was reported to have recently made a switch of investment in service robots from primarily domestic robots to a professional service robots orientation.

3.2.3. Domestic service robotics

Not much statistical data on service robotics for domestic or personnal use is available. For the last couple of years the International Federation of Robotics has started to push for a break-down in service robot sales by manfuacturer's origin region (Europe, North America, Far East and RoW), but there is no systematic analysis of the market size per region that is comparable to the data on professional service robots.

There are three main areas for service robots for personal and domestic use:

- Domestic robots (including vacuum cleaning and lawn-mowing)
- Entertainment and leisure robots (including toy robots, hobby systems, education and research)
- Handicap assistance (including personal transportation, home security and surveillance)

The total number of robots sold for domestic use was estimated to be 1,444,806 units in 2010 worth $370 million. Some 9.8 million units may be added in the period 2011-2014. [20]

According to the same source, entertainment and leisure robots sold worldwide totalled 753,000 units in 2010 with a sales value of $159 million (about 4.6 million units to be added in 2011-2014).

Based on the impressions gained on the lab tour, there are strong initiatives in the fields of vacuum cleaning (mainly in Korea where the initial vacuum cleaner market was established by Yujin, which had a strong position before LG entered the market). Entertainment robots are strong in Korea, and handicap assistance in all three countries visited.

3.3. R&D Funding

This chapter draws a picture of the expenditures on R&D in the three Asian countries visited on ECHORD's lab tour and the importance attached to scientific research and its development.

According to the bi-annual report "Science and Engineering Indicators 2012" produced by the National Science Board of the US National Science Foundation, the United States is still on top of worldwide R&D spending (about 31 % of global R&D expenditures are invested in the United States of America). [31] This short analysis of the trends in R&D funding suggests though, that particularly China is making headway by spending an increasing part of its GDP on R&D. Most of the global funding growth is being driven by Asian economies, which are expected to increase nearly 9 % in 2012, while European R&D will grow by about 3.5 % and North American R&D by 2.8 %. U.S. R&D is forecast to grow 2.1 % in 2012 to $436 billion.

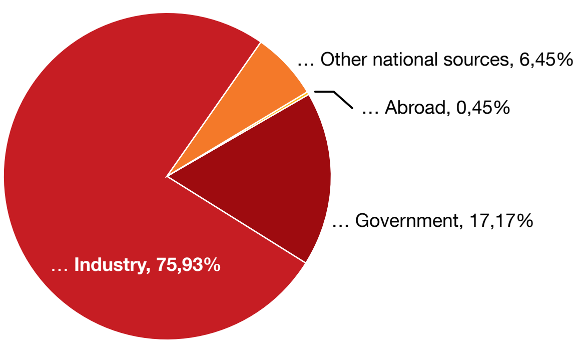
Based on the assumption that the amount of funding has a direct impact on the performance of R&D, a closer look at another "enabler of science and innovation" – the output of engineers and scientists – confirms the picture. "Between 2003 and 2007, the educational output of scientists and engineers increased Asia's share of global researcher pool from 16 % to 31 %", while the US share dropped from (51 % to 49 %) and Japan's share from 17 % to 12 %. [3]

Another indicator of the degree of R&D activities in a specific country is the number of scientific publications. Again, there is a strong increase in China (16 %). The annual number of scientific papers and articles is increasing, "with annual growth rates from the eight largest countries in Asia increasing by about 9 % annually. … European increases in the publication of scientific papers and articles is only about 1 % per year". [16]

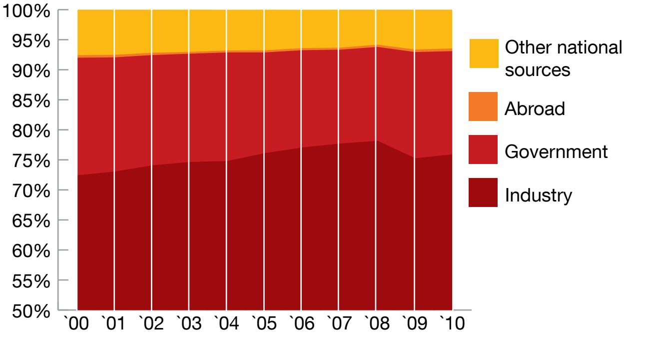
3.3.1. Major funding sources of R&D

The Main Science and Technology Indicators of the Organization for Economic Co-operation and Development (OECD) suggest that in all three Asian countries visited during the lab tour, the industry is the strongest stakeholder in R&D financing, ranging from 75.93 % in Japan (the highest level of all three countries) to 71.80 % (South Korea) and 71.69 % in China. [35] As already outlined earlier, the big industrial players in Japan are prepared to support prestige-driven fundamental research in Japan. This phenomenon is unique for Japan and was not found to be the case in the two other Asian countries.

Japan 2010
Percentage of GERD financed by



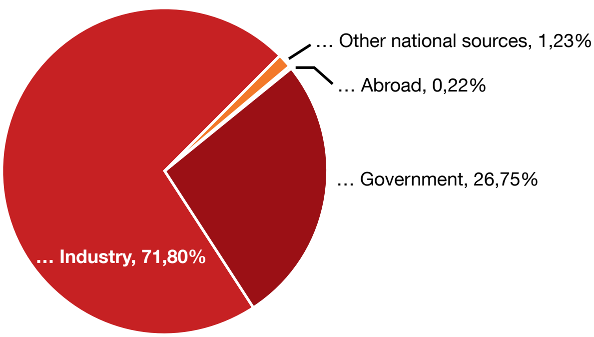
Japan 2000-2010
Percentage of GERD financed by...



According to the same OECD statistics, the shares of the "other national sources" and investors abroad has been stable for the past ten years. Government funding and industrial funding have a combined share of about 93 %, where government funding is balancing out the funds from industry.

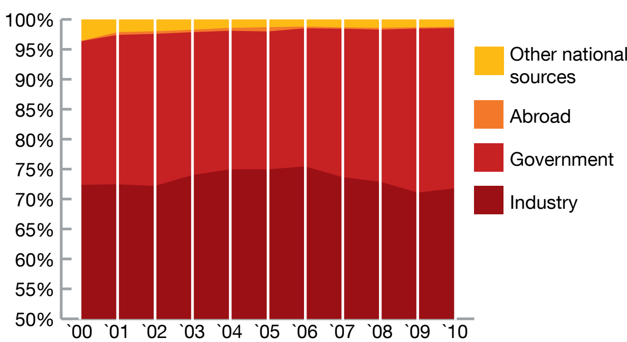
With nearly 27 %, the government has a significantly higher contribution to the financing of R&D than in China. The workshop with KIST and the visit to KAIST during the lab tour revealed some details about the funding structure and the role of the government in the R&D funding landscape of Korea.

S. Korea 2010
Percentage of GERD financed by



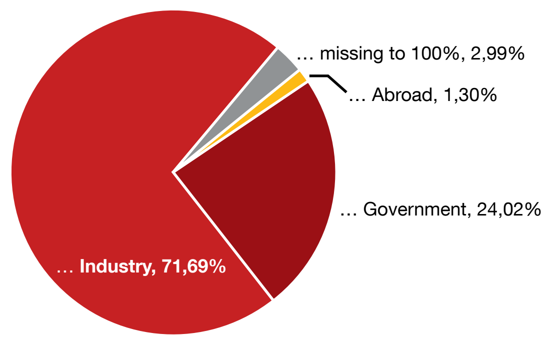
And the share of governmental funding has been increased since 2008 (maybe to equal out the drying up of industrial funds during the financial crisis of 2009).

S. Korea 2000-2010
Percentage of GERD financed by...

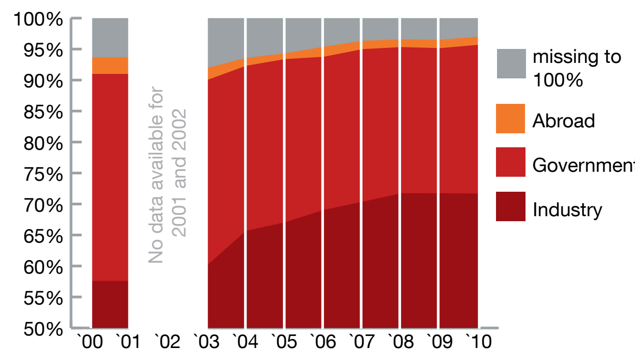


In China, industry has about the same share in R&D funding as in South Korea. The picture has not been as stable, though. The industry's share in the national expenditures on R&D has been growing for the past ten years. With about 24 %, the level of governmental funding is between Japan (with the lowest percentage of the three Asian countries) and Korea (with nearly 27 %).

China 2010
Percentage of GERD financed by



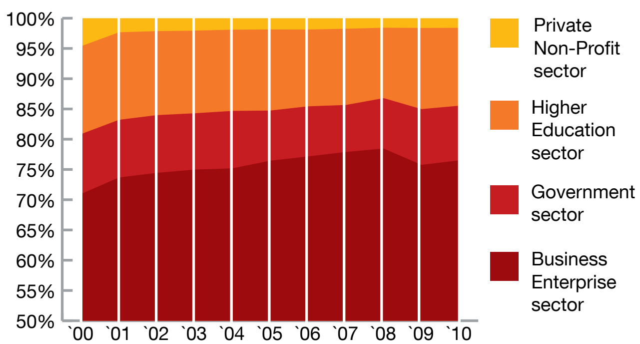
China 2000-2010
Percentage of GERD financed by...



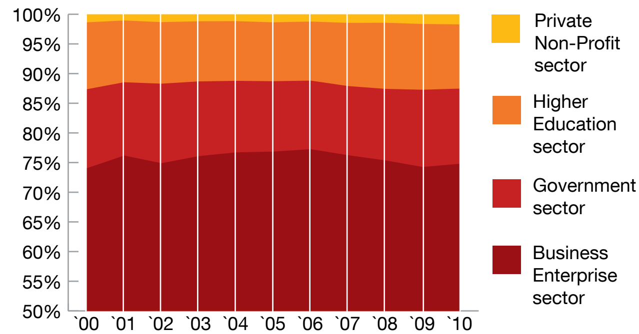
A comparison of the major performers of R&D in the three Asian countries reveals that the academic research has the lowest level in China (8.65 %) and the highest level in Japan (12.87 %), according to the OECD statistics. This suggests that there is a high percentage of fundamental research done in Japan. Korea is in-between with 10.82 %. The scientific research in robotics undertaken by higher education labs in Korea can be very application-orientated (see lab report on SKKU).

China has a high share of governmental research (18.12 %), while Japan has a very high percentage of R&D done at industrial labs (76.51 %):

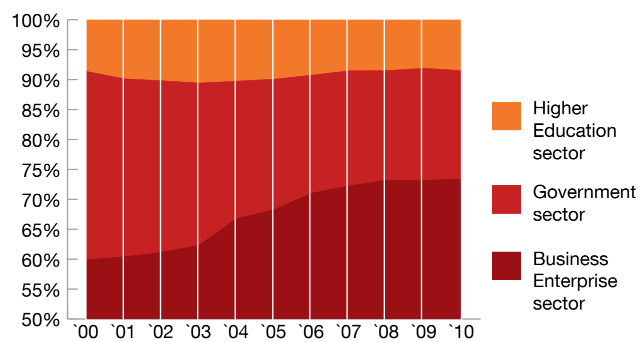
Japan 2000-2010
Percentage of GERD financed by...



S.Korea 2000-2010
Percentage of GERD financed by...



China 2000-2010
Percentage of GERD financed by...



3.3.2. Japan – funding landscape and major R&D programs on robotics

The financial resources are provided by the ministries/ agencies in Japan, which also set up competitive R&D programs, while the implementation is supervised by "independent administrative organizations". The following chart shows the flow from government S&T policy making to the provision of government R&D funds to grantees. [32]

Flow of Japan's S&T policies [32]

CSTP sets Japan's science and technology policies. To turn the political framework into precise R&D mandates, programs are set up by the ministries and agencies. The programs are then rated by the CSTP [33], and the ministries and agencies obtain budgets from the Ministry of Finance (MOF) [34]. Some of the grants are allocated to the beneficiaries directly by the ministries/agencies themselves, and some are provided by the organizations under the ministries and agencies. The mechanism largely depends on which players are involved in the program.

The following ministries and agencies are involved in R&D funding in Japan: the Cabinet Office (CAO), the MIC (Ministry of Internal Affairs and Communications), the MEXT (Ministry of Education, Culture, Sports, S&T), the MHLW (Ministry of Health, Labor and Welfare), the MAFF (Ministry of Agriculture, Forests and Fisheries), the METI (Ministry of Economy, Trade and Industry), the MLIT (Ministry of Land, Infrastructure, & Transportation) and the MOE (Ministry of Environment).

The Bagatelle Memorial Institute forecasts for 2012 a stable share of R&D expenditures on the GDP (3.5 % for 2012 – the same as in 2011; nominal: 157.6 Billions US dollar in 2012 versus 152.1 billion US Dollar in 2011). The Institute rated the R&D spending for 2010 at 3.4 %, e.g. 148.3 billion US Dollar. [3] When it comes to R&D funding dedicated to robotics, some programs, documents and visions are of major importance as they have a direct impact on the current research in Japan. [43]

Thus, the Fukuoka World Robot Declaration, issued in February 2004, [54] lists Japanese expectations for Next Generation Robots that co-exist with human beings, assist human beings both physically and psychologically, and contribute to the realization of a safe and peaceful society. There is a strong research trend on assistive robots in Japan at the moment.

Since 2000, Japanese and South Korean technocrats have been discussing and preparing for a human-robot co-existence society that they believe will emerge by

2030. Researchers have been studying potential robot sociability problems which include robot-related impacts on human interactions in terms of regulations, ethics, and environments.

Funds in Japan are allocated to research programs that address robot sociability problems and robot technical problems (including the testing of robot prototypes with the relevant committees and physical testing environments). In 1999, the Ministry of International Trade and Industry (MITI, which later became the above-mentioned METI) provided 450 million USD for a five-year research effort called "HRP: The Humanoid Robotics Project." The HRP project has triggered a trend towards prestige-driven research on humanoids (originally pushed by the HRP project) mainly conducted in academic labs, but it has gained a more application-driven connotation with intended applications for elderly people, waiting services, education, language teaching, playing, entertainment, etc.

The Ministry of Information and Communication announced a plan to put a robot in every South Korean home by 2020 [24].

Today, the NEDO project is the driving force behind robotics research funded on government level. The program is funded by the METI (Ministry of Economy, Trade and Industry) and implemented by the New Energy & Industrial Development Organization. It is the only large-scale robotic-based project with annual funding of more than 1 Mio. €. The NEDO project continues until 2015. It involves many of the big players in Japanese industry, several funding agencies as well as some universities. The main focus, though, is on governmental institutions and industry, the involvement of universities is rather low. This fact clearly shows the strong application focus of this project. The project is led by Prof. Hiro Hirukawa, Director of the Intelligent Systems Institute at AIST. There are several disciplines covered within this project:

- Safety assessment and evaluation
  Partners involved: JARI, AIST, JNIOSH, University of Nagoya, JQA, JARA.
- Manual mobile robots
  Research focus: robotic bed
  Partners involved: Panasonic, National Rehabilitation Center
- Autonomous mobile robots
  a. Research focus: cleaning robotics
     Partners involved: Fuji Heavy Industries
  b. Research focus: Security robot
     Partners involved: ALSOK, Hokuyo, Mitsubishi Electric Tokki
  c. Research focus: logistics robot I
     Partners involved: Daifuku
  d. Research focus: logistics robot II
     Partners involved: Hitachi Industrial Equipment Systems, Hitachi Plant Technologies
- Power suits
  a. Research focus: HAL
     Partners involved: CYBERDYNE, University of Tsukuba
  b. Research focus: walking assistant
     Partners involved: Honda R&D
- Personal vehicles
  a. Research focus: Winglet
     Partners involved: Toyota Motor, NCGG
  b. Research focus: smart wheelchair
     Partners involved: AIST, Nippon Signal, OPTEX, Witz, Chibi Institute of Technology

- Autonomous golf cart
  Partners involved: IDEC, Osaka University

There is no military funding in Japan. The space research receives funding from the Japanese Space Agency. NEDO provided some small-scale funding after Fukushima, which enabled work on mobile disaster robots. Industry did not contribute any funds. In addition to the start-up funding directly after the nuclear disaster, NEDO has committed to spending 0.5 Mio € annually for the next six years to support robotics research in disaster robotics.

Partly to support the rebuilding of industry in the Sendai region, there has been an investment in automotive manufacturing of 1.5 Mio € start capital and 5 Mio € for 2012. In addition to helping the two existing plants (one in Nagoja and one in Fukuoka), the investment is meant to support the building of a third Toyota plant in Sendai. There are two projects in this context:

- electromobility
- robot co-worker

Junior researchers can apply to the Ministry of Education for grants that typically last between two and five years. As you move up the academic ladder, the amount of funding as well as its runtime increases. This funding is separate from the project-related funding. This gives researchers the possibility to do their own first step research and then, at a later stage, one can employ graduates to do the research and then build a team. This funding is made available on a competitive basis subject to peer-review of submitted proposals.

3.3.3. South Korea – funding landscape and major R&D programs on robotics

Korea's R&D expenditures as percentage of GPD are likely to increase from 3.36 % (nominal 49.0 billion US Dollar) in 2010 to 3.40 % (resp. 52.7 billion US Dollar) in 2011 and 3.45 % (or 56.4 billion US Dollar) in 2012. [3]

Most of the Korean government's robotics funding originates from the Ministry of Knowledge Economy (MKE), although the Ministry of National Defense does fund sizable military related robotics developments as well as funding joint projects with MKE and smaller amounts come from other parts of government such as the Ministry of Environment. MKE channels robotics funding through a specially set up agency, the Korean Institute for Robot Industry Advancement (KIRIA). Some of KIRIA's funding is made available through direct grants but much of the funding is channeled through other agencies such as the Korean Institute of Science and Technology (KIST) via specific programmes, like the Frontier 21 programme. University infrastructure and staff support is available through the Ministry of Education. Lastly, some regional R&D funding is available for robotics companies.

South Korea intends to become one of the top three worldwide robot producers by 2013 and a leader of the global robot market by 2018. [55] To support these goals, in 2008 the Korean government enacted a special "robot law" aimed at facilitating the development and take-up of intelligent robotics. The key points of this law are:

- Five-Year Plan, implementation plan and law enforcement
  First-stage plan: the Minister of Knowledge Economy will set up and enforce the law based on the plans submitted by the related ministries.

- Implementation plan
  Late January of each year is the due date for the related ministries to submit to the Minister of Knowledge and Economy their law enforcement plans. The minister will review the plans, draw up and issue a comprehensive report.
- Support for the intelligent robot industry
  Five energy-related, state-run corporations, including the Korea Electric Power Corporation and the Korea National Oil Corporation, will contribute to the five-year intelligent robot project, both financially and administratively.
- Quality authentication for intelligent robots
  All regulations stipulated by certifying organizations must be enacted. Excluding industrial robots in the manufacturing field, all robots must be specified as service robots. The chief of the Korean Agency for Technology and Standards holds all authority related to authentication.[1]
- Construction and operation of Robot Land[2]
  Establishment of an institute that specializes in the study of intelligent robots [56]

SKKU: The Institute collaborates with other laboratories, universities, and companies on projects obtained through competitive calls (like in the EU). Participating companies have the opportunity to hire MS and PhD students when they graduate, and the companies can take on post-doc level researchers of the institute (e.g., LG) as well.

1 A quality evaluation and certification process has now been established – The “Quality Certified ROBOT”
2 Robotland is a robot oriented leisure park with the serious intent of providing a rigorous proving ground for the safe, reliable and robust operation of robots operating beside and among people.

KITECH gets 30 % of its total budget (USD 187 Mio in 2006) through government grants and 70 % on a contract basis. [18] This additional project based funding comes from other organizations such as the Ministry of Defense. KITECH works on an annual budget and is not required to raise additional income, other than for performing research and development projects.

“In Korea, robotics has been selected as one of the ten areas of technology for economic growth; the […] funding for robotics [from MKE] is about US$80 million per year.” [6]

3.3.4. China – funding landscape and major R&D programs on robotics

In China, the overall science and technology policy is set by MOST (Ministry of Science and Technology). Other ministries are also involved (e.g. the State Planning and Development Commission, the State Economic and Trade Commission, the State Environmental Protection Agency, the Ministries for Agriculture and Health). The Chinese Academy of Science is the main provider of fundamental and applied research in China. The Academy runs a nationwide system of more than 100 research institutes. The National Natural Science Foundation is China’s research council. In addition to the national agencies, science and technology is supported by the Chinese provinces. [58]

Statements made by the Chinese labs visited during the lab tour, e.g. that the Chinese government wants to push its technological progress beyond low-cost manufacturing towards innovative R&D (especially in emerging sectors), are confirmed by the Five-Year Plan targeting research and development that was recently delineated by the Central Committee of the Communist Party of China (CPC). China is committed to spend at least 3 % of its GDP on R&D (in 2010 it spent just $110 billion, e.g. 1.76 % of the Chinese GDP of $6.218 trillion). [22]

The Bagatelle Memorial Institute, though, forecasts for 2012 a stable share of R&D expenditures on the GDP (1,6 % for 2010 and 2011, nominal 174.9 billion US dollar in 2011 and 198.9 billion US dollar in 2012). The Institute rated the R&D spending for 2010 to 149.3 billion US dollar, equaling – according to their calculation – 1,5 % of GDP**.** [3]

The latest Chinese Five-Year Plan targets 22 urban development areas where the government hopes to promote increased R&D spending in eight emerging technologies: Biotechnology, Advanced Agriculture, New Materials, New Energy, Environmental Technology, Smart Grid, Electric Vehicles, and Traditional Chinese Medicine. These emerging technology domains have strong application links to robotics. The government is earmarking a 159 % increase in R&D ($18 billion). [22]

According to Naik [30]: "China is on the verge of overtaking Japan as the second-biggest spender on research and development after the U.S., […]." (expenditures on R&D 2011: $153.7 billion, in 2010: $141.4 billion).

Now to the major programs in robotics: ECHORD's lab tour included an in-depth discussion with high-level representatives of MOST. There are three major pillars of Chinese funding in robotics at present (the national S&T program trilogy). They are very similar to the IP programs:

- National High-tech R&D Program (863 Program) [59]
  Started in 1986, the National High-tech R&D Program, mainly the 863 Program, was implemented via three successive five-year plans to boost innovation capacity in the high-tech sectors, particularly in strategic high-tech fields, and to achieve breakthroughs in key technical fields that deal with the national economic lifeline and national security.
- Key Technologies R&D Program [60]
  Initiated in 1982 and implemented through 4 five-year plans, the program focuses on the R&D of key and common technologies to promote sustainable social development. The program provides advanced and applicable new technologies, materials, techniques, and equipment to industrial and agricultural production. The program also strives to facilitate the industrial exploitation of high-tech achievements to enhance the international competitiveness of key industries.
- National Basic Research Program of China (973 Program) [61]
  The program supports the implementation of key projects to meet the strategic needs of China (agriculture, energy, information, resources and environment, population and health, materials, and related areas).

Considerable achievements have been made in all three areas, but mainly in the 863 program. Examples given include a deep ocean exploration vessel, a moon exploration robot, as well as industrial robots mainly for the automotive industry (15,000 Chinese-built industrial robots have been sold so far), medical surgery robots (more than 5,000 brain surgery operations) and a humanoid robot which can play ping pong. The success was achieved by a combination of pull and push marketing.

MOST wants to pave the way from mass production in China to an advanced manufacturing society. Driven by an increased need for education and elderly care, service robotics is taking off.

3.4. State-of-the-art Research

Japan

Mori & Scearce, 2010, underline the tremendous pace at which its population is aging and point to “investment in robotics as a […] possible solution that will help bridge the shortfall in both the workforce and in elder care.” [28]

Assistive technologies

Consequently, one strong research focus is on assistive robotic technologies, an umbrella term for devices that augment mobility, automated manipulation systems (robotic aids for feeding, personal hygiene, etc.), robots for therapeutic purposes (e.g. Paro), robots that help caregivers, semiautonomous mobile robots and wheelchairs, robotic rooms that have the capacity to monitor the elderly. Research in these areas has a long tradition in Japan, but has recently gained momentum because elderly care has become one of the big challenges of Japanese society.

Humanoid robotics

Another research topic which has been and still is very prominent, is humanoid robotics. Japanese society is certainly more open to androids than western cultures. Although acceptance of technology and humanoid robots in particular – the helper humanoid was once a Japanese dream – tends to be higher in Japan than in other countries, this kind of technology is not generally endorsed and even sometimes rejected, especially by the elderly. [13] This has led the industry to focus more on the development of simpler devices such as health-monitor systems in clothes and pet robots for collecting and analyzing data, high-tech lavatories, and other specialized machines. Application-driven industrial research is often dedicated to the compensation of the shrinking labor force, as well as to providing products or services that could assist elderly people. Academic research is highly focused on basic research. Direct technology transfer opportunities are not the prime interest.

There is a long tradition of research on humanoids. Pushed by the Humanoid Robotics Project, short HRP, which started in 1998 under the leadership of Prof. Hirochika Inoue from the University of Tokyo, research on humanoids has always been of interest to Japanese robotics researchers and has led to highly sophisticated developments in the areas of movement and locomotion, manipulation, social interaction, miniaturization, and integration. A few prominent examples are given below.

For prestige reasons (we make it because we can make it), there is a strong industrial support of academic research in the area of humanoids

Research topics

Prabhu Guptara [17] also observed that with regard to humanoid robotics, research varies from motion capture, soft-body robots, artificial muscles, sensorized assistive humanoids, tendon-driven technologies to the modeling of musculo-skeletal humanoid systems. Human-robot interaction is another strong research topic in Japan. One can find a wide range of amazing examples of humanoid robots in Japan.

A new application is PaDY (in-time Parts/tools Delivery to You robot), developed by Tohoku University, a robot co-worker that assists his human companion with assembling while the human takes over the logistics.

The University of Tokyo labs are a great location to visit in order to get an impression of current research on humanoids in robotics. The highlights of the ECHORD lab tour to Japan include humanoids and assistive robotics. It is important also to mention our AIST visit with their HRP-4C (by Kawada Industries), a visit to many laboratories at the University of Tokyo with demonstrations of Kojiro and Kenshiro (the tendon-driven robots, in Prof. Masayuki Inaba's group), the movement recognition and generation system (Prof. Yoshihiko Nakamura), the fully sensorized learning baby robot Noby (Prof. Yasuo Kuniyoshi), and the impressive collection of MEMS-based sensors and actuators (Prof. Isao Shimoyama), and a visit to Tohoku University with its ambitious "Extreme Robotics" project (literally, robotics in "extreme" situations).

Industrial research wants to compensate for the decrease in the size of the labor force. Therefore, one clear research focus is human-robot co-workers, e.g. robots that will interact closely with humans and co-exist with them (the robot-human assisted domain).

In order to assist the elderly, one of the overall goals is to bring the technology that works in structured manufacturing environments into the unstructured, e.g. home, environment. Research disciplines include speech recognition and instruction, localization, manipulation, assistive functionalities, and a large environmental model database which is used as a reference for all behaviors (fetch, deposit, etc.), etc.

Housecleaning and nuclear sites have not been high research priorities of Japanese robotics thus far. But still, it was a Japanese robot developed at Tohoku University, Quince, which was implemented in the Fukushima Daiichi nuclear plant no. 2 reactor building (while American ones were used in building no. 3). Another robot to be mentioned in this context is the RobHaz developed by Yujin. Interest in rescue robotics research has seen a real increase due to Fukushima, also in academic labs (like the University of Tohoku) but is still in the development phase.

Asked about future trends in robotics, Yaskawa sees two types of robotics applications:

- Applications requiring autonomy for domestic use
- Applications for complex tasks in factories

Today, there are robots that can typically perform one specific task. But Yaskawa feels that the trend will be robots that perform multi-task services. Humanoids, according to one statement at the conference, „have no future". Also, high-level university labs, like the University of Tokyo with a very strong tradition in the development of humanoid robots, confirm that the technological trend should go beyond humanoids. Future research trends should embrace fast actuation and fast vision, rich sensors, mental development, dependable learning, emotion technology. The following new challenges have been identified in the area of service robotics:

- Surgery
- Home cleaning
- Personal mobility
- Welfare
- Agriculture

Military research in robotics plays just a small role in Japan. There are very few military robots. And there is no indication that this trend will change.

South Korea

According to the Korean Herald [51], robots in the automotive, electronics, food and metal industries are boosting the automation levels in Korea and worldwide.

On the lab tour, the ECHORD experts saw firsthand innovative research centered on service and entertainment robots, as well as on humanoids. There are only very few programs on underwater robotics (for instance at KITECH with its RobotFish Lab). These were the same observations Bekey and Yuh made on their tour [5,6].

It is striking that robotics research in Korea – even at the university level – has a very strong application orientation. Technology transfer is the strong driver behind scientific initiatives (see more under chapter 3.5.). The research philosophy is based on the conviction that research is instrumental to applications. SKKU, a university owned by the huge company group Samsung, carries out application-orientated research to a level where products are matched with a clear target price during the development phase and have a fixed launch date (see the development of the HomeMate). KITECH utilizes application-driven roadmaps to identify Root Manufacturing Technologies (RMTs). So far, some 8,000 RMTs have been identified. Wherever market-focus is an issue, robustness is a main guiding design principle. KAIST has a very sophisticated system for promoting technology transfer from the institute to the market place.

Due to the tensions with North Korea, some research is dedicated to defense purposes. For instance the Jinpung at KITECH, which means ‘Dragon Wind’ (comparable with the BigDog), has been designed to carry heavy packs. KAIST develops small UGVs mainly for rescue and military purposes. The LaunchBot, also developed by KAIST, is a very robust exploration robot in the shape of a grenade. Other examples are ZINEDYNE, a wormlike robot for exploration, as well as PILLBOT, a small exploration robot that protects itself by curling up in a similar manner to Pillbugs. Samsung confirmed at a workshop on the tour that the development in robotics is often boosted by military funding. Otherwise, the products would be much too expensive to develop. The innovative output of the companies receiving military funding is enhanced also by the spinoff products which sometimes contribute more strongly to the company’s earnings than the original military product. At KIST, a mobile robot ROBHAZ intended for rescue/military operation is under development.

Like in Japan, Korean researchers are very active in humanoids (see individual lab report on KITECH, KIST and KAIST), frequently as a component for service tasks at home (elderly care) or “as a component of urban technology designed for service tasks”. [5]

The HomeMate robot (developed by SKKU) is a home assistant/companion robot that has already reached an advanced stage. It was developed as a platform for dependable elderly-care robotic services based on w-cognitive robotics (‘w’ standing for ‘will’), and will be upgraded to commercial level and deployed in elderly-care centers in Korea and the US for testing. Impressive examples of the development and implementation of advanced algorithms for the recognition of human motions/features, such as facial expressions, motions, and gestures can be found in Korea. KAMERO is a humanoid that expresses various moods like anger, joy, and surprise. HUBO is a very dexterous humanoid that can mimic human motion, has remarkable whole-body movement abilities and stability with regard to external disturbances. The robot is very light (43kg), compared to other robots in its category. It is equipped with a 5-finger hand that only weighs 400 g. There is also a strong focus on humanoid robots at KIST. CIROS is a combination of a humanoid and a mobile platform, which comprises the torso of a humanoid but has no legs. It is equipped with a 3D camera and a 5-finger robot hand. The center pursues research on the MERO robot that can imitate facial expressions. A high-fidelity robot head was developed that can realistically mimic human facial expressions. The KIBO humanoid is the most advanced humanoid developed by KIST, which will soon be commercialized. Its human interaction and motion capabilities are impressive.

Research on humanoids in Korea has a strong focus on human-robot interaction which is a key issue for the factories of the future. ETRI is focused more on solutions for human robot interaction. They developed a face and body detection system that is able to recognize registered faces, known pictures, body postures and gestures, and written digits.

According to KIST, the paradigm shift from industrial robots towards intelligent robots took place between 1997 and 2001. The shift was necessary because the market for industrial robots showed signs of saturation (sales are decreasing), while sales of professional and personal service robots were increasing.

In addition to a strong ongoing effort to achieve fully automated factories in mass production, Samsung has identified human-robot interaction as the core issue in future developments and considers tele-operation to be the key to human-robot-co-working. This entails a stronger cooperation with disciplines other than robotics. In order to be really useful for SMEs, the robots have to be equipped with tools to support a number of different functions, which will, overall, lead to lower costs of the robot. Achieving this multi-tasking ability, which increases the robots‘ performance, is one of the important research trends. In mechatronics, the reduction of the weight of the system is an important goal as well.

Apart from human-robot interaction, the focus in the development of industrial robots over the next few years will be on network robots, i.e. robots that are connected to other robots, to an intelligent environment, to the internet, GPS, etc. Service robots with advanced human robot interaction capabilities (speech, facial expressions) and humanoid robots are ready for the market.

There is a wide range of service robots for domestic or personal use. LG demonstrated the application of SLAM and telepresence in a vacuum cleaner as well as Homebot, a vacuum cleaning robot with a mapping algorithm which can in addition be used for remote monitoring (connected to a mobile phone). KAIST showed our experts FURO, a service robot intended for home assistance, and an English Teaching Robot which is being developed and will be launched on the market very soon. Currently, Yujin is developing an assistant mobile wheeled robot for taking orders (not delivering orders, because it has no manipulation capabilities) in bars, cafes and restaurants, called Cafero. KIST also showed the visitors the ENGKEY robot, a mobile robot for English teaching. It is already on the market. This is a good example of system integration and human-robot interaction.

Apart from teaching and entertaining robots, medical robotics are seen as another future market with huge potential. About eight years ago, there was almost no interest in medical robots and attempts to find partners to launch such products failed (as reported by KAIST). This has substantially changed since. Currently there are two major projects at KAIST: a robot for minimally invasive surgery, which is very dexterous with six integral degrees of freedom; the second product is a telemanipulated robot for bone surgery. ETRI is focused on the convergence in robotics software. Internet combined with interactive TV will provide tools for medical inspections.

In the area of networked robots, the Korean Ministry of Information and Communication sponsors a large national research project, Ubiquitous Robotic Companion (URC), using network-based intelligent robots. [5,6] Yujin also sees the future evolution of the service robotics market going towards network robotics (‘robotics in concert’) and in particular, in the connection of the service robot platforms to intelligent environments and a plethora of devices (i.e., washing machines, ovens, etc.). Long term term (in several years), Yujin envisions a second generation (in Korea they already have the first!) of service consumer robots capable of errand manipulative tasks. They share the vision of cognitive consumer robotics (Sukhan Lee’s HomeMate) as a medium-term perspective for the conumer robot market.

To date, industrialization has largely been bottom up (i.e. technology driven). There seems to be general agreement that in order to further push innovation, a top down approach is needed which would define services that can usefully be carried out by robots and derive the functions and technologies necessary to fulfil those services.

Examples for research on autonomous vehicles can be found at LG where an Autonomous Driving Assistance System (ADAS) was developed (apparently one of the most advanced in the world).

China

Current research and future trends in robotics is, to a certain degree, steered by MOST, the Ministry of Science and Technology, in China. At least at the university level, MOST wants to pave the way from mass production to an advanced manufacturing society (more information in chapter 3.3). Driven by the increased need for public security (e.g. rescue in disasters, maintenance of power facilities), healthcare, elderly care, and education (educational robot), service robotics is really taking off.

Because China has less restrictive health and safety legislation than most countries, surgical robotics is a prominent area for research and development, and so medical robotics is a strong focus in China (as in Korea).

Examples of surgical robotics can be seen in all Chinese institutes visited on the lab tour. Just a brief selection of the highlights in this area: the surgeon robot and the trauma orthopedic robot developed by the Robotics Institute of Beihang University have obtained a national health medical license. They have been used on more than 5000 patients in over 20 hospitals.

Shanghai Jiao Tong University has a strong scientific interest in prosthetic products, medical and rehabilitation robots, as well as robots to support the elderly (e.g. an intelligent wheelchair, an assistive robot arm, safe human-robot interaction). During our visit, they demonstrated their EMG-based prosthetic hand, a rehabilitation system with functional electrical stimulation based on brain-computer interface, a cranio-maxillofacial surgery assisted robot, an intelligent wheelchair, as well as a walking-assistant robot.

The IRI in Beijing Institute of Technology developed five generations of humanoid robots (from BHR-1 to BHR-5). IRI researchers proposed methods for BHR-2 to generate humanoid gait patterns based on human walking characteristics, contributing to the problem of complex motion planning for humanoid robots. The humanoid robots can mimic dexterous human motion to perform Chinese kung fu and play ping-pong. These works showed a part of Chinese robotists' effort to promote fundamental research in robotics.

The degree of clinical testing that is carried out to obtain data on real-life applications in China is really amazing. There is a strong push to test assistive technologies in the real world, e.g. in homes for the elderly.

Some of the research is based on the exploitation of existing technologies, but novel technologies are being developed as well. Since major effort is going on in this area now, significant progress in the area of assistive technologies and medial surgery can be expected from China. From the extensive testing in the real world, in particular in homes for the elderly, major results can be expected in the near future. The trend towards developing low-cost and standardized devices also promises innovation.

Interesting results for industrial use with the focus on small lot sizes were seen at Shanghai Jiao Tong University. To counteract rising labor costs, China's industry is turning to automation. Aimed at the production of small lots, plug-and-play methods for rapidly changing jigs are being developed. Prototypes have been developed for the robot welding cell for Shanghai Jiao Yun Ltd. the laser cutting system for Benteler Shanghai and Shanghai Bao Steel, and a robot unload system for plastic injection machines for Shanghai Essilor. So, the industrial contacts are in place.

Currently, the Chinese government is showing a rapidly increasing interest in robotics, mainly in service robotics. This trend is likely to last for at least another decade. The investment in the industrial side is growing as well. Despite MOST's initiative of steering industrial robotics away from mass-production into high value-added and intelligent manufacturing, the price is still a crucial point of interest Some companies are developing low-cost industrial robots (e.g. Siasun and Foxconn – the Taiwanese giant) to be installed in China over the next 2,5 years. This trend also holds true for service robotics, e.g. the quest for a low-cost, intelligent wheelchair which will be available for about EUR 1000. At the same time, robot industrialization including both industrial and service robot is widely emphasized and supported by the central government (e.g. MOST) as well as local governments (e.g. Kunshan in Jiangsu Province).

3.5. Technology Transfer, IP handling and Start-ups

In order to illuminate the technology transfer mechanisms in the three Asian countries visited during the ECHORD lab tour, the following chapter summarizes the information on Intellectual Property Rights handling and then gives an overview of the approach towards spin-offs and commercialization. The report highlights similarities and differences in academia-industry collaboration between the three countries and provides some details on how success is measured and which tools are used to promote the collaboration (if any).

3.5.1. Intellectual Property Rights

The major intention behind Intellectual Property Rights in Asia is to strengthen the competitiveness of the respective country via patents and to protect the country from the globalized market. While IPR have a long tradition in Japan, they are claimed in the literature to be a relatively new phenomenon in Korea and particularly in China. Nevertheless, particularly in Korea, the ECHORD experts found a very consequent and sophisticated management of patents and licensing fees that is implemented by different academic institutions. This might be a direct result of the strong application-orientation and the drive to transfer scientific research into market benefit that is characteristic for robotics research in Korea. Japanese companies, which are known in Europe for walling themselves off in order to protect their R&D, are maybe forced now to open themselves up to international collaboration which has an impact on the IPR handling. This is a direct offspring of the series of crises the country has had to cope with. Even though China is strong in medical research and surgery as the legal environment is less rigid with regard to clinical testing, international IPR regulations are adopted for their own sake.

The findings of the Asian countries visited on the tour also suggest that IPRs can shape or at least preserve the industrial structure of a specific country. Although the direct link between strong IPR protection and a high level of competitiveness is hardly challenged, some market specialists insist that this statement needs some modification with regard to the development level of the respective country and the size of the enterprises or institutions affected by IPR.

The widely spread assumption that the protection of IPRs leads to an advance in technology does not prove true for South-East Asian countries. Macdonald and Turpin [25] claim that above all SMEs in less developed countries do not benefit from strong IPR protection (e.g. patents). This kind of protectionism has an adverse effect by keeping SMEs from innovation. This is also the case of the South-East Asian countries, organized in the Association of South-East Asian Nations (ASEAN). Innovation there takes place outside the IPR system, which can actually become a barrier to technological creativity. The authors conclude that the impact of IPRs in the form of trademarks, copyrights, etc. on the competitiveness of SMEs "is not determined by a linear economic process that converts knowledge into product or process. Rather, it is a product of the various ways that IPR can become usefully embedded in business strategy. IPR within business strategy is important for SMEs, not IPR itself." Most of the SMEs and their competitiveness rely on marketing and niche opportunities. An SME-friendly IPR policy has to ease the accessibility to user-friendly information about IP in the context of potential business plans and develop, for example, a regional database on the use of IPR by SMEs. In general, the system has to adapt more to the needs of smaller firms and their understanding of competitiveness and technology transfer.

Japan [29, 48]

With the intention to significantly strengthen the competitiveness of industry and research, a legal system regulating the cooperation between industry and academia in Japan was established in the late 90s. Modeled on USA's Bayh-Dole Act[3], legal regulations like the Universities Technology Transfer Promotion Law (1998) and the Industry Revitalization Special Measures Law (1999) were implemented. But this initiative did not produce the intended result – to protect the innovative power of small manufacturing companies because there seems to be much less active knowledge flow between universities and industry in Japan than there is in the US. Nagata [29] points out, that the number of patents cannot serve as the sole indicator of innovation in Japan, as technology transfer is not always linear and cannot be summarized under the formula that universities resolve concrete technological problems for firms. The cooperation between academia and industry in Japan is much more complex. Nagata underlines that there has always been an active informal exchange between firms and universities which is difficult to measure but has led to "invisible cooperation". For Japanese firms, this informal technology transfer is as important as the information gained through official channels. Hence, future policies should not only rely on legal instruments for IPRs but also on supporting the described informal exchange between industry and academia, making it more visible.

3 See ECHORD's Final Report of the Lab Tour to North America, chapter 3 "Analysis".

The tour revealed that – despite the crisis and the financial constraints for Japanese firms – there are very huge companies that are still willing to invest in 'marketing-orientated' research and development with non-product defined outcome to show technological leadership. This attitude and the pride of the technological leadership inspired by academic research pushes the research on humanoids in Japan.

The major barrier to academia-industry collaboration in Japan from the perspective of universities does not seem to be IPR, but safety (while YASKAWA considers the IPRs to be a major handicap for industry-academia collaboration). But as safety is such a brake-shoe in industry-academia collaboration, the NEDO project (see chapter 3.3), which is one of the big academia-industry cooperative projects (the second one is the IRT innovation for Aging Low Birthrate Society), includes a major program in safety with a test facility which costs 20 Mio to develop. Trehe NEDO project is bigger than anything similar in the US.

Japan's universities struggle with the fact that sometimes industry expects initial results free of charge before they decide on funding. So, the universities take the initial risk and there is no risk-sharing mentality. This is considered to be one of the major barriers of industry-academia collaboration from the academic side. In addition to this, there seems to be a lack of government-supported funding of small-scale, industry-academia collaborations.

In general, the role of the universities in Japan is to show the possibilities of and to concentrate on basic research. The situation in robotics seems to be a bit different, as robotics has not been successful in industry for very long. Therefore, universities get more involved in application-orientated research and in the analysis of customer/user needs than in other areas of research.

Big companies like YASKAWA confirm that they prefer to develop their products in-house rather than collaborate with partners outside the company. At the same time, YASKAWA has project-based collaborations with universities and points to a longstanding open innovation history in robotics, going back to 1989 to a collaboration with Kyushu Electric Power Company (for more information see report on YASKAWA).

South Korea [38]
Taking the performance of software firms as an example, Suh, Hwang and Oh [38] study the impact of IPRs on Korean firms. The software industry is considered one of the sectors where intellectual property is the most concentrated. This kind of legal protection serves as an incentive for investors and therefore, should promote technological innovation. According to this study, one can say that software copyrights positively affect the performance of firms. Software patents have an even stronger impact on the efficiency than software copyrights.

The impressions gained during the lab tour suggest that successful management of IPRs exist, but the patents (when held by academic institutions) are not implemented for the sake of protectionism, but rather as an instrument to generate additional funds. Because academic institutions (like SKKU, which is about to commercialize the HomeMate robot) want to transfer their scientific results into products, they are willing to compromise with their industrial partners, even if they own the rights. Also according to KIST, Intellectual Property Rights are not an obstacle to academia-industry collaboration. The industrial partners have to pay a lump sum at the beginning and therefore benefit from lower royalties throughout the runtime of the license/patent. This is contrary to Europe – working without an initial lump sum payment, but enjoying higher royalties.

If the research is funded by the government, the patent belongs to the university. If the research is done under the umbrella of a collaborative project, the pattern is jointly owned by KAIST and the industrial partner (50:50). Thus, the background is owned by the universities, but the foreground development is usually done by industry. Otherwise, the industrial partner has to pay for this (license fees).

The question of intellectual property becomes more complicated, of course, when the research results from previous projects with various partners/academic institutes.

Large companies in Korea seem to have a preference for developing their products in-house. Nevertheless, software development should take place at universities (statement by Samsung). In addition to this, universities act as the long arm of industry for R&D, which is too expensive and too time-consuming for the industrial stakeholders to carry out themselves. For large companies, the decisive factor for cooperating with universities is the completeness of the technology. The major problem in academia-industry cooperation is the completeness of technology, liability of the system and robustness, which cannot be taken for granted when hardware is supplied by universities. There is a feeling from industry that efforts at commercialization from government-backed research institutes are not helpful as they tend to license systems that are not yet ready.

Small and medium-sized companies like Yujin seem to cooperate more intensively with universities and research centers. They seem to outsource part of their product development to these institutions.

Even when it comes to the exploitation of R&D results developed by companies, the management of IP appears to be less strict in robotics than in other contexts. LG, for instance, does patent very specific components at a national level. The national patenting system is closer to the European model than to the American one. Thus, it is, for instance, not possible to patent the usage of visual SLAM in vacuum cleaners.

It is also fair to state that all institutions visited on the tour have a very strong drive to commercialize their R&D results. KITECH clearly states that the default intention is for all projects to result in the transfer of knowledge to SME companies, either as products or services. For products and services resulting from internal R&D projects, companies are identified which can exploit the results. It is not clear whether exploitation rights are granted or licensed.

SKKU – fully owned by Samsung – intensively cooperates with industrial partners, taking into account launch dates as well as target prices identified through market intelligence. The most recent example is the HomeMate robot for elderly people, which will be commercialized at the end of 2015 at a target price of 15,000 €. The three parameters that are crucial for the development of service robots are: dependability, sociability and affordability. SKKU develops products along these lines. KAIST also classifies robustness as the main guiding design principle.

KAIST strives to collaborate very closely with industrial partners to produce prototypes as a pre-commercialization step. Depending on the funding mode, KAIST either decides on the research foci by themselves (governmental funding) or the research foci are determined by industry (cooperative projects). In any case, the commercialization of the products or services generated is the final goal of the scientific activities. The number of patents as well as the royalties generated with the licences is the measure of success of the technology transfer. KAIST's licences and royalties are managed by a special funding office within the institution.

When commercializing personal service robots, the price and the aftersales service are the crucial problem. Concerning international trade, the different certificates for robots are considered as one of the major trade barriers. From the industry's point of view, it would be desirable to have just one certification worldwide because having to cope with various certificates is expensive.

Conferences are a good medium in Korea to present scientific findings to industry and to find industrial partners for the commercialization of products. In addition, there are strong ties with industry due to the graduates that take senior positions in companies.

China [9, 19, 46, 47]
Intellectual Property Rights in China are regulated via the Patent Law which was implemented in 1980 and amended three times since then in order to adapt it to international regulations and to extend the patentability. The latest patent reform took place in 2008 and had a huge impact on patent output and indirectly on technological innovations in general. At the same time, both the number of patents applied for and the number of patents granted in China has been increasing significantly. Nevertheless, compared to other countries, the protection of IPRs in China is fairly low. This fact causes problems in terms of imitation, reliability and quality.

It is common knowledge in the technical literature that independent innovation ability and an advanced international position in state-of-the-art technology cannot be achieved without the protection of IPR. “The quantity and quality of IPR owned by enterprises has become the key element of core competitiveness. It is urgent to accelerate the implementation of independent innovative strategy and increase the contribution of IPR in the increase of profit of enterprises.” [19]

Nevertheless, there is a huge discrepancy between this knowledge and the current situation in China. And so there is a huge variation among the different regions in China which benefit in different ways from positive developments. Over 98 percent of Chinese businesses function without patents. While in some areas such as Beijing, Shanghai and Guangdong the regional technological innovation is effective through the successful implementation of IPR diffusion, in central China there is obviously a lack of this kind of diffusion. Respective countermeasures could be, for example, a significant development of the basic research in those regions, an enhancement of the independent innovation ability in IPRs domain; strengthening technological innovation guidance and demonstration; speeding up the construction of a technological innovation network between research institutes and enterprises; the promotion of the construction of an entrepreneurial venture capital system or the optimization of technical innovation resources. In general, the establishment of IPRs diffusion network system with a focus on the technology transfer is in demand and is necessary. China has to make sure on the one hand that the country keeps up in the international market and on the other hand, that disadvantaged regions gain specific treatment regarding the diffusion of IPRs.

It was difficult for the ECHORD expert group to glean any information on IPR, technology transfer mechanisms or the commercialization of the product. The discussions with the Chinese labs were more centered on scientific research – often with a fundamental or military character.

The need for initiatives in these areas has been realized though. MOST clearly strives to support SMEs and to facilitate the technology transfer and international cooperation.

At the University of Beijin, there are not yet any fully commercialized robots, but several humanoid robots have been rented to museums and shows in China. Several components for robot motion control have been sold on a small scale. Beihang University collaborates with some companies, supplying (according to their own statement) key solutions to enterprises, including Chery, GSK, Up-Tech and others. The University of Tsinghua equally confirms having close cooperation with a large number of famous, world-class companies via joint laboratories, contract research, and connection to Tsinghua alumni.

Shanghai Jiao Tong University is about to set up co-operation with foreign companies like ABB, Microsoft, Yaskawa, Cypress Semiconductor, Omron, and National Instruments. In the domestic environment, they co-operate, for instance, with Shanghai Electric, with Jilin and Shandon Electric Power. There are some successful examples of commercial product development such as industrial robots (robotic manipulation) for an automobile manufacturer in Shanghai and cooking robots for a domestic company in Shenzhen. The university very actively pursues the technology transfer for the industrial partners. It also encourages patent application and transfer via an Advanced Industrial Technology Research Institute, which has been set up to provide services in the IP handling.

An interesting initiative to promote industry-academia collaboration was presented at KSITRI. They set up a university-industry platform which provides technological projects and intellectual resources. It seems that the platform managed to network the following academic partners: Institute of Microelectronics (Kunshan Branch, Chinese Academy of Sciences), Peking University Science Park in Kunshan, Nanjing University Innovation Institute, the Xidian University Kunshan Innovation Research Institute and the Kunshan Institute of Enterprise Innovation. According to the information provided by KSITRI, the center is geared to the industrial needs of Kunshan and has successfully started more than 30 enterprises and projects, many of them involve academic and industrial partners.

Kunshan launched an impressive initiative to push the successful commercialization of R&D and to exploit the innovative power in China. The National Level Industrial Development Zone KSND is an important platform in Kunshan to implement independent innovation vigorously with favorable conditions, accelerate clustering of hi-tech industry, and promote the improvement of economic development methods. KSND is the central industrial park of Kunshan City. All kinds of resources of Kunshan City are integrated in KSND. The construction of a robot industrial park with a planned land area of 500 acres has begun, with a total investment of 360 million RMB for the first planning phase. To cooperate with internationally well-known companies and research institutions, the main R&D and production areas are industrial robot bodies, controllers, vision sensors, and offline programming and other robot related technology.

In addition to this, the ITRI will set up a venture capital firm and an ‘angel fund’ to provide financial support for enterprises and innovative and entrepreneurial groups in the institute.

3.5.2. Spin-offs and support of SMEs

The industrial landscape in Japan is dominated by a few large players. This makes it difficult for spin-offs in Japan to stand their ground. It appears that they can only have commercial success if they profile as suppliers for these large enterprises.

Due to the decrease in industry money, there has been a stronger initiative by universities to found spin-offs in the last two years. This was triggered by the nuclear disaster in Fukushima and by the Lehman Brothers failure.

Nevertheless, the economic crisis in Japan (and the consequent drying up of industry funding) has motivated academic stakeholders to promote the spin-offs to commercialize their R&D. Furthermore, Fukushima triggered the recognition of the need for practical robots. And the Lehman Brothers failure also forced universities to think about ways to commercialize their products on their own. The job market is another aspect. The traditional professional career route has been to either go to a big company (usually directly after graduation) or to continue in research. These were traditionally seen as jobs for life. Recent economic problems have led to increased job insecurity which in turn means that careers in small companies and spin offs are starting to be seen as more attractive.

However, there is little evidence of support mechanisms and experience with small high-technology businesses. Japanese companies like to develop their technologies by themselves. It is difficult to start high-tech start-ups in Japan due to a lack of private investment, a lack of trust in safety and a lack of venture-capitalism. The ROI in robotics takes much longer than in other areas. The idea of service robotics is not well understood. The business models are not clear to the parties involved. In addition to this, the technology is not transparent to the investors.

Nevertheless, in 2003 the Robots Industry Development Council was founded by the Fukuoka Perfection Council, Fukuoka city and Kyushun city. The main purpose of this organization is to promote SMEs in robotics. This is done because, in contrast to the large companies, these SMEs are supposed to develop products where only a low market potential is expected. In general, there is a strong initiative in Japan to change the industrial infrastructure mainly consisting of only large company groups and to facilitate the foundation of SMEs. Just like in Europe, however, one of the major problems for young SMEs is to generate venture capital.

There are 343 robot companies in Korea. 81.7 % are SMEs. Thus, the entrepreneurial spirit of the Korean research institutes and universities is very different from Japan. SKKU has produced a spin-off company called InG, Co., based on the commercial 3D cameras it has developed. KAIST releases spin-offs to commercialize the products and services in robotics. KAIST has founded a venture company called Future Robots (20 % owned by KAIST).

KITECH has been set up with the explicit target to mentor SMEs. Any successful scientific research at KITECH is intended for commercialization via SMEs which are selected for this purpose and mentored by KITECH to do so. The general mode of cooperation and knowledge transfer at KITECH is mentoring SME companies. Each SME company that seeks support gets assigned a mentor that is a full time member of the KITECH staff. There are 1,400 staff members. It would seem that each mentor only has a few companies to look after. The role of a mentor is to advise the company regarding best practice use of technologies, equipment and processes.

Usually, a new product is developed by creating a specialized management structure within a division assuming ‘low’ initial revenues. If revenue increases enough, the creation of a specialized ‘division’ – a more complex management structure, including several smaller ‘units’ – is justified. If the product is extremely successful, a ‘company’ (including several divisions) is created, i.e. a specialized legal entity.

Yujin, as a medium sized player on the market, has been doing manufacturing automation for more than 20 years. In order to be able to focus more on a new line of business – the development and commercialization of service robots, which requires different marketing channels, the respective business division was spun off in 2002.

The Chinese industry is dominated by many state-owned as well as private companies. A number of such large companies are established in the world market. Surprisingly, it does not seem to be common in China to found spin-off companies. Some graduates from the Robotics Institute of the University of Beijing have established a company named Beijing Universal Pioneering Technology Co., Ltd (Up-Tech) to provide some intelligent automation equipment and components for the users. This was the only example of any spin-off activities mentioned by the Chinese universities visited during the tour.

Interesting details about the foundation of spin-offs and even venture capital firms were gathered during the visit to KSITRI. KSITRI reports to have set up a venture capital firm and an ‘angel fund’ to provide financial support for enterprises and innovative and entrepreneurial groups in the institute. KSITRI created nearly 10 spin-off enterprises, including robotics and automation.

3.6. Education with respect to Technology Transfer

Japan

There is not systematic industrial placement in Japan. There are some special programs at some universities where companies can determine the content of courses. Internships are done with some universities on request. There is very little exchange of students with industry (e.g. via internships). Thus, education is centred on fundamental research, not by industrial needs for applications. Even though robotics is an important part of the general education system, not only for engineers, and students are very interested in robotics and engineering, some companies (for instance YASKAWA) find it hard to recruit skilled people. The candidates’ weak points are often in the area of communication skills and creativity. Gender management is becoming more significant now as service robotics gain importance. As long as the focus was on automation, gender was not as important because most of the workers (users) are males in this field. In service robotics, though, a lot of users are females. Therefore, females need to be involved in the R&D process as well.

Currently, there are very few female students in engineering. The government is promoting women to study engineering. AIST underlines that after-school training should include robotics.

Ultimately, it is a tightrope walk, trying to balance between creativity and direct applicability. This is why in Japan, still, especially in engineering, most students go to work for companies after the Master’s degree, rather than continuing at the university towards a PhD – this is in fact an old and well-known problem to Japanese authorities.

South Korea

In Korea there are various approaches to bridge the gap between academic and industrial training, providing students with the possibility to gain industrial knowledge parallel to their academic training.

The cooperation with universities and other industries is funded by means of common governmental projects obtained through competitive calls. Huge companies in Korea tend to hire good PhD-students from excellent labs. This is LG's approach also.

The commitment of Samsung goes a step further. The reason is that even the large manufacturers in Korea are having difficulties recruiting good engineers and researchers for robotics. Special initiatives have been set up to facilitate the recruitment of highly skilled candidates. Samsung Techwin sponsors a robot membership program with 10 universities for promising undergraduate students who are interested in robotics. This is a hobby based initiative and large scale meetings are held twice per year. The benefit to students is that membership can give them a preferential position when it comes to applying for employment. Samsung also has joint labs with major universities in Korea and is the owner of SKKU. SKKU is remarkable in that it is a university completely owned and run by a single company. The curricula are aligned to the needs of a high-tech society.

Yujin has had an internship program with international students since 2007. At the moment, three foreign developers/employees are working in Yujin in service robot development.

In addition to joint projects with different companies, SKKU tries to integrate practical training at the industry sites into the curriculum of their faculties. The time they spent working in the industry plays an important role in the technology transfer (e.g. with GM). ISRI has recently established a double PhD degree program with Pascal Institute/CNRS-UBP, France, so that ISRI can offer prospective graduate students an opportunity to receive their PhD degrees from both SKKU and UBP.

Also KAIST confirms a strong exchange of students and professors between KAIST and its industrial partners. KITECH has no formal role in the education of students, although an implicit role is the education of staff in SMEs. KITECH recruits most of its staff directly from universities and other research institutes, although a small amount of recruitment from industry does occur.

China

Chinese companies work with universities. Internships are an integral part of the students' studies. Companies approach universities for collaboration. Mostly the projects are completely funded by the companies. There are no dedicated programs for university/industry collaboration. Some companies in China revealed to us that most universities are rather disconnected from industry needs. On the other hand, there are universities, e.g. Shanghai Jiao Tong University, that jointly define projects with companies.

4. Individual Lab Reports

4.1. National Institute of Advanced Industrial Science and Technology (AIST)

With its 2,500 researchers (5,000 including industrial research) AIST is one of the largest research institutions in Japan. 60 scientists with PHDs work in robotics. There is a major Japanese-European collaboration with CNRS, specifically LAAS in Toulouse (Jean-Paul Laumond) in humanoid robotics. As a result of this, there are a substantial number of French PhD-students and postdocs working at AIST.

4.1.1. Research topics and future trends

The big project is about functional safety of service robots (15 Mio € per year funding over a period of five years-NEDO project). Functional safety is per definition related to the effects the robot can produce on its environment or people in its environment. The other research topic is humanoid robots. The HRP project a couple of years ago triggered the development of humanoids which resulted in very sophisticated humanoids in all respects (facial expression, central controlled instead of decentralized, voice production, HRP-4C, miniaturization of weight, average ability Japanese woman, system integration, etc.). With regard to service robotics, AIST concentrates on four application areas:

- Human-robot collaboration
- Cleaning and logistics (with a focus on logistics)

- Powered suits (rehabilitation and support)
- Personal vehicles

Robots in the near future will not demand advanced technologies. The idea of AIST is to provide dependable technologies at lower levels. They want to find a way to serve public need. Public funding as well as industry funding has been reduced significantly.

HRP-4C: A humanoid robot resembling a young Japanese female

4.1.2. Results and innovation

Scientific/technological outcome

Impressive is the level of integration of all aspects (vision, speech, planning, monitoring) and everything is integrated on a small platform. Research seems to be disconnected from the market. They might lead the area with the research if they succeed, but if not they are disconnected from international research.

Business models

4.1.3. Funding modes and statements regarding funding

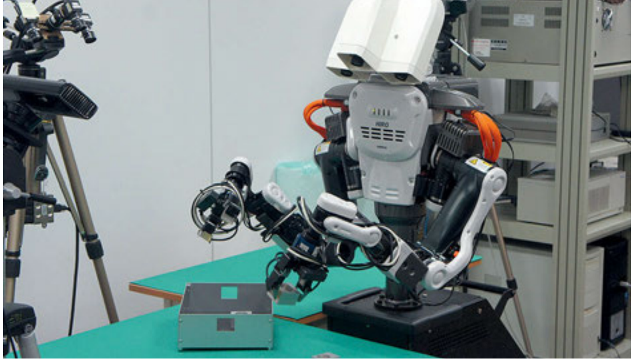
There is no military funding in Japan, but there are funding agencies.

The only large-scale project with an annual funding amount larger than 1 Mio € is the NEDO project, which involves many of the big players of Japanese industry, several funding agencies, as well as some universities. The focus, though, is on governmental institutions and industry, and the involvement level of universities is rather low. This fact clearly shows the strong application focus of this project. The project is led by Prof. Hiro Hirukawa, Director of the Intelligent Systems Institute at AIST (for details see chapter 3.3).

4.1.4. Knowledge Transfer, Cooperation, and IP handling

In general, the role of universities in Japan is to show the possibilities of basic research. In robotics, though, the situation is different, as robotics has not been very successful in industry. Therefore, universities get more involved in application-orientated research and in the analysis of customer/user needs.

The most appropriate measure to track technology transfer is whether the technology that has been developed is being used in products. The key question is how much money you can get from industry.



HIRO performing a complex task

A lecture on software developement at AIST

Industry reads scientific papers in robotics because they are easy to understand (as opposed to complex mathematics papers).

The major barrier is safety. Because of this, they have a major program in safety that includes a test facility which cost 20 Mio to develop. This is part of the NEDO project, which is bigger than anything similar in the US.

Cooperation modes

Commercial activities

The first product which results from the NEDO project will be marketed in late 2015.

Spin-offs

Japanese companies like to develop their technologies by themselves. It is difficult to start high-tech start-ups in Japan due to a lack of private investment and a lack of trust in safety. Another aspect that makes setting up a new business difficult is the lack of venture-capitalism. There are manifold reasons for this: the return on investment in robotics takes much longer than in other areas. The idea of service robotics is not well understood. The business models are not clear to the parties involved. In addition to this, the technology is not transparent to the investors. Due to the decrease in industry money, there has been a stronger initiative by universities to found spin-offs in the last two years. This was triggered by the nuclear disaster in Fukushima and by the Lehman Brothers failure.

IP handling

4.1.5. Education

Robotics is an important part of the general education system, not only for engineers. There is very little exchange of students with the industry (e.g. via internships). Thus, education is very much driven by fundamental research and not so much by applications for industry.

4.1.6. Statements by the people visited

“In Europe and in the US, a lot of companies are led by young people. In Japan, young people face a real difficulty to be taken seriously as a company leader.”

4.2. University of Tokyo – School of Engineering – Department of Mechano-Informatics

The University of Tokyo has world class laboratories in basic robotics research, especially in humanoid research. This includes the following laboratories:

- Inaba-Okada Laboratory – JSK Laboratory (many humanoid robots, tendon-driven musculo-skeletal humanoids, sensor suits, sensor technologies)
- Ishikawa Oku Laboratory (sensor fusion, vision, meta-perception)
- Shimoyama-Matsumoto-Takahata Laboratory (MEMS technology, nano-fabrication, insect-inspired robotics, camera and micro-lens development)
- Nakamura-Takano Laboratory (motion recognition and generation, musculo-skeletal models)
- Hirose-Tanikawa Laboratory (virtual, augmented, mixed reality, multimodal interfaces, ubiquitous computing)
- Sato-Shimosaka Laboratory (human behavior understanding, intelligent rooms/environments, robotic services)
- Kuniyoshi-Harada Laboratory (developmental robotics, emergence of movement from self-organization, haptics, musculo-skeletal robots)

University of Tokyo
Tokyo, Japan

4.2.1. Research topics and future trends

The research topics are dominated by humanoid robotics, or 'hyper-humanoid', like motion capture, soft-body robots, artificial muscle, sensorized assistive humanoids, tendon-driven technologies, modelling of musculo-skeletal humanoid systems, etc. The labs use a number of different platforms, e.g. different versions of HRP robots (Daily Assistive Humanoid HRP-2JSK, Outdoor Assistive Humanoid HRP-2W, Omni-directional Mobile Humanoid HRP-2V, Wide-and-Zoom Vision Humanoid HRP-2VZ), the Omnidirectional Mobile Personal Robot PR2 from Willow Garage, the tendon-driven robots Kojiro and Kenshiro (presumably currently the most advanced tendon-driven robots – the Inaba group has many years of experience and is clearly top-notch). Highly visionary basic robotics research is conducted in the Kuniyoshi-Harada Laboratory, which is guided by biological inspiration, and where development, emergence, and self-organization are key concepts. The cooperate very closely with people from neuroscience, developmental psychology, and materials. All the theoretical work is supported and tested in simulation studies and physical systems, such as the baby robot Noby which is covered with fully sensorized skin. Kuniyoshi laboratory is a pioneer in investigating the role of morphology and materials in cognitive development.


The group with two humanoids at Prof Inaba's lab

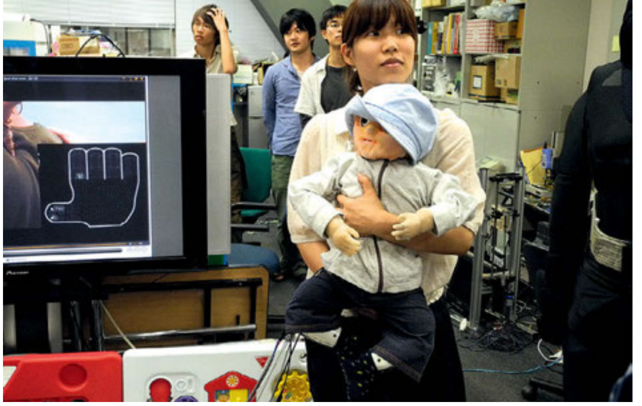
The dominating software used in robotic laboratories in Japan is OpenRTM, which is also used at the University of Tokyo. They are now interested in merging the OpenRTM with the ROS system.

The technologies in artificial intelligence and perception are also being applied in robot components such as the whole-body sensor suit, learning of cooperative behaviors, whole-body sensor suit 'flesh', MEMS technology (where the Shimoyama-Matsumoto-Takahata Laboratory is clearly world-class), components, tactile sensors, 3D force sensing, human-centered perception (counting pedestrians, pose estimation), fast 3D tracking vision module, 3D tracking vision module, high-power robot driving system.

Application areas lie mainly in service robotics, such as assistive living, home assistance, kitchen assistance, watching, recall support, etc.

The technological trends should go beyond humanoid, such as fast actuation and fast vision, rich sensors, mental development, dependable learning, and emotion technology and include:

- Sensor fusion theory and implementation in engineering systems
- Meta perception of capturing, manipulating and presenting information
- Open source robot software with advanced functions



Baby robot Noby simulates a 9 months old baby

- Humanoids for space and deep sea limited space usage
- Mobile robots with one (or later two) arms and rich sensors
- Multimodal user interface for partner-like human robot communication
- High user experience by using robots in real environments
- Developmental robotics – interdisciplinary cooperation with neuroscience and developmental psychology

Their main, long-term vision of robotics research is:

- Advanced components for soft-bodied and sensorized robots
- Highly sensorized humanoid robots with cognitive functions
- High intelligence of robots with capability to learn from successes and errors based on brain-inspired information processing
- Purposive, seemingly goal-directed behavior from a developmental process based on self-organization

4.2.2. Results and innovation

Scientific / technological outcome

Business models

4.2.3. Funding modes and statements regarding funding

Funding varies from chair to chair. In Prof Matsumoto's chair, 30 % of the funding comes from the government and 70 % has to be generated by industrial sources. The chair competes on a project-by-project basis. In general, in government projects, it is 50 % government funding and 50 % from industry. Since 2009 (the Lehman brothers crash), industry funding has been drying out. The peak for robotic funding in Japan was reached in 2006.

Most government funding requires proposals to be submitted in a call. There is a fixed date for the call, just like with the European Commission.

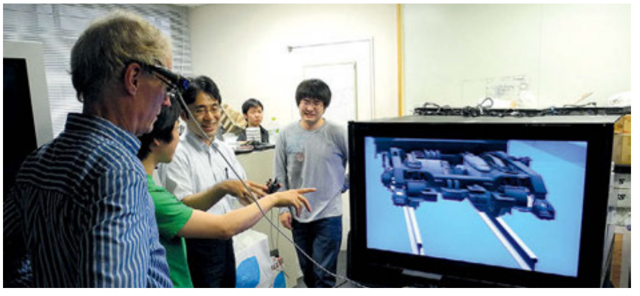
At present, there is just one large-scale government-funded robotics research programme (more than 1 Million €). This is the NEDO-funded project in the area of certification and middleware. There is no military funding in Japan.

4.2.4. Knowledge Transfer, Cooperation, and IP handling

Cooperation modes

Most of the groups are performing basic research, normally via internal projects. The cooperative projects with industrial companies usually focus on basic research and are not application oriented. Big cooperative projects are the IRT innovation for the Aging Low Birthrate Society and NEDO which are reported separately.

Commercial activities



Realistic and immersive simulation of robots

Spin-offs

Parallel to the drying up of industry funding, several chairs at the University of Tokyo have recently founded start-ups, which provide robot components, software and humanoid platforms for laboratories. No comprehensive results of the success of these start-ups have been collected yet. There are various factors that motivate this development and the Fukushima disaster in particular triggered the recognition of the need for practical robots.

Prof Matsumoto's lab recently spun out a company with the goal of commercializing a tactile sensor.

Most big Japanese companies are interested in robotics at least for prestige. For now, it is still unlikely that a robot will directly become a company's commercial product. Of course, the technologies derived from robotic research may often be applied to their products.

IP handling

IP's which derive from research are owned by the university. Basic inventions are filed by the university itself, but the application inventions are often filed in collaboration with the companies because of the high filing cost. In the case of joint research with a company, IP's are owned by the university and the company together, depending on the ratio of the contribution to the invention.

4.2.5. Education

There are no industrial placement programs in Japan. There are some special programs where companies can influence the course content of university courses. University courses are selected by students in their second year. At Tokyo University, robotics was the most often selected choice next to aerospace.

25 % of students in Prof. Matsumoto's lab are from other Asian countries. It is easy for the University of Tokyo to attract students from other areas in Asia. Surprisingly, there are not any students from Australia.

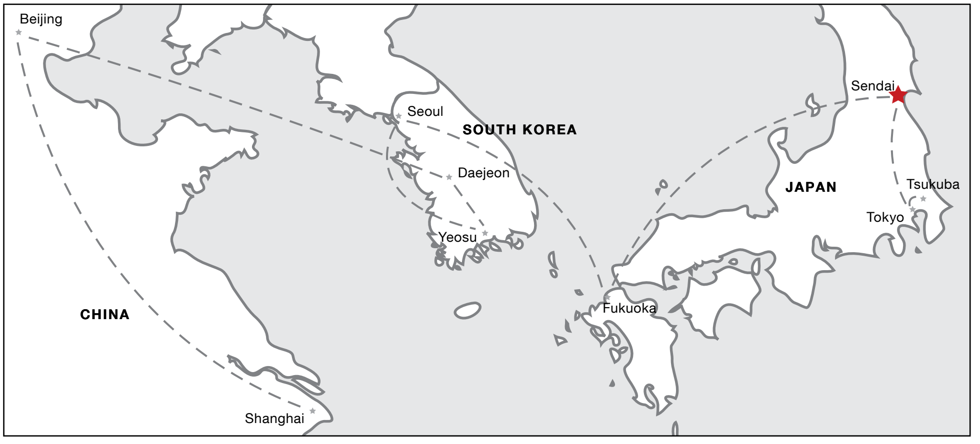
4.2.6. Statements by the people visited

"Humanoids are a symbol for research, but it is likely that products will be different."

"The technical gap between universities, research and industrial applications is similar to Europe, meaning that the gap is growing."

The mobility products should start appearing in the market place within the next five years, but "I do not know when the main household market will emerge." (Matsumoto)

4.3. Tohoku University



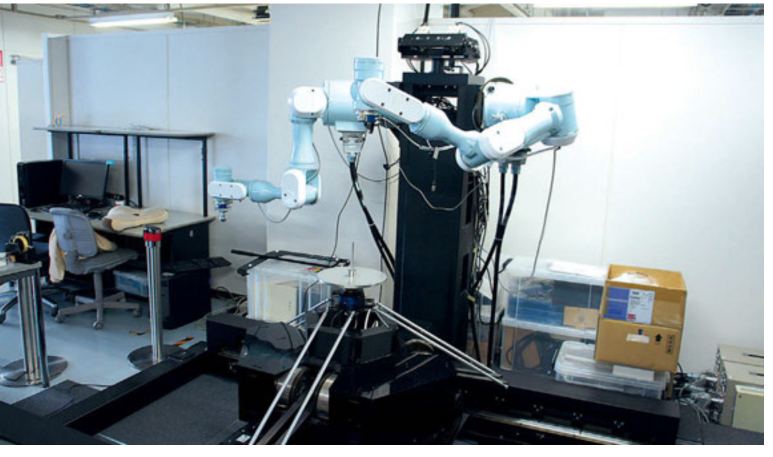
Tohoku University was founded in Sendai in 1907 as the third Imperial University in Japan. The School of Engineering was then founded in 1919 with three departments and has been expanding ever since. Today, it consists of five undergraduate departments, 17 graduate departments and three research centers.

4.3.1. Research topics and future trends

Extreme robotics is the overall theme of the department, including field and space robotics, medical and molecular robotics.

- Rescue robotics has seen a push due to Fukushima but it is still in the development phase. Quince was developed by the International Rescue System Institute, Tohoku University and Chiba Institute of Technology. It is a good, rough terrain system with impressive stair climbing ability and it is now delivering data from Fukushima. It was funded via NEDO but it didn't receive funding from TEPCO. There is no military application because there is no such agency in Japan. Quince can operate for 3-6 hours at a time. Its compliance to various radiations has been tested.
- Telerobotic systems: a system is initially being developed for teleoperation for in-orbit space robots. The core technologies have been spun off to develop a brain surgery simulator. The handling system employs two parallel manipulators.

- Haptic devices: two types of haptic devices are being developed for the brain surgery simulator. One is a hand-held type of haptic device by a five bar parallel mechanism for 3 DOF orientation and DELTA parallel mechanism for 3 DOF translation. The other is an encountered-type of haptic device using magnetorheologic fluid (MR). The MR emulates physical characteristics of the tissue.



Bi-manual kinematics based on PA10 robots

- A telemanipulation system for physical microgravity simulation has been developed. It allows for testing the docking of satellites. The manipulation is achieved with a parallel manipulator.
- The development microsatellite for observing sprites started 3 years ago. The first satellite was launched, but according to their report, it failed (it entered 'blue script mode').
- A planetary rover for the moon and for Mars is being designed. A prototype is working and is being tested in realistic sand conditions. Current research focuses on novel sand-wheel contact modeling.
- Neuroscience: there are tools for neuro scientists to observe the behaviour of C. elegans with focus on muscle neuroactivity. The tool includes automatic tracking of C. elegans' motion to enable visualization and registration of muscle activation.
- Another overarching theme is human-robot interaction. In this field, the dancing robot is still being used for human-robot interaction. A new application is PADY that assists workers in production lines. The assisting function is relieving workers from logistic tasks to allow them to focus on the assembling task.
- A passive walker was developed that avoids colliding with obstacles via a braking function.
- An automatic dish washing system was developed that can place dishes into the machine.
- Wire harness assembly
- Cell phone tracking system using cell phone accelerometers: It can identify who is carrying which cell phone by visual tracking.

Future trends are:
- Rescue robots with a certain level of autonomy
- Practical and implementable robotics

4.3.2. Results and innovation

Scientific / technological outcome

- Rollover avoidance of Quince is remarkable
- If the C. elegans tool is generalized to other species, this could be used as a tool for neuroscience

- Magnetorheologic fluid used for imitating brain surgery.
- Vertical take-off unmanned aerial vehicle

Business models

Most of the labs in the university are carrying out fundamental research for future robotics. Therefore, university policy does not have a certain defined business model.

4.3.3. Funding modes and statements regarding funding

Government funding for university research comes from various levels

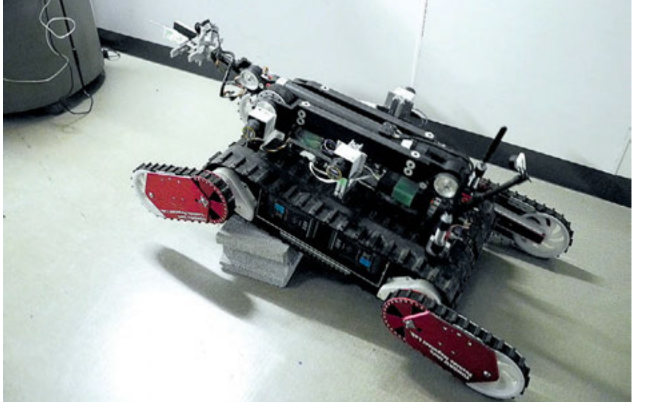
- Infrastructure support
- Teaching support for post graduates (support of PhDs)
- Selective support directly of post graduates (support of PhDs)

Junior researchers can apply to the Ministry of Education for grants that typically run between two and five years. As you move up the academic career, the amount of funding as well as its runtime increases. This funding is separate from project-related funding such as NEDO. This gives researchers the possibility to do their own first step research and then, at a later stage, as higher graduates, do the research and build a team. This funding is made available on a competitive basis subject to peer-review of submitted proposals.

Partner Ballroom Dance Robot

Specific-topics, large-scale programs are sometimes created by government departments and are available on a competitive basis. One example for this is the NEDO project (New Energy and Industrial Technology Development Organization). NEDO is the robotic-based project which receives more than 1 Mio € per annum. Another example is the Center of Robotics for Extreme and Uncertain Environment (CREATE), to which 9 robotics labs belong, and which gets financial support from the Ministry of Education, Culture, Sports, Science and Technology in Japan. In addition, research projects for next generation mobile systems are currently underway, and this includes robotics technology. The project has 1.5 Mio € of funding from the university, and 3.0 Mio € from the Ministry of Economy, Trade and Industry in Japan.

The space research receives funding from the Japanese Space Agency. But this does not fund all the work done in this area. NEDO provided some small-scale funding following Fukushima, which enabled the work on mobile disaster robots to get started. The industry did not share the financial burden of the disaster. In addition, there is an ongoing 0.5 Mio € NEDO funding for the next six years to continue this support.



Quince search and rescue robot

Partly to support the rebuilding of industry in the Sendai region, there has been an investment in automotive manufacturing of 1.5 Mio € initial funding and 5 Mio € for this year. In addition to the two existing plants (one in Nagoya and one in Fukuoka), the investment is meant to support the research needed for building a third Toyota plant in Sendai. There are two projects running in this context:

- electromobility
- robot co-worker

One of the barriers of industry-academia collaboration is that industry sometimes expects initial results free of charge before they decide to fund. So, the universities have to take the initial risk and there is no risk-sharing mentality. There seems to be a lack of government-supported funding of small-scale, industry-academia collaborations.

4.3.4. Knowledge Transfer, Cooperation, and IP handling

Cooperation modes

Prof. Uchiyama is the director of a new initiative specifically set-up by the university of Tohoku to promote industry-academia collaboration, namely the New Industry Creation Hatchery Center (an incubator, NICHe). The center supports fundamental researchers who have the possibility to start a new business. The researchers in the engineering department are executing the research projects in collaboration with industrial parties or government.

Commercial activities

In some cases, the technological outcomes born in the engineering department and in the NICHe are commercialized by small companies established by professors in the projects or through the partner companies for projects.

Spin-offs

The traditional professional career route has been to either go to a big company (usually directly after graduation) or to continue in research. These were traditionally seen as jobs for life. Recent economic problems have led to increased job insecurity which, in turn, now means that careers in small companies and spin offs are starting to get more serious consideration. However, there is little evidence of support mechanisms for this and limited experience with small, high-technology businesses.

IP handling

The intellectual property division in the university claims and exploits the intellectual property rights pertaining to research undertaken within the university. The division files patent applications, and protects and manages the rights in addition to educating staff in the university on intellectual property matters. The division also plans tactics for exploitation and negotiates agreements for joint patent applications, including liaising between university groups and external parties. The intellectual property division aims to maximize the use of intellectual properties created as a result of research undertaken at the university.

4.3.5. Education

4.3.6. Statements by the people visited

4.4. YASKAWA – Corporate Research and Development Centre

Yaskawa was founded in 1915. Today the company has a capital of 23,062 million yen. Annual net sales amount to 307,111 million yen (consolidated) and 170.848 million yen (non-consolidated). Yaskawa is engaged in four different business areas:

- System engineering 12 %
- Information technologies 6 %
- Motion control business 49 %
- Robotics (collaboration welding and assembly operation) 33 %

Robotics accounts for 33 % of these net sales. Smart robotics is part of the Technology Development Division, but some robotics development is also carried out under Corporate R&D (also part of the same division).

4.4.1. Research topics and future trends

Yaskawa Electronics Company (YEC) is pursuing four main topics in R&D: systems engineering, robotics, motion control, and information technologies. They are working towards creating a market for robotics that will interact closely with humans and co-exist with them (the robot-human assisted domain). Another future trend is environment and energy, which is fairly separate from the robotics area and will not be further discussed.

YASKAWA
Fukuoka, Japan

Topics for Yaskawa are: collaborate welding, transfer robots, assembly operation by dual-arm control, mobile manipulation, ambient intelligence, ambient assistive living, e-mobility (electric cars – not directly related to robotics), SmartPal VII (a service robot aimed to co-exist with humans with mutual cooperation). Although they have an interest in service robotics (and have a number of pertinent projects), their interest in the short term is in manufacturing.

A service robot developed at Yaskawa

One of the overall goals is to bring the technology that works in structured manufacturing environments into the unstructured, e.g. home, environment. The aim is to develop a TMS (Town Management System) a term intended to cover basically everything. This includes: speech recognition and instruction, localization, manipulation, assistive functionalities (bringing objects from a fridge to a person just by being told to do so), a large environmental model database which is used as a reference for all behaviors (fetch, deposit, etc.), etc. For example, the database, by communicating with the robots, keeps track of the location of people, objects, etc., which greatly facilitates fetching and depositing tasks. By setting up a kind of 'ecosystem' in which multiple robots, intelligent objects (tables, refrigerators, and shelves) communicate with each other and with an intelligent ambient environment, they are establishing a detailed model of the environment that can later be used as a reference to achieve the tasks they were instructed to complete.

To build an environmental model and to achieve tasks in this unstructured environment, they rely on the following types of sensors: vision, Kinect, RFID, force-torque sensor (e.g. in table), LRF (on ground, robot, and table), ultra-sound, etc. This implies using:

- passive RFID
- barcode
- loadcell (detect position of all objects)
- connection with robot (robot has access to object information via the database).

Examples:

- House (TMS, Town Management System - they received the house from the Kyushu government for free): This implies the construction of a 3D map of the room, the house, and a block of the town surrounding the house. This requires communication between robots and environment. An interesting parent-child robot concept was developed. Moreover, the tracking of people, mobile robots, other objects (e.g. cars) that change their position very quickly and tracking everyday objects is required.

The group at Yaskawa

- Fetch-me-shirt-and-shoes scenario
- Put something in the fridge (demonstration was shown)
- Force-torque sensors in a 3-finger hand which are necessary for compliant finger control
- Skin with tactile sensors on arm which is used for safe interaction

Yaskawa sees two types of robotics applications in the future:
- Applications requiring robot autonomy among people at home
- Applications for complex tasks in factories

Human-assisted robotics are about to be established as a business domain. Today there are single task robots, i.e. they can typically do one specific task. But Yaskawa assumes that the trend will be robots that perform multi-task services. Humanoids, according to one statement at the conference, “have no future”.

The company is interested in the ambient environment in the context of the Robot Town Project by providing facilities on the company premises (where they have an experimental space with an intelligent room / apartment).

The following new challenges have been identified in the area of service robotics:
- Surgery
- Home cleaning
- Personal mobility
- Welfare
- Agriculture

Research activities are done on components which go into units and then into systems. Yaskawa clearly delineates these three levels but it is not clear yet, if the company intends to generate sales on all three levels.

Yaskawa sees the need for market creation in the area of service robots and is adopting a structured 3 phase approach to developing business in this area, i.e.
- Create the needs
- Create the values
- Create the products

In this context, much of Yaskawa’s current research is aimed at exploring the needs before investing funds in service robotics. For domestic service robotics, the price is very important. In professional service robotics, the price-performance ratio and the features are important. Therefore, the time does not appear to be ripe for pushing service robotics.

4.4.2. Results and innovation

Proof of innovation is given by the fact that the company will be celebrating its 100th anniversary in 2015. Innovation has been achieved in many domains, e.g. electrical motors (potentially to be used in cars), sensor-less servos, etc.

Scientific / technological outcome

In the area of robotics technology, there is an impressive level of integration in the SmartPal VII Robot, in particular in terms of electronic components.

Business models

For the new robotics business (time range 2015) the Robotics Human Assist Business Domain has been identified.

Yaskawa has undergone a transformation from automobile industry supplier to general industry to service industry and then expansion.

The company has undertaken a full range of initiatives in the robotics field. However, none of these initiatives has been successful yet in terms of new business generation. These have included live line working, hospital worker and humanoid robots.

On December 21, 2011 the SRC (Smart Robotics Center) was set up within YEC with the sole purpose of creating new business based on lessons learned from the past. Its goal is to accelerate the development of human-assistive robotics.

Humanoids are not considered to be a big opportunity for creating business. Yaskawa's main interest is to get intelligent robotics technology into both the manufacturing and the non-manufacturing process.

4.4.3. Funding modes and statements regarding funding

4.4.4. Knowledge Transfer, Cooperation, and IP handling

Cooperation modes

In general, Yaskawa prefers to develop their products in-house rather than running cooperative projects with partners outside of the company. Apart from this, Yaskawa has subject-based collaborations with universities. The IPRs are considered a major handicap of industry-academia collaboration. Yaskawa claims to have a longstanding open innovation history in robotics, going back to 1989 to a collaboration with Kyushu Electric Power Company. The company has always developed solutions in close cooperation with partners from academia and industry. Some examples are: Kyushu University, TRC (USA), Fujitsu, etc. Yaskawa is setting up an increasing number of national and international collaborations, including Stanford University (visiting scholar program), Shanghai JiaoTong University, Yaskawa Service and Mechatronics Lab, Willow Garage, Agile Planet, and Universal Robotics. The company currently does not have any strong research links with European organizations. Nevertheless, they want to create the market with worldwide partners and is now looking for partner universities in Germany.

Yaskawa undertakes its research on a global basis with non-Japanese resources including:

- SJTU – Yaskawa Service Robot and Mechatronics Lab in China (set up in 2008)
- Yaskawa America, Inc. - this unit has strong research links with both Universal Robotics and Willow Garage. Moreover, there's an affiliated program of visiting scholars with Stanford University in the United States.

One important example of a cooperation initiative is the Robot Town Project realized in cooperation with Kyushu University (19.000 students, 1.365 professors), Prof. Tsutomu Hasegawa. In addition to Yaskawa, this town project was realized in cooperation with NEC Kyushu, TMSUK, Toyota, Nissan and Daihatsu. The project is funded by the government with an annual fund of .5 million US dollars. Yaskawa is the principal organization in this project. Some of these funds go to the industrial partners to finance the employees working on this project.

The industry sponsors the project mainly by supplying hardware – partly because the town is a testbed for robot applications and is a opportunity for industry to get feedback from the final users.

Yaskawa service robotics application

The main purpose of Robot Town is the development of common platforms. The initiative was / is supported by the following funds:

- 2006 – 2008: Cabinet Office of Japan ($1.5m)
- 2008 – 2010: Ministry of Economy, Trade and Industry ($1.2m / year)
- 2010 – 2012: Ministry of Education, Culture, Science & technology

Commercial activities

Spin-offs

IP handling

4.4.5. Education

Internships are done with some universities on request. Even though students are very interested in robotics and engineering, the company finds it difficult to recruit talented people. Apart from a pure scientific background, good communication skills have become increasingly important. Another issue of interest is gender management, which has a growing significance as service robotics gain importance. When the focus was on industrial robotics and automation of assembly lines (i.e. production processes), gender was not as important because most of the workers (users) are males in this area. In service robotics, though, a lot of users are females. Therefore, females need to be involved in the R&D process as well.

4.4.6. Statements by the people visited

“METI has forecast a potential robot market in Japan of 2.9 trillion yen ($36bn) by the year 2025.”

“Big companies can’t develop niche markets.”

“Recently, (the setting up of) spin off companies has been encouraged by national and local government.”

4.5. Korea Institute of Industrial Technology (KITECH)

KITECH was established in 1989 as the nation's only R&D institute as a spin-off of KIST with the specific mission to support manufacturing SMEs. KITECH has a number of regional centres. The headquarters located in Cheonan (just south of Seoul) was set up 10 years ago and one of the regional centers, located in Ansan, was built 5 years ago, which is the lab we visited. Overall, the organization has 1,400 staff members. KITECH is under the jurisdiction of the Ministry of Knowledge Economy (MKE). The mission of KITECH is to help SMEs penetrate global markets by providing them with support so they can develop core technologies with commercialization potential while preparing for future markets by acquiring new industrial technology.

One of KITECH's four-legged robots

4.5.1. Research topics and future trends

As a whole, KITECH has a wide technology spread based on certain application themes. These feature specific market segments such as bicycles and packaging, but also include more broad application themes. The Ansan Center has 3 main application foci, these being:

- Robotics
- Advanced Textiles
- Convergence technology

KITECH utilizes application driven roadmaps to identify Root Manufacturing Technologies (RMTs). So far, some 8,000 RMTs have been identified.

Within robotics, the technology range is wide and is driven by the application need of the companies supported and by project needs. However, there is a clear competence in the area of system integration and in the production of working systems.

Many of the researchers at KITECH were absent on the day of the visit but, nevertheless, the study team was shown 3 labs with different application foci. The first lab focused on military and rescue robotics. Here 3 main projects were discussed:

- Rough terrain logistics robot
- Unmanned Arial Vehicle (UAV)
- Wearable robot

The rough terrain logistics robot (called Jinpung, which means 'Dragon Wind') is a walking robot designed to carry supplies for soldiers, with similar characteristics to Big Dog from Boston Dynamics. This hydraulically actuated robot has been under development for 5 years and there have been several different models built in that time. The current version shows autonomous capability to walk over uneven surfaces and is robust to outside disturbances but seems to have had little testing outside the lab.

The UAV is an autonomous flying rescue vehicle with a torus structure and internal propulsion fans. It uses 2 types of power source; one is lithium polymer batteries and the other is gasoline engines. The UAV with a gasoline engine weighs 2kg and its engine gives it a one to two hour operational range. Its primary mission is to go to a pre-specified position over water (navigating by GPS) and drop a couple of life vests.

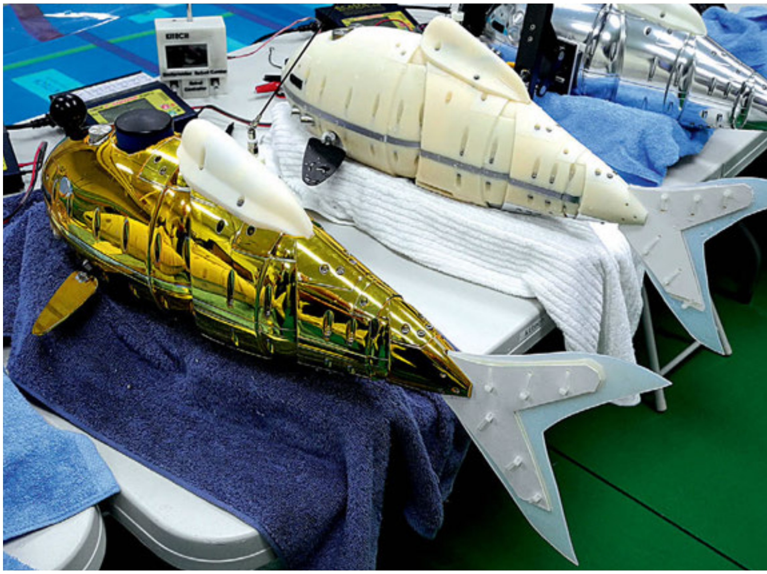
The wearable robot is a support suit for soldiers to enable them to carry heavier packs and have longer operational endurance. It is primarily a leg support/amplification system with hydraulic actuators driven from an electrically driven hydraulic pump fitted within the backpack, which also houses the batteries. The whole suit weighs around 20kg. The current suit is the third evolution of the system.

The next lab was the Android Robot Lab. This development has been going on for eight years and has gone through three application focused evolutions. The first was aimed at the secretary/receptionist robot with the second being a singer. The current evolution of EveR (Eve Robot) continues the entertainment focus with an actress robot. Much of the technology development focus has been on emotion production. EveR has silicone skin and 33 motors capable of producing a wide range of facial motions, including activation of the tongue. While the system is mechanically very competent, the production of motion and speech involves humans first performing the actions with motion capture and sound recording being used to reproduce these actions. EveR does have a range of pre-programmed emotion display states which can be activated through a single command and which causes a set of facial movements to be displayed. The current version of EveR is 157cms tall and weighs 50kg. EveR is a key attraction at the Yeosu Expo in Korea and welcomes guests to the robotics exhibition.

The final lab visited was the Robot Fish lab. This featured 0.5m long robot fish with natural- looking swimming ability. The application focus for this work was water quality monitoring and the fish contain sensors capable of measuring 5 parameters, namely:

- Conductivity (EC)
- Degree of oxidation (DO)
- Hydrogen ion concentration (pH)
- Turbidity (SS)
- Temperature (T)

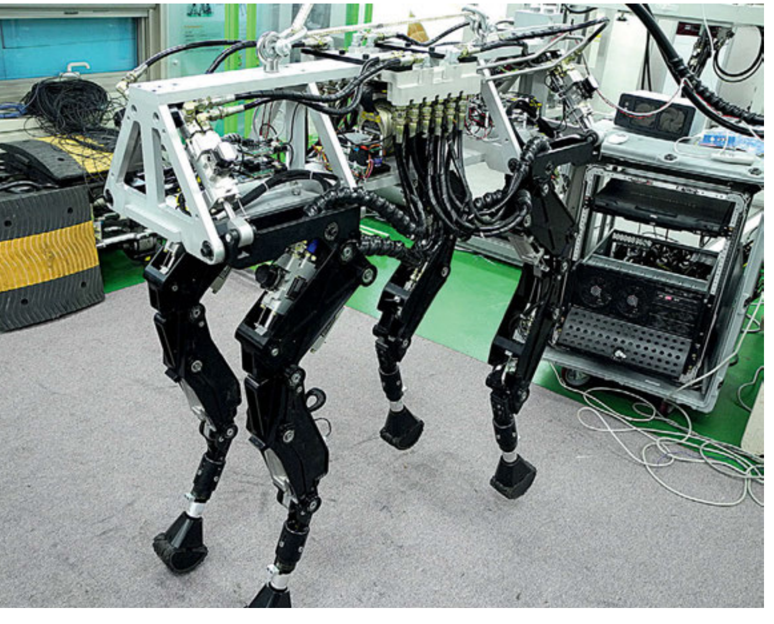
The reason for using fish in this application as opposed to conventional underwater robots was their maneuverability. The fish in the large experimental tank certainly displayed the ability to both accelerate quickly and to make tight turns. However, the price to be paid for this



KITECH's robot fish

maneuverability was a 20 % drop in energy efficiency compared with a conventional type with propeller AUV. Nevertheless, the fish have a top sustainable speed of 3~4 knots and their endurance was longer than 1 hour. (5~6 hours with 1 Knot (0.5m/s))

The fish featured a range of sensors including ultrasonic sensors for collision avoidance and GPS and an USBL (ultra-short baseline) system for localization and navigation, RF and ultra- sonic for communication. The means of communication with the base station was wireless. The fish were primarily tele-operated but could be commanded to swim to a pre-determined point. Capabilities such as following a pollution stream are seen as future developments.



A four-legged robot with high dynamics

The general trend in KITECH would seem to be evolutionary, rather than revolutionary, development. Much of the expected development appears to be in the area of increased autonomous function in various applications, coupled or at least in tandem with increases in robustness (particularly environmental robustness) of the underlying electro-mechanical systems. In this respect, KITECH is not a leader in underlying technology development. However, this is in no way a negative criticism of KITECH's capabilities as their strengths lie in the application of technology and making this relevant to SMEs.

4.5.2. Results and innovation

Scientific/technological outcome

The key emphasis of KITECH is clearly on innovation aspects with a strong competence in system engineering. All the work demonstrated had an application focus and obtaining high reliability within persuasive demonstration systems seemed to be a key focus.

Business models

KITECH gets 30 % of its total budget (USD 187 million in 2006 [18]) through government grants and 70 % on a contract basis. This additional project based funding comes from other organizations such as the Ministry of Defense. KITECH works on an annual budget and is not required to raise additional income, other than for performing research and development projects.

4.5.3. Funding modes and statements regarding funding

The majority of funding for KITECH operations comes from MKE. This is a block funding that underpins their support to SMEs. In addition to this, KITECH bids for specific project funding through competitive procedures. Again, most funding comes from MKE, although the Korean Ministry of Defense funds several projects in the defense/security area and other funding agencies provide minor funding (e.g. the Ministry of Environment in the area of environmental monitoring). Several projects also involve joint funding between two funding agencies.

KITECH receives no direct industrial funding in terms of membership fees or project development funding. SMEs apply for funding (or cooperation with KITECH), and then the winning applications are selected y a special panel.

4.5.4. Knowledge Transfer, Cooperation, and IP handling

The general mode of cooperation and knowledge transfer is via mentoring SMEs. Each SME that seeks support gets assigned a mentor that is a full time member of the KITECH staff. There are 1,400 staff members. It would seem that each mentor is assigned a low number of companies to look after. The role of a mentor is to advise the company regarding best practice use of technologies, equipment and processes.

The other main mode of knowledge transfer is through the output of research and development. The default intention is for all projects to result in the transfer of knowledge to SMEs as either products or services. In some cases, projects may go through several development phases (as follow up projects with separate funding rounds). The identification of exploitation can take place at the start of the project, during the project (especially towards the end) or even after the project has been completed.

Cooperation modes

KITECH was set up specifically to cooperate with Korean SMEs and the primary mode is through mentoring. As mentioned above, KITECH also cooperates with some SMEs in terms of development projects. KITECH also cooperates with international partners on R&D projects. One specific example that was mentioned was that KITECH is an international partner of the Italian Institute of Technology and of Wi Huosheng-Hu at Essex on the FP7 projects FILOSE and SHOAL which dealt with the development of robot fish.

Commercial activities

The primary commercialization activities of KITECH are done via the SMEs they support, but they also provide an efficient conduit for technology from projects to reach the market.

Spin-offs

No spin-off activity was mentioned.

IP handling

For products and services resulting from internal R&D projects, companies are identified which can exploit the results. It is not clear whether exploitation rights are granted or licensed.

4.5.5. Education

KITECH has no formal role in the education of students, although an implicit role is the education of staff in SMEs. KITECH recruits most of its staff directly from universities and other research institutes, although a minimal amount of recruitment from industry does occur.

4.5.6. Statements by the people visited

"The growth of the Korean robotics industry is currently running 30 % per year" – Korean English language TV programme 'Arirang Today' featuring KITECH technology.

4.6. LG Future IT R&D Lab

This lab is the main IT R&D department of LG. LG has a wide spectrum of specialty areas ranging from home consumer products to turn key heavy industry plant design and commissioning. The role of the department (within LG Electronics legal entity) is to support 'long term' (meaning Y+3) research and development of consumer products for the home. The objectives of the lab are similar to those in IST in FP7.

The lab has proven its ability to pragmatically adapt its research to develop or improve consumer products within the $500-$1000 price range (e.g. visual SLAM and optical flow navigation on a vacuum cleaner; extending the functionality of the Homebot by including a telepresence functionality). It also leads the industry in the field of automatic driving and is present at scientific conferences and technology fairs.

4.6.1. Research topics and future trends

- ADAS (Autonomous Driving Assistance Systems)
  The purpose of this research program is to develop advanced autonomous driving techniques: an increasing number of driver‘s assistance functions shall be gradually introduced into the consumer market. The lab envisions that automated driving under controlled condition, e.g. on highways, will be introduced in the next ten years. Autonomous driving in urban environments is a future topic. This research is backed by close cooperation with the automotive industry.
- Motion recognition (people and vehicles) in urban contexts
- Security surveillance systems for buildings are another focus of LG’s activities, comprising security video cameras, recording systems and turn-key security systems. Recent developments have been intelligent monitoring systems using up to 12 screens at 20-30 fps, running on a pc with GPU (based on CUDA).
- SLAM and telepresence in a vacuum cleaner
  A vacuum cleaning robot – Homebot – with a mapping algorithm based on sensor fusion of visual SLAM and Optical Flow navigation data, telepresence, and patrolling functions has been introduced in the Korean market, exploiting cloud computing and data base facilities.

4.6.2. Results and innovation

Scientific / technological outcome

Business models

In order to improve existing products or services of LG, the lab continuously monitors the state-of-the-art in robotics, machine vision and machine learning and identifies those which are potentially relevant for the development of future applications with regard to consumer products. Repeatability, robustness and dependability of the results are a major selection criterion. LG approaches potential cooperation partners – usually targeting the marketing department initially, in order to determine the feasibility of a joint cooperation. If the outcome is positive, the project is passed on to the engineering department and enters the standard product lifecycle. The R&D department is continuously being updated on the market reaction of the newly introduced features and products.

4.6.3. Funding modes and statements regarding funding

The lab is funded by the company. The lab increases or decreases in size based on its products in the consumer markets.

4.6.4. Knowledge Transfer, Cooperation, and IP handling

Cooperation modes

The cooperation with universities and other industries is funded by means of common governmental projects obtained through competitive calls. The composition of employees is about 60 % PhD and 40% Master graduates. The key people are from Sukhan Lee‘s laboratory at SKKU (see below).

Commercial activities

The commercial activities are developed together with the marketing divisions of LG Electronics. LG Electronics is a consumer electronics company.

Spin-offs

Spin-offs are not a usual part of company practice. Usually, a new product is developed by creating a specialized management structure within a division assuming ‘low’ initial revenues. If revenue increases enough, the creation of a specialized ‘division’ – a more complex management structure, including several smaller ‘units’ – is justified. If the product is extremely successful, a ‘company’ (including several divisions) is created, i.e. a specialized legal entity.

IP handling

The management of IP appears to be less strict than in other contexts: LG does patent very specific components at a national level. The national patenting system is closer to the European model than to the American one because it is not possible to patent the usage of visual slam in vacuum cleaners (despite the fact that LG developed it and has a robot vacuum cleaner using visual slam on the market).

4.6.5. Education

The model LG pursues is hiring good PhD-students from excellent labs (in this case, mainly from Sukhan Lee‘s laboratory at SKKU).

4.6.6. Statements by the people visited

“Future is current year + 3 for us.”

4.7. SungKyunKwan University

The SungKyunKwan University (in short SKKU) was founded about 600 years go in 1398. In 1996 the University Foundation became part of the Samsung Group. In 2011, the university had 1,109 full-time faculty staff members, 19,424 undergraduate students and 10,311 graduate students. Samsung's role in SKKU reflects the perception of the company that it is responsible for high-level education in Korea.

The Intelligent Systems Research Institute (in short ISRI) was founded in 2003 as a key centre of the 21st Century Frontier Program for Intelligent Robotics, sponsored by the Ministry of Knowledge Economy and Gyeonggi Province. Since then, ISRI has grown as an internationally renowned research institute, carrying out a dozen government and industry funded research projects and collaborating with many domestic and international partners.

4.7.1. Research topics and future trends

Cognitive vision/robotics, HRI, 3D reconstruction/modeling, visual manipulation/grasping and autonomous vehicles are among the main research topics. The laboratory's philosophy is based on the conviction that research is instrumental to applications. Emotion simulation in HRI and 3D vision 'co-exist' in the same research lab. HomeMate (see below) is a fascinating home assistant/companion robot that has already reached an advanced stage. One of the guiding principles is the so-called 'w-Cognitive Robotics for HRI'. The "w" stands for "will" and the idea that true intelligence and believable and dependable interaction has to originate from a motivated agent.

Interactive service robot HomeMate developed at SKKU

The 'w-Cognitive Robotics Framework' proposed and developed originally by the laboratory poses a new approach for the yet-to-be solved problems in robotics, that is, guaranteeing the reliability in performance in robotic services as well as defining the natural HRI resulting from the robot being itself as a motivated agent.

4.7.2. Results and innovation

Scientific/technological outcome

In addition to a strong basic research orientation, there is also a high interest in the development of applications in the consumer market based on advanced cognition and robotics technologies. One of the main objectives is a home robot assistant/companion called HomeMate that the lab anticipates will be ready for market in 3-5 years. To this end, HomeMate, developed as a platform for dependable, elderly-care robotic services based on w-cognitive robotics, will be upgraded to a commercial grade and deployed in elderly-care centers in Korea and the US for evaluation.

At the component level, the highly accurate (2 mm res., 2 hz) 3D camera based on structured light, which was developed in the laboratory, promises a wide application potential. The results obtained thus far with the HomeMate platform in terms of functionality compare favorably with those of the PR-2 (for example).

Business models

4.7.3. Funding modes and statements regarding funding

The lion's share of the funding (about $2 million per year) comes from the government via the Ministry of Knowledge Economy and Gyeonggi Province, South Korea. Some financial contributions also come from industry, such as General Motors, LG and Hyundai Heavy Industries Co.

4.7.4. Knowledge Transfer, Cooperation, and IP handling

Cooperation modes

ISRI strongly cooperates with industrial partners and the research has a strong focus on applications backed by market intelligence. The research takes into consideration the value-price-cost inequality criteria for successful product development, thus helping the industry long term. Five examples of collaborative research with industrial partners were mentioned as being successful international industry collaborations:

- The KORUS project – to develop an elderly home robot (HomeMate): along with SKKU on the academic side, Yujin Robots and Bona-Vision are involved on the industrial side. Because the robot's application is not only planned for Korea but also for the US market, Georgia Tech was involved as well, and has contributed many user acceptance surveys which were arried out in elderly homes in the US. Pennsylvania State University is now involved for the user evaluation.
- Bin picking program: carried out in conjunction with General Motors
- Education robots: research projects in this area involve KIST and a wide range of Korean companies
- Robotics transporter with Pascal Institute (RoboCab)
- Contributions to new ROBOKING robot vacuum cleaners developed by LG

Commercial activities

There are three parameters that have to drive the development of service robots if they are going to achieve market acceptance:

- dependability
- sociability
- affordability

The HomeMate robot for elderly people will be commercialized at the end of 2015 at a target price of 15,000 €. Even though this is still a lot of money at first sight, market surveys suggest that this price level is acceptable for institutions. To penetrate the private home market, the possibility of establishing a contribution from the insurance industry like in some European countries is being investigated. The approach that was used to achieve this target price is to add more intelligence to the systems rather than use cheap component parts.

The group with HomeMate

This development approach made the needs of the customers/users the focus and is not merely technology-driven. The industry considers the HomeMate as the major product for the future. In addition, they are trying to evaluate the robot with 25 seniors from the Jongro Senior Welfare Center.

Spin-offs

ISRI has produced a spin-off company called InG, Co., based on the commercial 3D cameras it has developed.

IP handling

The university owns the rights to all scientific findings resulting from their research. As the academic institutions in Korea want to create an added value for the population, they strive to apply their technology to commercial products. Even though they own the rights, they are willing to compromise with their industrial partners. The question of intellectual property becomes more complicated of course, when the research results from previous projects with various partners/academic institutes who also have to be integrated in projects.

4.7.5. Education

In addition to joint projects with different companies, young researchers often spend some time working in the industry, which plays an important role in the technology transfer (e.g. with GM). ISRI has recently established a double PhD degree program with Pascal Institute / CNRS-UBP, France, so that ISRI can offer prospective graduate students an opportunity to receive their PhD degrees from both SKKU and UBP.

4.7.6. Statements by the people visited

"Price/value/cost and dependability, sociability, and affordability are the key to a service robotics solution success."

"1 robot 1 home in 2020."

"Elderly assistance is of major importance."

4.8. Electronics and Telecommunication Research Institute (ETRI)

ETRI is the largest government-owned research organisation and was founded in 1976 to carry out ICT R&D. Today there are 1,894 regular employees (of which 780 hold a doctoral degree) in the institution. In total, ETRI has more than 2000 researchers and comprises 12 labs on the Daejon campus focusing on the following 8 technologies:

- IT convergence technology
- Convergence components materials
- Broadcasting & telecommunications convergence
- Advanced communications
- SW-SoC convergence
- BigData SW
- Creative content
- Cyber security

Robot development is carried out in the Robot Cognitive Convergence Research Department, which was established last year. This is the successor to the Cognitive Robot Research Division (set up in 2008) and before that, it was the Intelligent Robot Research Division (founded in 2004). The department currently has 84 staff members of which 31 hold PhDs. Originally work centred on the Ubiquitous Robotics Companion but the focus has shifted recently to 3 core themes:

- Robot software platform
- Application oriented robot technologies
- Core cognition/intelligence technologies

Between 2008 and 2010 the main sponsorship was transferred from MIC to MKE (Ministry of Knowledge Economy). The research focused on HRI solutions and core chip sets and the open robot SW platform: OPRoS (Open Platform for Robotic Services) was initialized. A prototype has already been developed. Another project of major importance is the development of an elderly-care robot. Recently, two teams (the spatial information research team and the spatial cognition research team) have been added to the existing robotics group. A new 5-year HRI project of MKE has just started. Its focus is on HRI cognition and decision-making/expression.

4.8.1. Research topics and future trends

Being the biggest government funded research institute, ETRI pursues research in various areas. The Robot/Cognitive Research Department of ETRI is developing software solutions for robotics. As such, the department is developing an open robot operation system, called OPRoS, similar to ROS from Willow Garage and to OpenRTM from AIST. They realize the need for interfacing with other operation systems such as ROS and OpenRTM. Our experts were told that together with the ROS and OpenRTM groups, ETRI is working on a standard for robotic operation systems. This seemed more like a general statement rather than an affirmative initiative. Currently, the strategy to extend OPRoS is to introduce interfaces for exchanges with ROS and OpenRTM.

Another research focus is on solutions for human-robot interaction. We saw a face and body detection system that is able to recognize registered faces, known pictures, body postures and gestures, and written digits. One area of current developments is the 'Future Robotics Computer' which will have the interaction characteristics of a human and feature a 3D projector based on the Anamorphic Illusion. Software for translation of spoken sentences was presented.

One larger research project is on outdoor navigation. A navigation system for known environments has been

The group of experts at ETRI

developed and is currently being used in a robotic shuttle car. This car is intended for use in closed terrain environments such as museums. The navigation includes path planning.

RoboSem and interactive robot

There will be a convergence in robotics software. Internet combined with interactive TV will provide tools for medical inspections.

It was noted that industrialization has, to date, largely been bottom up (i.e. technology driven). A top down approach is needed which would:

- Define services which can usefully be carried out by robots
- Derive the functions and technologies necessary to fulfill those services

4.8.2. Results and innovation

Scientific/technological outcome

ETRIs innovations can be found in different areas where robotics is probably not the center of the research initiative. Their main innovations, as displayed in their exhibition hall, include a 4G high speed mobile network technology to be introduced in Korea, a very small urine testing device, a wearable shirt which measures the wearer's ECG, respiration, and temperature in real-time, and also software for animating movies.

Business models

4.8.3. Funding modes and statements regarding funding

4.8.4. Knowledge Transfer, Cooperation, and IP handling

Cooperation modes

ETRI is currently involved in a development project in collaboration with CMU in the USA which is aimed at the development of a mower for apple orchards. ETRI is also collaborating with the automotive industry to develop robot technology for cars, most notably an automated overtaking system named iOvertake.

Commercial activities

ETRI focuses on personal service robots, but has found that the price is a crucial problem when it comes to commercialization. Another challenge is aftersales service. ETRI distributed 850 robots to private homes, but as a whole the project failed because it was impossible to provide the necessary aftersales service. ETRI staff also noted that technical developments were still needed in order to find useful applications and that the identification of applications with mass market appeal is also still a problem.

A humanoid developed at ETRI

Spin-offs

IP handling

4.8.5. Education

4.8.6. Statements by the people visited

“I don’t think anybody can expect a killer application in robotics.”

“The robotics market is difficult right now.”

4.9. Korea Advanced Institute of Science and Technology (KAIST)

KAIST – the Korean Advanced Institute of Science and Technology – was founded in February 1971 as Korea's first research-orientated graduate school in science and engineering. The mission was to educate scientists and engineers who could enable Korea's transition from an agricultural country to a centre of technology. The purpose of KAIST's establishment was the "education and training of highly qualified scientists and engineers equipped with theoretical and practical expertise, to create an R&D hub based on national policies, and to support national research activities." [64]. Today, KAIST has 6000 graduated researchers and 4000 undergraduates and an annual budget of approximately 662 million US dollars.

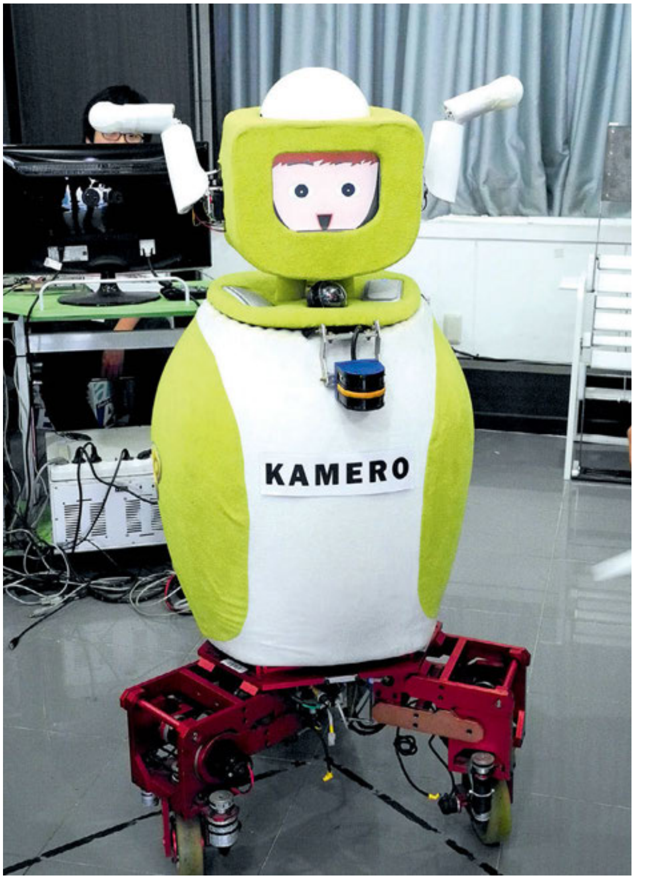
KAIST
Daejon, South Korea

The campus in Daejeon visited during the lab tour was established in 1989. The Department of Mechanical Engineering, Telerobotics and Control Laboratory focuses on three main research areas:

- Human-robot interaction with a focus on personal service robotics and emotional interaction: the Human-Robot Interaction Research Center (HRI-RC) was founded in 2003 and 4 professors in KAIST are involved. HRI-RC has researched an emotional interaction method according to the recognition, generation and expression of emotion. This emotional interaction architecture has been embodied in various service robots such as an education robot, a silver-care robot and an ordering robot. These projects are done in collaboration with KIST and external companies. The government funded this research.
- Medical robots (currently there are two different systems developed, one of which was led by industry). Back in 2004, no company was interested in medical robotics. This has changed drastically. The Center for Future Medical Robotics was founded in 2008 and 4 professors in mechanical engineering and 2 medical doctor teams are involved. So far, the developments of KAIST in this area have not been commercially successful. Most striking now is the development of a single port laparoscope robot that could be a successor of the daVinci robot.
- Haptics: the main object of haptics research is developing tactile and kinesthetic feedback actuators to generate the realistic feeling of a ‘button click’ in touch screen based mobile devices. Recently, Samsung and LG, which manufacture smart phones, have shown interested in these research topics at KAIST.

The following labs were visited at KAIST:

- Telerobotics and Control Lab chaired by Prof. Kwon
- Mechatronics, Systems and Control Lab chaired by Prof. Kim
- HuboLab chaired by Prof. Oh



The KAMERO robot

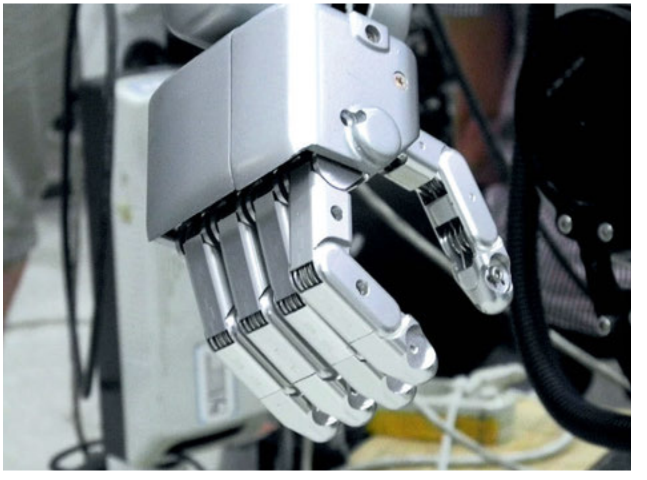
4.9.1. Research Topics and future trends

The laboratories have five main research directions:

1. Human robot interaction

The aim is to develop and implement advanced algorithms for the emotional human-robot interaction according to the recognition, generation, and expression of emotion

- KaMERo is a hybrid mobile robot that can interact with humans. It can recognize human emotions according to the facial expression, voice and touch, and generates its own emotion with the hybrid emotion process and the intimacy-based emotion architecture. It also expresses various emotions like anger, joy, and surprise.
- ROTI, an English Teaching Robot was developed. Its mechanical setup is equivalent to Segway except that it has passive assistant wheels with springs added for stability and energy reduction. It is remote controlled and was used in schools for teaching English. It was commercialized by the company Rastech Inc. The commercialization phase was supported by the government as a pilot project.
- FURO is a service robot intended for restaurant service. It has an integrated payment system which uses credit cards. The robot accepts orders and handles the payments. It was commercialized by Future Robot Co. Ltd.



A dextorous 5-finger robot hand

2. Medical robotics

- Robots for minimal invasive surgery have been developed. The first prototype was not successfully commercialized. The new version has six internal degrees of freedom and includes an elbow, not only a wrist. The latter is uncommon to other such surgical robots. It therefore is very dexterous.
- Flexible surgical robot for NOTES (Natural Orifice Transluminal Endoscopic Surgery) has been developed. Without any incision, surgeons can perform surgery with the robot system through the mouth, vagina, and anus. First animal testing was done in 2012.
- A tele-manipulated robot for bone surgery was also shown. In terms of sensors and stiffness, it seems comparable to other commercial devices.

3. Haptics

- The lab develops tactile actuators that can exert strong force in a wide frequency bandwidth. The aim is to integrate them into mobile devices. Currently, the lab collaborates with LG and Samsung regarding the commercialization of tactile displays, particularly with respect to magnetic rheological buttons. The prototypes shown have not yet been integrated in really small sensors or displays.

4. Biomechanics and Mechatronics

The lab develops small UGVs mainly for rescue and military purposes.

- A ground vehicle was developed that is mechanically very robust and has very good shock resistance. Its design follows that of other full tracked vehicles but it is said that its design, and in particular its center of mass, is better (e.g. the 'flipper'-feature, a full 360° rotation) and it incorporates a sprung wheel design. SLAM is possible but not yet implemented. It is remote controlled and water-proof.
- LaunchBot is a very robust field exploration robot that has the shape of a grenade. The last version is the result of a series of improvements. While the first version was the size of a football, the current version is of the size of a regular grenade and can be deployed as one. Once deployed, it can be remote controlled. The robustness and compactness of this device is remarkable.
- ZINEDYNE is wormlike robot. Its 2x8 legs are actuated by one single motor. This is more a study object rather than a prototype.
- PILLBOT is a small exploration robot that protects itself by curling up in a similar manner to Pillbugs.
- A 5-finger robot hand has been developed for use with the lab's humanoids. It has very good dexterity, but currently no tactile sensors. It weighs 400 g.

5. Humanoids

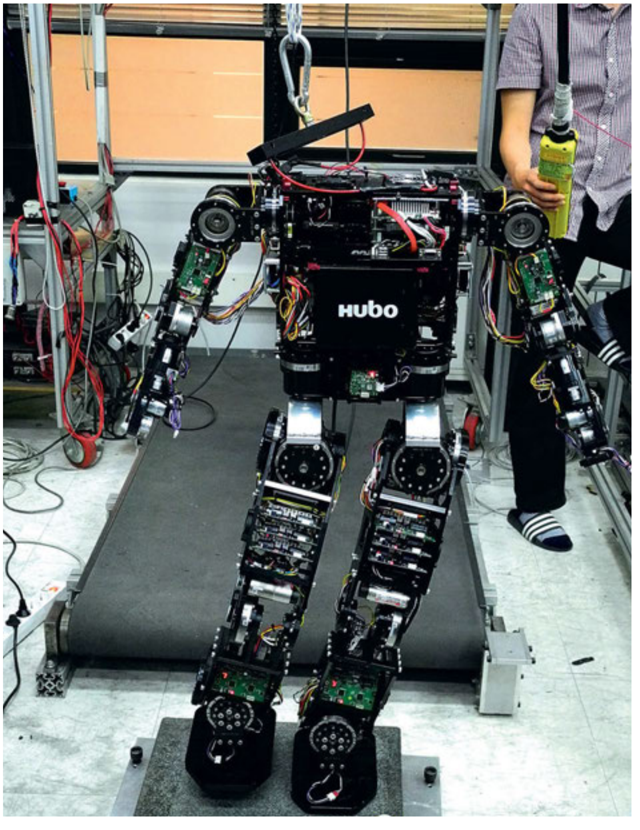
- HUBO is a very dexterous humanoid with remarkable stability with respect to external disturbances. The robot is very light (43kg). It is equipped with a 5-finger hand that only weighs 400 g. We were shown that it can reproduce human motion, which was recorded by a motion capture system. It will be commercialized by a company of which the ‚university' has 20 % shares.
- A light weight robot arm (4.5 kg) for dexterous manipulation was demonstrated. This seems to have high dexterity. The applicable payload is rather large (2kg) compared to its weight. It will be commercialized by a KAIST spinoff company.

Cognition is crucial for future robotics. Future robots must have facial expressions and eye motion. Moreover, medical robots will play an important part in robotics. In 2004, no company was interested in medical robotics. This has changed. Currently there are two major projects. One is led by a company and the other by KAIST.

4.9.2. Results and innovation

Scientific/technological outcome

Robustness is a main guiding design principle. The lab is very market oriented and tries to commercialize each development, thus the necessity for robustness. Remarkable is the robustness of the humanoid HUBO (demonstrated by on-site experiment) and of the ground vehicle (shown in a video). We cannot say much about



The HUBO robot

the LaunchBot. The tactile actuators are rather behind the state of the art.

Business models

4.9.3. Funding modes and statements regarding funding

KAIST benefits from an annual funding of approximately 148 million US dollars from the Ministry of Knowledge Economy. In addition, there is a small amount of funding from the industry (about 10 %), as well as some minimum financial support for basic research from national sources. The share of the funding that goes into robotics is fairly small, but the efforts to make achievements are high.

The Hubo lab receives a half a million per year from MKE.

Apart from this, the government financially supports pilot projects to open up new markets and application areas for robotics. The financial support is usually granted for one year. This includes a test period of the products or services at the users/customers location, who can test it free-of-charge for six months before they have to make a purchase decision.

4.9.4. Knowledge Transfer, Cooperation, and IP handling

Cooperation modes

KAIST strives to collaborate very closely with industrial partners to produce prototypes as a pre-commercialization step. Depending on the funding mode, KAIST either decides on the research foci by themselves (governmental funding) or the research foci are determined by industry (cooperative projects). In any case, the commercialization of the products or services generated is the final goal of the scientific activities. The number of patents as well as the royalties generated with the licences is the measure of success of the technology transfer.

KAIST's licences and royalties are managed by a special funding office within the institution. Apart from licences there are various modes of cooperation with the industry:

- Spin-offs (see below)
- Students (see below)
- Cooperative projects with industrial partners (large and small companies)
- Even government-funded projects usually incorporate industrial partners

The runtime of a regular project is between 3-5 years. 2 million US dollars per annum is the average size of a project. Usually 3-5 groups are involved, some universities, some research institutions and several industrial partners.

Conferences are a good medium in Korea to present scientific findings to industry and to find industrial partners for the commercialization of products. In addition, there are strong ties with industry due to the graduates that take senior positions in companies. Therefore, companies also visit KAIST pro-actively. Many of the companies which have collaborated with KAIST in joint projects come back again, which reflects the level of satisfaction of the industrial partners with the cooperation.

One reason for the scientific success of the Hubo Lab is the fact that all parts and components for the products developed at Hubo are manufactured in the lab. The use of standardized hardware components is restricted to a minimum.

Commercial activities

The LaunchBot funded by the Korean Ministry of Defence (DAPA) will be commercialized next year. The Hubo lab has developed a hand with 5 degrees of freedom for each of the fingers. This will be commercialized via the KAIST venture company Rainbow Co. Ltd. within the next months. The price will be between US$ 50,000-100,000.

Spin-offs

KAIST releases spin-offs to commercialize the products and services in robotics. KAIST founded two venture companies: Rastech Inc. and Rainbow Co. Ltd. (20 % owned by KAIST).

IP handling

If the research is funded by the government, the patent belongs to the university. If the research is done under the umbrella of a collaborative project, the patent is jointly owned by KAIST and the industrial partner (50:50).

4.9.5. Education

There is an active exchange of students and professors between KAIST and its industrial partners (e.g. two PhD students regularly work on small UGV at the premises of the company licensing the technology).

4.9.6. Statements by the people visited

The lack of standards in service robots is hindering progress.

The robot labs at KAIST tend to work independently of each other.

4.10. Yujin Robot Co. Ldt.

The company was founded in 1988. The CEO is Shin, Kyung Chul. Capital: US$ 7.8 million. Today the company has 120 employees, is an Intelligent Robot Specialized Company and is listed on the Korean stock market KOSDAQ (the Korean version of the Nasdaq). The market capitalization is about US$ 10 million. While they mainly targeted industrial robots in the early years of their existence, Yujin now generates about 2/3 of their revenue from service robots.

Yujin Robot has two assembly lines – one for the final assembly and one for the sub-assembly. The company has 6 locations. Some of the research projects have been selected by the company's own initiative, some have been picked because of the foci set by governmental funding.

4.10.1. Research topics and future trends

Yujin's research and development foci are in line with the general trends in Korean research labs: network based service robot (including cloud computing concepts). Their main business fields are:

- Cleaning robot/home service robot/entertainment robot
- Tutoring/teaching robot/rescue robot
- Industrial robot/manufacturing automation systems

Yujin's robotized wheelchair

One particular focus of Yujin's activities is to develop a software framework for authoring contents on the service robotics platforms.

They see the future evolution of the service robotics market going towards network robotics (they call it 'robotics in concert' and in particular, in the connection of the service robot platforms to a plethora of various devices (i.e., washing machines, ovens, etc.).

In the long term (several years), Yujin envisions a second generation (in Korea they already have the first!) of service consumer robots capable of errand manipulative tasks. They share the vision of the cognitive consumer robotics (Sukhan Lee's HomeMate) as medium term perspective for the conumer robot market.

4.10.2. Results and innovation

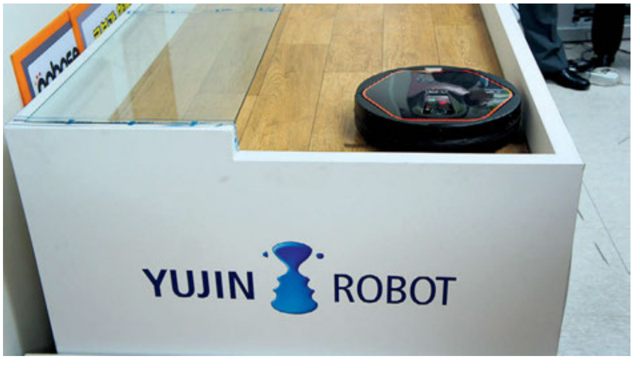
Scientific/technological outcome

Yujin Robot was the first industrial player in Korea to develop a cleaning robot (iClebo). Today, though, the interests of big companies like Samsung, LG and iRobot have taken over the leading position in cleaning robots in Korea.

The main achievements of the company are:

- 2001.10. Game/Entertainment Robots Development Project by MOCIE
- 2003.02. Awarded as a superior manufacturing technology Center by MOCIE
- 2003.08. First President of Korea Intelligent Robot Industry Association
- 2004.07. Introduced Home Robot irobi by Business Week
- 2004.11. irobi, awarded The Best Intelligent Robot in Robot Technology Valuation by MOCIE
- 2004.12. ROBHAZ (military rescue robot), acquired KT Mark by MOST
- 2005.01. Cleaning Robot iClebo, press release
- 2005.10. Rescuing Robot, ROBHAZ received the President Award
- 2006.04. Introduced Home Robot Jupiter by The New Times

Currently, Yujin is developing an assistant mobile wheeled robot for taking orders (not delivering orders because it has no manipulation capabilities) in bars (café) and restaurants, called Cafero. This robot has basic speech recognition and synthesis capabilities (tailored to the application). A similar platform, physically smaller, called iRobiQ, is designed to play games and teach English in kindergarten (2000 installations). A third product, which they are working on but is not yet on the market, is what they call the 'riding robot' platform: a robotized wheel chair. In this application, design is a major issue as this robot looks more than an automated



The iClebo cleaning robot

armchair than a medical tool. The target market is elderly care. The fourth product which was shown to the visiting experts is a Kindergarten-Robot produced using the Cloud Computing system.

Business models

Yujin is very interested in verbal remediation of autistic children by robot. If local partners in Europe develop the verbal remediation contents with Yujin and then develop the market, it would result in contents and robot business together, and this would be a good business model.

Yujin has already developed the technology to integrate their cleaning robot (which is currently marketed by Philips in Europe) into a more comprehensive home cleaning system. They do not want to launch the product on their own, but are looking for an industrial partner to cooperate with.

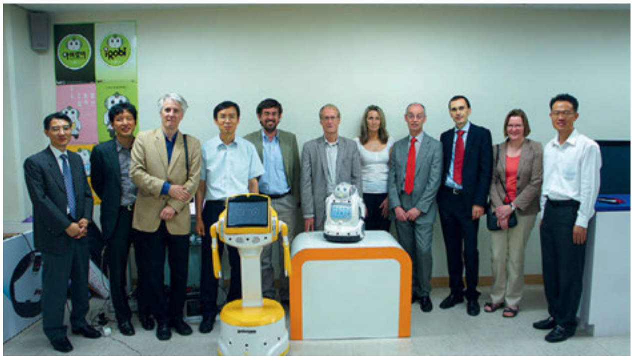
4.10.3. Funding modes and statements regarding funding

The military robot ROBHAZ was funded by the Ministry of Defense and was sold to the Korean Army. The Korean government selects companies for funding. Most of the support is limited to R&D. Yujin is participating in the OPRoS project which was initiated by the Korean government. The local government provides funding for R&D projects. They make an annual R&D plan.

R&D is funded by competitive cooperative projects on the national, regional and even city levels.

Yujin was successful at winning a competition for a project against the biggest ICT public research institute in Korea.

An interesting public funding scheme through pre-competitive procurement gives private and public customers the money they need to purchase new robot products.



The group with their hosts at Yujin Robot Co.

4.10.4. Knowledge Transfer, Cooperation, and IP handling

Cooperation modes

Yujin is developing a number of service robotics systems in strict cooperation with Sukhan Lee's lab at SKKU. In research, they cooperate with universities, research centers and other companies in Korea and the US, but not yet in Europe. There are cooperations with universities and research institutions. In other words, the entire product development is not done in-house. In terms of international relationships, Yujin has a cooperation with Philips in Germany, St. Gallen University in Switzerland, as well as with Georgia Tech in the US. Yujin is the software provider for ROS. They also collaborate with Willow Garage. Currently, they are looking for additional partners from Europe.

Commercial activities

In the teaching robots area there are three target groups to tackle: children, parents and teachers. The fact that different countries are working with different certificates for robots is considered as one of the major trade barriers. It would be desirable to have just one certification worldwide. Having to cope with various certificates is expensive.

Spin-offs

Yujin has been doing manufacturing automation business since 1988. However, in order to be able to focus more on the service robot business, this business division was spun off in 2002.

IP handling

4.10.5. Education

Yujin has had an internship program with international students since 2007. At the moment, three foreign developers/employees are working in Yujin in service robot development.

4.10.6. Statements by the people visited

An interesting comment from the sales manager: "R&D invents new products and I have to find a way to sell them" (in other terms 'technology push' inside the company).

4.11. Korea Institute of Science and Technology (KIST)

KIST (Korea Institute of Science and Technology) was founded in 1966. It is a multi-disciplinary research institute with the aim to develop technologies and transfer them into products and services. The specific focus of KIST is on fusion technologies that will power Korea's economic growth, especially in the areas of the environment, energy, health, security, and materials. KIST is a global player with a foreign branch in Saarbrücken – the Korea Institute of Science and Technology Europe Forschungsgesellschaft mbH, established in 1996. KIST Europe wants to build global S&T networks with prominent EU research institutes in the field of basic and application-orientated research. It has partnerships with research institutes and industrial companies in Europe and Korea.

Apart from carrying out scientific research, KIST also has the authority to train and graduate students. Thus, KIST pursues a joint degree graduate program, a training program for research and an international R&D academy. At present, KIST has 3000 students. Contrary to the statement that was frequently heard at the tour, that it was difficult to recruit students for disciplines like engineering and computer science, KIST itself does not face this difficulty. They receive more applications than required. It is difficult, though, to recruit experts to run the institute. KIST has an intensive exchange of researchers with universities. This might be one of the reasons for their success in attracting students.

The mobile robot ROBHAZ intended for rescue operations

4.11.1. Research topics and future trends

These include humanoid robots (network 2005), ROBHAZ (military robot), industrial artificial diamonds, and organic solar cells. Another focus is on life science (for instance, the development of an anti-cancer agent and anti-cancer pills). Newer research topics include brain science research (development of an endoscope), and pollution-free automotives and a water-purification facility. Other topics include:

- 3D object recognition: a very compact and light-weight stereo camera has been developed. An object recognition system was demonstrated that is able to detect known objects (like cups with certain texture) in unstructured environments.
- CIROS is a combination of a humanoid and a mobile platform. It comprises the torso of a humanoid but has no legs. It is equipped with a 3D camera and the 5 finger robot hand developed at KIST.
- The ENGKEY robot is a well-known mobile robot for teaching English. It is already on the market. This is a good example of system integration and human-robot interaction.
- The center pursues research on a MERO robot that can imitate facial expressions. A high-fidelity robot head was developed that can realistically mimic human facial expressions.
- The KIBO humanoid is the most advanced humanoid developed by KIST and will soon be commercialized. Its human interaction and motion capabilities are impressive.
- A mobile robot ROBHAZ intended for rescue/military operation. This is a robust tele-operated platform.
- Impedance controlled robot arm intended for domestic service applications.
- A speech separation system, with an improved noise cancellation technique, that allows the robot to be directed towards a person. This system is still in its development phase, but could be used for navigation purposes.
- Multimodal interaction technology that is based on the analysis of human motion.

KIST developed from the industrial robots area (which started with the automotive industry), and moved towards service robots. The paradigm shift from industrial robots towards intelligent robots occurred between 1997 and 2001. The shift was necessary because the market for industrial robots was showing signs of saturation. The sales there are still increasing, but sales of professional and personal service robots are increasing much more rapidly. It will be crucial to have a flexible framework for integration of knowledge-based systems and content-based reasoning.

4.11.2. Results and innovation

Scientific/technological outcome

Service robots with advanced human robot interaction capabilities (speech, facial expressions) and humanoid robots are ready for the market.

Business models

- Biz Model I: cooperation with Nordic countries (Finland, Denmark) to develop an elderly care robot which is to be commercialized very soon.
- Biz Model II: the second development is a teaching robot which will also be commercialized very soon.
- Biz Model III: venture company to commercialize robots. This is done in cooperation with Denmark.

4.11.3. Funding modes and statements regarding funding

The 21C Frontier Program, hosted by MKE started about nine years ago with a funding of 80 million US dollar for a total duration of ten years, up to 2013.

The government drives the robot industry. KIRIA (Korea Institute for Robot Industry Advancement), the central source of government funding in Korea, was established in 2010 and started with a robot pilot project with a funding of 87 million US dollar for 3 years (2011-2013). The Robot-Cluster-Project was launched in 2012 and will last until 2016. Today, it is the contact center for government pilot programs.

KIST CIR (Center for Intelligent Robotics) receives the main funding – a total of 90 million US dollar for 10 years (2003-2013) from the government MKE to develop robotic technologies in the 21C Frontier Program of Korea. In addition to that, CIR received funding from many different sources including KIRIA. KIRIA administrates government funds in the amount of 30 million US dollars per year (2011-2013) to promote creating market applications for robotic technologies.

Alois Knoll in interaction with the KIBO robot

4.11.4. Knowledge Transfer, Cooperation, and IP handling

Cooperation modes

There are active collaborations between KIST, universities and companies in the 21C Frontier Program. KIST and universities research core technologies while companies focus more on commercializing the core technologies or developing practical ones on their own.

The MERO robot imitating human facial expressions

Commercial activities

KIST has been putting a lot of effort in improving robot technologies' practicality by performing many pilot projects in real fields such as robotic English teaching in elementary schools, robotic cognitive training for the elderly in dementia centers, etc.

Spin-offs

KIST is going to spin off a venture company that will handle the commercialization of KIST robotic technologies. The company will continue the Biz Models above. It is expected to launch in October 2012.

IP handling

Intellectual Property Rights are not an obstacle in academia-industry collaboration for KIST. KIST owns the rights, but gives them entirely or partially to companies. The industrial partners have to pay a small amount at the beginning and therefore collect less royalties during the runtime of the license/patent. This is contrary to Europe – no initial lump sum, but higher royalties.

4.11.5. Education

KIST provides joint degree programs at a graduate level with at least 7 universities in Korea.

4.11.6. Statements by the people visited

4.12. Samsung Techwin, Hyundai and the Korean Association of Robot Industry (KAR)

Samsung Techwin is the largest defense company in Korea with 4,800 employees. The mobile security robot section was set up in 2010. The industrial infrastructure of Korea reflects about 80 % SMEs, which are mainly suppliers for service robots. SMEs, though, cannot create brand power. Therefore, it is important to have the commitment of huge company groups in robotics. The development of robotics in Korea started with a focus on domestic service robotics mainly driven by companies such as Yujin Robot between 2003 and 2008. There has been a recent shift in government funding policy towards professional service robotics, which was added partly to attract larger company groups, but also because the midterm markets appear to be in this area.

Hyundai Heavy Industry manufactures 20 % of all the large ships in the world and 35 % of all marine engines. Their main robotics interest is in industrial robots, where they have 30 current models. The main market is automotive, but they have a specialized niche robot product that is able to handle very large LCD glass panels for the global display industry.

Samsung Techwin, Hyundai and KAR
Seoul, South Korea

The Korean Association of Robot Industry (KAR) was set up in 2008 as a merger of the Robotics Research Association (established in 1999) and the Korean Advanced Intelligent Robot Association (founded in 2003). It has 158 members (25.9 % industrial robot companies, 32.3 % service robot companies, 16.5 % components manufacturers and 25.3 % others). The Association publishes a Robot World statistical survey and is engaged in standardization. Today's focus is on creating robot projects based on the initiatives from its members.

4.12.1. Research topics and future trends

Examples of robotics developments at Samsung Techwin include a security guard robot, an Automated Ammunition Resupply Vehicle for a self-propelled Howitzer, a remote controlled weapon system with an intelligent camera system and the newly developed Samsung Techwin Autonomous Robot (STAR). The development of STAR 2 is currently underway, which will be a diesel based platform featuring both GPS and GPS-less based navigation. Samsung Techwin also uses robotic technology in the development of a map based 'Total Surveillance Management' system: a system that integrates massive amounts of data from many remote sensors and other sources.

Human-robot interaction will be the core issue in future developments. In addition to a strong ongoing effort to achieve fully automated factories in mass production, the cooperation between human workers and robots will become more the main focus. This entails a stronger cooperation with disciplines other than robotics. In order to supply SMEs, the robot has to be equipped with several tools so that it can fulfill several functions. Another issue is the price. The research trend is to reduce the price and increase the performance of the robots at the same time (multi-tasking ability). In mechatronics, the reduction of the weight of the systems is a crucial factor - no fancy motors, but regular machines with lower weight. The focus over the next few years will be on network robots. Samsung believes that teleoperation is the key to human-robot co-working. Often the development in robotics is boosted by military funding, otherwise the products would be much too expensive to develop. Samsung strongly benefits from working in the military field as well as in the consumer markets (see spin-off technologies later). There is a belief that future robotic developments will see a convergence of mechanisms and applications.

4.12.2. Results and innovation

Scientific/technological outcome

Business models

4.12.3. Funding modes and statements regarding funding

The Korean government spends about 70 million US dollar on robotics R&D every year. The Ministry of Knowledge Economy (MKE) provides funds to foreign companies or organizations to promote their participation in Korean fairs. 50 % of the expenses are covered by these funds administered by the Korean Association of Robot industry (KAR).

Samsung Techwin gets about 10 % of its robotics R&D funding from MKE.

4.12.4. Knowledge Transfer, Cooperation, and IP handling

Cooperation modes

The large companies in Korea like to develop their products in-house, although they do work with universities as partners, e.g. Korean and US universities are participating in the development of the STAR2 program with Samsung Techwin. The major benefit in robotics development (for instance, in the case of Samsung Techwin) is not only in robotics itself, but most of the profit is made on spin-out technologies that can be exploited by developing new products on the side (for instance, due to military funding). For large companies, the decisive factor for cooperating with universities is the completeness of the technology. Software development should take place at universities. In addition to this, universities act as the longer arm of industry for R&D, which is too expensive and too time-consuming for the industrial stakeholders to carry out themselves.

In general, industry is dissatisfied with the technology transfer between universities and the industry. Therefore, industry mainly concentrates on the recruitment of students when it comes to cooperation with universities. The major problem in academia-industry cooperation is the completeness of technology, liability of the system, and robustness, which cannot be taken for granted when hardware is supplied by universities.

Samsung Techwin stated that, in general, it is constantly on the lookout for appropriate technology all over the world.

Commercial activities

There is a feeling from industry that efforts at commercialization from government-backed research institutes are not helpful as they tend to license systems that are not ready.

Spin-offs

IP handling

The background is owned by the universities, but the foreground development is usually done by industry. Otherwise, the industrial partner has to pay for this (license fees).

4.12.5. Education

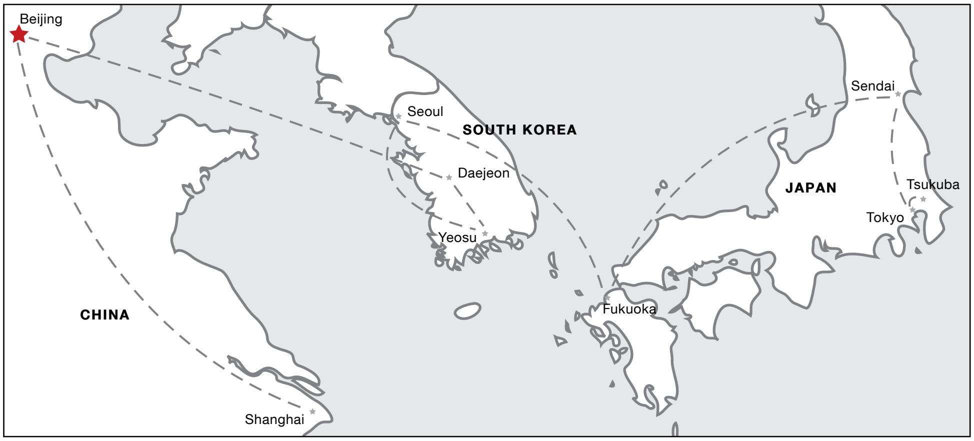
Even the large manufacturers in Korea are having difficulties recruiting good engineers and researchers for robotics. Special initiatives have been set up to facilitate the recruitment of such personnel.

Samsung Techwin sponsors a robot membership program with 10 universities for promising undergraduate students who are interested in robotics. This is hobby based and large scale meetings are held twice per year. The benefit to students (other than interest) is that membership can give them a preferential position when it comes to applying for employment.

Samsung also has joint labs with major universities in Korea.

4.12.6. Statements by the people visited

4.13. Ministry of Science and Technology China (MOST) – Workshop with the High-Technology Research and Development Center (HTRDC)



There are three major pillars of Chinese funding in robotics (the national S&T program trilogy), and they are very similar to the IP programs (see chapter 3.3):

- National High-tech R&D Program (863 Program)
- Key Technologies R&D Program
- National Basic Research Program of China (973 Program)

In addition to this, MOST strives to support SMEs, and to facilitate technology transfer and international cooperation.

Considerable achievements have been made in all three areas, but mainly in the 863 program. Examples given include a deep ocean exploration vessel, a moon exploration robot, as well as industrial robots mainly for the automotive industry (15,000 Chinese-built industrial robots have been sold so far), medical surgery robots (more than 5.000 brain surgery operations) and a humanoid robot which can play ping pong. The success was achieved by a combination of pull and push marketing.

Stimulating discussion at the round table

The ECHORD experts with representatives of MOST

MOST wants to pave the way from mass production in China to an advanced manufacturing society. Driven by an increased need for education and elderly care, service robotics is taking off.

Seven strategic areas have been selected by the government:

- Advanced manufacturing
- Energy technologies
- Public transport
- Information and Communication Technology (ICT)
- New materials

Three measures are considered key to achieving breakthroughs in those areas:

a. Standardization and the use of modular systems
b. Industry-academia cooperation
c. Establish the legal framework

The Chinese government has defined several regions in China as industrial enterprise areas for robotics. The government wants to encourage the transformation of R&D-based research into company-based technology.

Potential areas of collaboration between MOST and the EC:

- Selected projects
- Selected areas of global interest (for instance medical care)
- Student exchanges
- Roadmaps and standardization
- Involvement of Chinese scientists in evaluations and vice versa

The focus in the near future will be on industrial service robotics. The general market is not yet ripe for domestic robots.

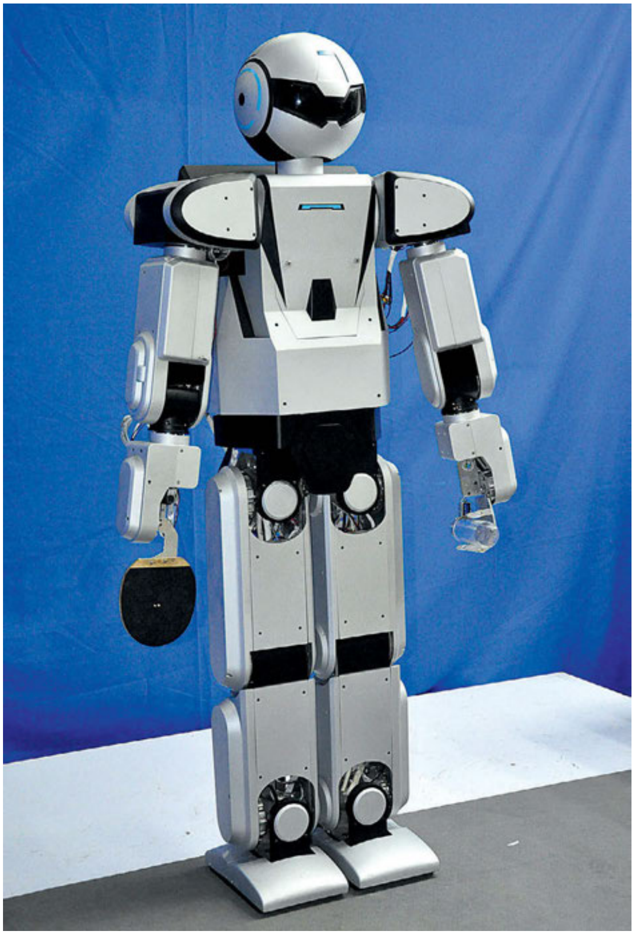
For the budget of MOST for different projects see [62]. The majority of the funding is dedicated to the purchase of hardware equipment and about 10-15 % for administrative personnel. The research institutes are expected to provide the administrative personnel from their regular staff. The level of overall funding is fixed by the People's Congress in China, but specific topics are selected for funding by MOST.

4.14. Beijing Institute of Technology – The Intelligent Robotics Institute

Beijing Institute of Technology (BIT) is an open, international and research-oriented university of science, engineering and humanities. The Intelligent Robotics Institute (IRI) of BIT was founded in 2005. The IRI is an innovation base and part of the Project of Introducing Foreign Talents and Intelligence (abbr. as "111" Project) which was approved by the Ministry of Education and State Administration of Foreign Experts Affairs in 2008. At present, the IRI is an independent entity, and at the same time is an integral component of the Key Laboratory of Biomimetic Robots and Systems, Ministry of Education since 2010, and it has also been an integral part of the State Key Laboratory of Intelligent Control and Decision of Complex System since 2011. The IRI has 21 staff members, including 7 professors, 8 associate professors and 6 lecturers, 30 Ph.D. students and 80 master students.

4.14.1. Research topics and future trends

The IRI has three main research directions: kinetic biomimetics, bio-sensing and interaction, and cybernetics and systems integration. It carries out research in areas like humanoid robots, quadruped robots, space robots, medical robots, search and rescue robots, and micro-nano robots. About 15 important projects were accomplished in the



The BHR-5 robot

IRI in the past five years. For example, three projects involving a humanoid robot, funded by the National High Technology Research and Development Program of China, aimed at solving the technology needed for the robot to perceive its environment and then perform tasks according to the environmental conditions, multi-robots coordination to complete tasks, and fast responsive planning and motion based on robot vision measurement and estimation.

Generally speaking, the IRI has developed both basic theories and advanced technologies at the international level. A series of research outcomes involving the fore-front exploration and industrial application of robotic technology have had significant impacts. Presently, IRI plays a core and pioneer role in China's biomimetic robot research and is an important global robotics research organization.

IRI will focus on fast bipedal walking, humanoid environmental adaptability, and key robotic technologies for humanoids in order to perform complex tasks in human-engineered environments. Also, the researchers endeavor to develop quadro-ped robots for dangerous environments, and to explore medical robots and biological micro-nano robotics.

4.14.2. Results and innovation

IRI developed five generations of humanoid robots (from BHR-1 to BHR-5).

Scientific/technological outcome

BHR-1 is the first humanoid robot in China that can walk and perform tasks without external cables. The researchers of the IRI proposed methods for BHR-2 to generate humanoid gait patterns based on human walking characteristics and solved the problem of complex motion planning of humanoid robots. The BHR-3 series, market-oriented robots were on display in three museums where they perform twice a day. The BHR-4, which is a 'clone' of one of the professors, can vividly imitate human facial expressions. The key technology for developing the BHR-5, the fast responsive planning, operation, and stability control based on visual prediction was a substantial breakthrough. The BHR-5, completed in 2011, is the first humanoid robot in the world that can play table tennis and was unveiled in July, 2012.

Medical robot for photodynamic therapy

Business models

IRI places great emphasis on fundamental scientific and technological issues and industrial application. A cooperative system between IRI and some enterprises, universities, and research institutions plays an important role in the course of research and development. Once these issues have been dealt with, IRI will develop the prototype robots, apply for patents, improve its reliability, and then apply them to industrial applications.

4.14.3. Funding modes and statements regarding funding

The research projects were mainly funded by the National High Technology Research and Development Program of China, and the National Natural Science Foundation of China. The total research budget of the IRI is about 15 million US dollar (2006-2011).

4.14.4. Knowledge Transfer, Cooperation, and IP handling

Cooperation modes

IRI cooperates with many domestic and foreign universities and enterprises to do research and development. The Chinese Academy of Science, China Aerospace Science and Industry Corporation, Nankai University and other well-known, domestic universities in China are IRI's key partners. In addition, IRI closely cooperates with international institutions. IRI has signed cooperation agreements with many reputable laboratories, such as the Center for Micro-Nano Mechatronics of Nagoya University, Japan, and Humanoid Institute of Waseda University, Japan. IRI has sent more than 15 staff members and PhD students to Waseda University, Nagoya University and to other universities as exchange students and visiting scholars in the past five years. More than 50 famous professors and researchers have been invited to do research at IRI in the past five years.

Commercial activities

Most of the large projects in IRI are still of fundamental character. However, several full-sized humanoid robots have been sold or rented to museums and commercial shows in China. Several important components, such as motion controllers and motor servo drivers, have been sold in small scale.

Vascular interventional surgery robot

Spin-offs

Beijing Huakaihui Information and Technology Co. Ltd is a spin-off of IRI. This company does research and development of intelligent robots and intelligent mechatronical systems.

IP handling

IRI has applied for more than 100 patents, and more than 50 patents have been granted. Some patents are being transferred to industrial products.

4.14.5. Education

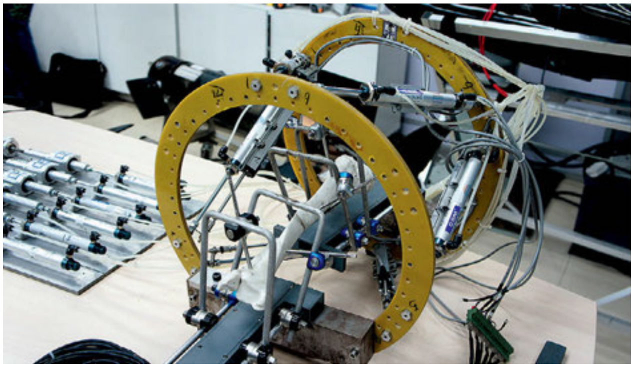
IRI offers more than 10 courses on robotics every year. IRI enrolls 10 PhD students and 40 master students every year. Five PhD students were granted the best paper awards at the 2005 IEEE IROS, 2007 IEEE ROBIO, 2010 IEEE ICAL, 2011 IEEE ICMA, and 2011 IEEE ICAL.

4.14.6. Statements by the people visited

4.15. Beihang University – Robotics Institute (BUAA)

BUAA is a multi-disciplinary, research-oriented university of engineering science and technology with an emphasis on aeronautic and astronautic engineering. Advanced manufacturing and robotic technology are BUAA's predominant research areas. In 2011, the School of Mechanical Engineering and Automation had a total of 1,868 students, including 196 PhD candidates, 622 master degree students, and 1,050 undergraduate students.

Established in 1987, the Robotics Institute of Beihang University, which belongs to the School of Mechanical Engineering and Automation, is a key laboratory of service robotics in China. It is an organization that integrates scientific research and technological development and educational activities, especially in the fundamental research of machinery science and robotic technologies. On the application side, it focuses on robotic technologies and applies them to large aircraft manufacturing, nuclear industry robots, anti-terrorism robots, tele-medical robots, service robots and more. It consists of the Industrial Robotics Lab, the Field Robotics Lab (professional service robots) and the Medical and Service Robotics Lab.



A surgical robot device

The center has undertaken many research tasks in recent years, including the National Outstanding Youth Science Fund Project, the National Nature Science Foundation, the National 863 Plan project, the National 973 Plan project, the National Science-technology Support Plan projects, just to name a few.

4.15.1. Research topics and future trends

Fundamental technologies: the ability of mobile platforms to move around in unstructured and harsh environments, new mobile mechanisms with renewable energy, dynamic modeling in high-speed and overloaded conditions, collision prevention mechanisms in interactive operation, smart material and structure, etc.

Mobile and operating experiments: high-speed and overloaded mobile platforms, mechanical arms, real-time identification and control, biomimetic underwater vehicles, high temperature and high radiation detection, reliability experiments in harsh circumstances, etc.

Platforms and applications: high-tech platforms, nuclear power operation and maintenance, service robots in an aging society, etc.

In the future, the institute wants to concentrate its focus more on the following research areas:

- World’s first-class robotic technologies: underwater bionic structure and dynamics experiments, high level of high-speed mobility, smart material integration flying fish, modeling and control within unstructured environments, the domestic first-class intelligent unmanned mobile platforms, medical robot surgical planning and modular technology to set the international standard.
- High-end platforms for serving major national projects: intelligent unmanned mobile platforms, high-speed, cross-country mobile platforms, flying fish, the polar expedition unmanned robots, robots working within a nuclear environment, ITER inspection robot research platform, drilling riveting robots for larger aircraft.
- Future applications and achievements transformation: handling robots, anti-terrorism anti-riot robots, two-wheeled intelligent balanced electric vehicles (essentially, a stronger version of the Segway), bed-chair integration intelligent nursing system for the aged and disabled, embedded modular electronic control systems with more than 5,000 sets applied in the industry.

4.15.2. Results and innovation

Scientific/technological outcome

Modular robot: the first robot modular international standard proposal in China (ISO/TC184/SC2/WG8/SG4).

Embedded intelligent technology has been being developed since 2005. More than 30,000 sets of controllers, GPS and displayers were applied in the GSK, LOVOL, SUNWARD INTELLIGENT and Chery robots.

First application of China's UAV in the Antarctic.

Medical Surgical Robot: the surgeon robot and the trauma orthopedic robot have obtained the national health medical license, and they have been used on more than 5,000 patients in more than 20 hospitals.

The robotic fish have been applied to underwater archaeology in Dongshan, Fujian Province and water quality detection in Taihu Lake.

Business models

- Jointly apply for the national projects with other institutes and enterprises, and share the intellectual property.
- Provide special automation solutions for professional users.
- Provide consumer automation products for common uses via dealers.

4.15.3. Funding modes and statements regarding funding

4.15.4. Knowledge Transfer, Cooperation, and IP handling

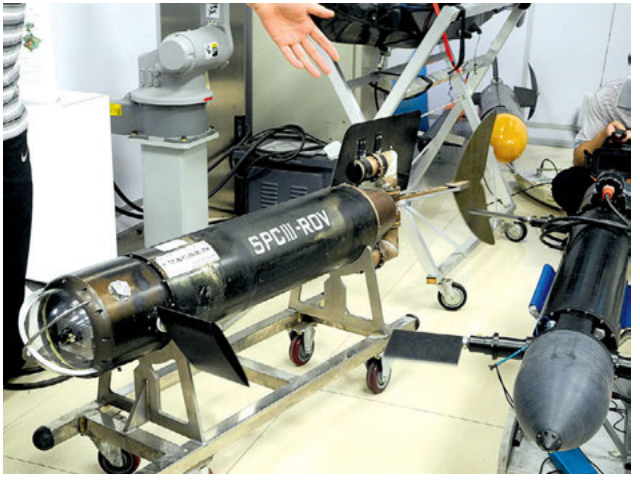
Cooperation modes

University-university collaboration: the center jointly researches and develops high-end platforms with other institutes for the country.

University-industry collaboration: the center supplies the key solutions for the enterprises, including Chery, GSK, Up-Tech and others.

One of Beihang's off-road-vehicles

Commercial activities



An underwater robot for water measurements

Spin-offs

Some graduates from the robotics institute have established a high-tech company named Beijing Universal Pioneering Technology Co., Ltd (Up-Tech) to provide some intelligent automation equipment and components to the users.

IP handling

4.15.5. Education

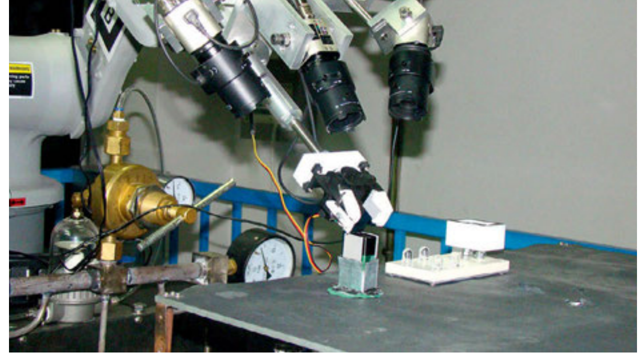
4.15.6. Statements by the people visited

4.16. Tsinghua University – State Key Laboratory of Intelligent Technology and Systems (LITS)

In the past five decades, the Department of Computer Science and Technology (usually ranked number 1 in China) has made significant contributions to the development of computer science and technology in China, and promoted teaching, research and product development in this field.

The State Key Laboratory of Intelligent Technology and Systems (LITS) has been funded by the Chinese government since 1990. It has an excellent reputation and was selected as the experimental lab for all of China in the area of intelligent systems and robotics. The laboratory consists of a central lab (the intelligent technology and systems), and three branch labs (intelligent signal processing, intelligent image processing, man-machine interaction and media integration). The personnel of the laboratory consist of 54 members, 1 academician of the Chinese Science Academy, 1 academician of the Chinese Engineering Academy, 30 professors, including 20 supervisors for the graduate students of the doctoral program, and 8 associate professors.

LITS
Beijing, China



An advanced gripper with visual supervision

4.16.1. Research topics and future trends

LITS studies the fundamental issues in information exchange, processing, understanding, and utilization, from semantic, syntactic, and application levels, together with cognitive and system science, aiming to obtain a series of high-level theoretical results. The research focuses on language, text, image, and video processing and intelligent robotics by combining fundamentals, key technologies and application, striving to achieve technological innovation and complete tasks that could bring significant benefit to the national economy and defense.

The researchers explore the methodology and technology of future information processing, and carry out prospective research in quantum information processing fields:

- Formalization of intelligent information acquisition
- Theory and method of information processing of huge size data sets
- Internet information retrieval, data mining and analysis (UGC analysis, opinion mining, user behavior analysis, social computing)
- Multi-media technology including speech, graphic, image, word and language processing
- Robot perception and processing (computing, communication, control)
- Advanced space robotics systems, intelligent mobile robotic systems and unmanned vehicles
- Advanced man-machine interaction technology and systems
- Interdisciplinary study of neural, cognitive sciences

Recently, the Centre of Computational Neuroscience has been established to enhance the interdisciplinary research and its application in cognitive robotic systems.

4.16.2. Results and innovation

Scientific/technological outcome

- Theory and Methodology of Intelligent Information Processing: intelligent information processing; information security; information retrieval; knowledge mining; natural language processing (Chinese language and characters processing); multimedia information processing; signal processing; and intelligent information processing.

Tsinghua University's autonomous car

- Intelligent Control Theory and Applications: intelligent modeling and control theory of non-linear systems with multiple time scales and distributed parameter systems; modeling, control and application of both aerial robots and space robots; theory and application of mobile robots, autonomous/unmanned vehicles and service robots; advanced manufacture technologies and equipment.

- Theoretical methods of AI and robotics: fundamental theories of artificial intelligence; theory, methodology and application of machine learning; formal methods; quantum computing and quantum information; theory of quantum software.

Business models
The laboratory has received 35 patents and 127 software copyrights in the last five years. Licensing of these patents and software copyrights is the main mechanism.

4.16.3. Funding modes and statements regarding funding
The basic funding of the laboratory is from Tsinghua University and the Chinese Government (National Lab). In the last five years, the third party funding of the laboratory has been about 20 Mio Euros via 284 projects, including national projects (72 %), industrial projects (16 %), international projects (11 %) and others (1 %).

4.16.4. Knowledge Transfer, Cooperation, and IP handling

Cooperation modes
Close cooperation has been realized with a large number of famous, world-class companies (Google, HP, IBM, Intel, Microsoft, Fujitsu, Toshiba, Fuji Photo, OMRON, etc.) With some of them, there are joint laboratories. The lab also conducts contract research with them and with companies run by Tsinghua-Alumni.

Commercial activities
Not applicable.

Spin-offs
As a laboratory of Tsinghua University, there are no direct spin-off companies. There are cases of graduates who started up companies, but they are independent of the lab.

A robot for use in space applications

IP handling
IPR depends on the individual contribution of the participating units. IP agreements are decided on a case by case basis.

4.16.5. Education

4.16.6. Statements by the people visited
Tsinghua is in a phase of internationalization, seeking for a better position in the international, higher-education institutions. We are also looking for a stronger cooperation with the EU.

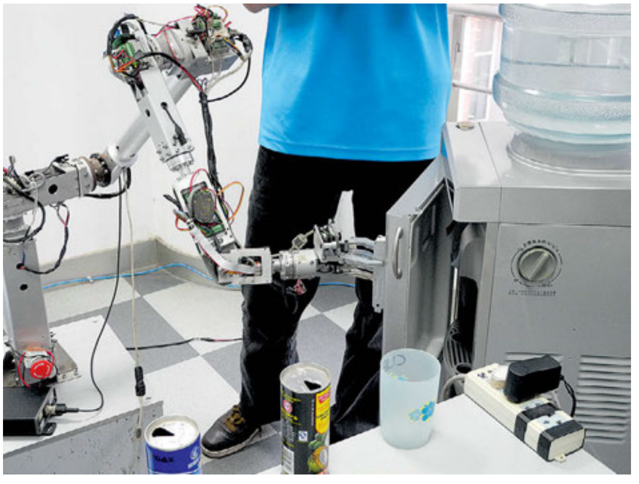
4.17. Shanghai Jiao Tong University – School of Mechanical Engineering – Institute of Robotics

The Laboratory of Robotics was established in 1979 and in 1985 became the Institute of Robotics with 12 faculty members. The current state is:

- Director: Prof. Xiangyang Zhu
- Staff: 29 faculty, 8 full professors, 15 associate, 6 other
- over 50 Phd students and over 60 master students
- Participation in National Basic Research Program (973)

4.17.1. Research topics and future trends

- biomechatronic systems (prosthetics, neural-machine interface, rehabilitation robotics, etc.)
- industrial robots
- service robots
- mobile robots
- field robots


A dexterous and tactile robot arm

The institute pursues a wide variety of projects from very different areas of robotics. Here are a number of examples:

- EMG-based prosthetic hand
  This multi-DOF, under-actuated hand is based on multi-channel EMG measurement using online, non-stationary, feature extraction and feature selection.
- Rehabilitation system of functional electrical stimulation based on brain-computer interface
- Feature extraction and classification methods for analyzing EEG signals to recognize subjects' motion intentions. A training setup with lights flickering at different frequencies was successfully applied to an FES controller.
- Cranio-maxillofacial surgery assisted robot
  The goal is to support the surgeon in tasks such as osteotomy, grinding, fixation, etc. The movements of the 7-DOF robot are optimized using an optical navigation system.
- Walking-assistant robot
  This multi-functional walking assistant can support eight tasks: identify the walking intentions of the users, support standing up and sitting down, assist walking, navigation, obstacle detection and avoidance, prevent falling, alarm if tipping over is imminent, and health monitoring. Sensors include omni-directional cameras, ranger finders, and force sensors (for detecting the walker's intentions).
- High payload palletizing robot
  This 4 DOF robot which was developed for pick-and-place tasks in automatic warehouses has a payload of 180 kg. It has passed some initial acceptance tests.
- Mobile robot detection system
  These mobile robots are designed to perform inspection (and later maintenance and repair) tasks in the cable tunnels of urban power networks. These environments are extremely hazardous because of toxic fumes, water accumulation, and the danger of fire. The basic functionality is complemented by a decision support system for rescue in disaster scenarios.
- Industrial robots
  Because of rising labor costs, an increasing number of robots will be used in China's factories. Aimed at the production of small lots, plug-and-play methods for rapidly changing jigs are being developed. Prototypes have been developed for the robot welding cell for Shanghai Jiaoyun-Inter Company, the laser cutting system for Benteler Shanghai and Shanghai Bao Steel,

and a robot unload system for plastic injection machines for Shanghai Essilor. So, the industrial contacts are in place. It is interesting to note that this work on industrial robotics was done parallel to service robot developments, rather than in a separate department.

- Autonomous Lunar robots
  The goal is to develop a navigation system based on stereo and omni-directional vision, including perception, autonomous localization, on-line map building and path planning in a lunar 3D environment.

The future research will focus on advanced prosthesis, human-machine interface, rehabilitation robots, service robots and medical robots. The Institute of Robotics will enhance cooperation with companies, and try to minimize the gap between academy and industry.

4.17.2. Results and innovation

Scientific/technological outcome

Some of the achievements in recent years are as follows:

- Electromyography (EMG) controlled prosthetic hand
- Brain-computer interface controlled functional electrical stimulation system
- Lower limb rehabilitation robot (exoskeleton system)
- Walking assistant robot
- Cranio-maxillofacial surgery assisted robot

Business models

The Institute of Robotics gets funding support to cooperate actively with companies. There are some successful examples of commercial product development such as industrial robots (robotic manipulating) for an automobile manufactory in Shanghai and cooking robots for a domestic company in Shenzhen.

The intelligent wheelchair

4.17.3. Funding modes and statements regarding funding

In 2011, the Institute of Robotics received total funding of CNY 22.64 million. About 70 % of the funding comes from government and other official organizations (longitudinal projects) including NSFC, Ministry of Science and Technology of China (973 Program, 863 Program), the Ministry of Education of China, Shanghai Committee of Science and Technology and so on. The other 30 % of the funding comes from industry (latitudinal projects), including some well-known domestic and international companies.

4.17.4. Knowledge Transfer, Cooperation, and IP handling

Cooperation modes
The Institute of Robotics has strong cooperation with some companies, which provide funding for projects.

Commercial activities
The commercial activities are encouraged and conducted through cooperation with some companies.

Spin-offs
There have not been any successful spin-offs so far.

IP handling
Every year the Institute of Robotics applies for about 30 patents and about 10 patents get authorized. If a company is interested, they may purchase the IP from SJTU.

4.17.5. Education
The Master's education at the Institute of Robotics is combined with other departments, and it is part of the Mechatronic Engineering Program.

Well-known robotics researchers are invited and give lectures (about 12 per year). There is a summer school on robotics for postgraduate students every year.

There are exchanges with foreign universities which is attractive for students.

4.17.6. Statements by the people visited
"You should not follow, you should create."

The walking-assistant robot

4.18. Shanghai Jiao Tong University – School of Electronic, Information and Electrical Engineering – Department of Automation – Institute of Robotics and Intelligent Information Processing

The School of Electronic (Director: Prof. Weidong Chen), Information and Electrical Engineering consists of five departments:

- Automation
- Electrical engineering
- Computer science and engineering
- Electronic engineering
- Information measurement and instrumentation

It has 348 faculty members, including 117 full professors, 161 associate professors, and 70 others. The school has over 3,000 undergraduates, over 1,800 master students and 845 PhD students. The Department of Automation has 64 faculty members, among them 24 full professors, 36 associate and 4 others. There are also 20 engineers and other staff.

Shanghai Jiao Tong University
Shanghai, China

4.18.1. Research topics and future trends

Because of the rapidly aging population, partially as a result of the one-child policy, the focus is on daily life assistance and medical services, in particular for mobility, manipulation, and cognitive aids. The main issues tackled include safe interaction in unstructured environments. Representative projects are an intelligent wheelchair, an assistive robotic arm, and a robotic home. In addition, other promising areas of service robotics are also being pursued (e.g. in surveillance and inspection).

- Intelligent wheelchair
  A key component of the intelligent wheelchair is a hybrid human-guided localization and navigation system. Humans can drive the robot which then builds a metric and topological map of the environment based on probabilistic estimation using data from a LRF and an odometer. The interface consists of a touch screen, a joy stick, a microphone, and a BCI (brain computer interface). Extensive testing (six months) was done at the 2010 Shanghai World Expo and on-site testing in an actual home for the elderly in Shanghai.
- Assistive robotic arm
  In this vision-based manipulator, safety, one of the biggest technological challenges, is achieved through lightweight technology, speed limitation, and active control using joint-torque sensors and an obstacle avoidance system.
- Robotic home
  This includes an intelligent room (with intelligent appliances, sensor networks), an intelligent wheelchair (see above), a walking assistant robot (see above), an assistive robotic arm, personal health monitoring, and home service robots.
- Power station inspection robot
  Equipped with a camera and an infrared thermograph, this robot, which rides on a monorail, can detect temperature and equipment failure and can communicate with a remote monitoring center. This is a collaboration with State Grid Jilin Electric Power Co., one of the largest Chinese electric power companies.

Currently, the Chinese government is showing a rapidly increasing interest in robotics, especially service robotics (e.g. the Ministry of Science and Technology, which is the main funding agency in China for robotics). This trend is expected to continue for at least another decade. Also, interest from the industrial side has been rising. Some companies are aiming at developing low-cost industrial robots (e.g. Siasun and Foxconn – the Taiwanese giant). This trend also holds for service robotics, e.g. for the low-cost intelligent wheelchair which will be available for about EUR 1,000.

There is a strong focus on assistive technologies and performing tests in the real world. Because some of the research is based on the exploitation of existing technologies, and because of major effort going in to this area now, we can expect significant progress in the near future.

4.18.2. Results and innovation

Scientific/technological outcome

From the extensive testing in the real world, in particular homes for the elderly, major results can be expected in the near future. The trend towards developing low-cost devices also promises innovation.

Business models

The university is actively engaged in both national high-tech R&D program (the 973 Program and the 863 Program) and regional high-tech industry development projects, especially in Shanghai and in the entire Yangtze Delta metropolitan region.

4.18.3. Funding modes and statements regarding funding

Approximately 50 % of the funding comes from the government, the other from companies (obviously these percentages can vary substantially). A number of various forms of cooperation with companies co-exist. In most cases, the company defines a project together with the university and then provides the funding, e.g. roughly EUR 40,000 to develop the low-cost intelligent wheelchair. Sometimes the company publishes a call for solutions (e.g. to a particular optimization problem). Alternatively, the companies provide equipment and testing facilities for free, as in the case of the power station inspection robot, where the funding comes from Jilin Electric Power Co. The company also built the monorail for the robot.

4.18.4. Knowledge Transfer, Cooperation, and IP handling

Cooperation modes

There is some cooperation with industry, e.g. Shanghai Electric (for the domestic environment), with Jilin and Shandon Electric Power. There are also some ties to foreign companies such as ABB, Microsoft, Yaskawa, Cypress Semiconductor, Omron, and National Instruments. Most of these cooperations are in the process of being set up.

Commercial activities

The research focuses on basic technological innovation for the long-term national strategic technology development and, at the same time, they are pursuing the technology transfer for the industrial partners.

Spin-offs

Currently, there are no spin-offs.

IP handling

The university encourages patent application and transfer. An Advanced Industrial Technology Research Institute has been established for providing services in the IP handling.

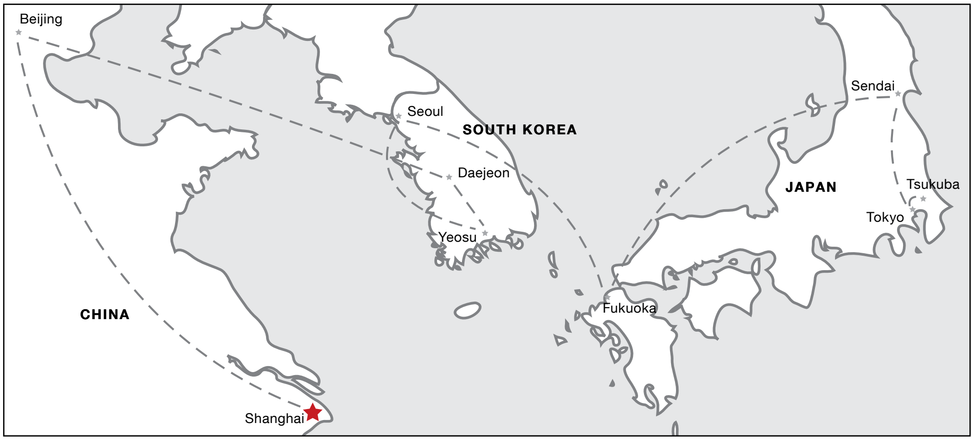
4.18.5. Education

They foster high-quality students via rigorous training in scientific research and engineering in both hardware and software development in R&D projects.

4.18.6. Statements by the people visited

There are a lot of opportunities in service robotics and its applications, especially considering the huge aging population in China, but low-cost and high-safety issues should be emphasized for technology development and commercialization.

4.19. Kunshan Industrial Technology Research Institute (KSITRI)



Kunshan City, under the jurisdiction of the city of Suzhou and located in the province of Jiangsu, 40 km west of the centre of Shanghai, is located in the Yangtze River Delta, between Shanghai and Suzhou. KSITRI (Kunshan Industrial Technology Research Institute) was funded by the Jiangsu province government to develop high-tech industries in one location, to support the development of technology, to attract young talent and to give support for start-ups. Particular emphasis is put on the development of industrial structures and on fostering self-sustained innovation to “enhance the city’s core competitiveness and inner strength”. The leitmotiv is the “three learnings: to learn from Singapore in overall development, to learn from South Korea in industrial upgrading and to learn from Taiwan in self-innovation.” Based on Kunshan’s industrial structures, applied technology research is carried out and technological services are provided to the public.

KSITRI is a non-profit organization operating as an enterprise. It was set up in 2008. Today it is the province’s only comprehensive industrial technology research institute. It is divided into five research institutes, a public technology service platform, a technology transfer and incubation center and an industry-university platform. It has already won over RMB 200 million in financial support for talents and scientific projects.

As of today, the complete center/institute has attracted a workforce of 644 people, with 162 holding an MSc degree and 82 holding doctoral degrees.

4.19.1. Research topics and future trends

As one of the main research institutes of KSITRI, the Institute of Intelligent Robot Engineering focuses on application oriented research on service robots, special purpose robots, medical robots, elderly and disabled assistive robots, educational robots, etc. It works in close cooperation with the local industries, which have strong molding, prototyping and manufacturing capabilities. Within only three years, it has become a major Chinese institute of robot R&D with its special bridge function between research and commercialization.

KSITRI concentrates on upcoming industries and will support their development very systematically:

- New display technology AMOLED, commercialized through a company called Visionox
- New technologies (bio and sensor), commercialized through a company called Ribo Life and Science
- Robotics, and automation devices, commercialized through RoboTechn (service robots and education robots) and Ameditec (Medical and Rehabilitation robots)

4.19.2. Results and innovation

Scientific/technological outcome

- Service robots – home security robots, intelligent Robotic Scrubber.

A modular robot system developed at KSITRI: humanoid …

- Special purpose robots – line-walking robots for inspection of power transmission lines, wall climbing robots and throwable mobile robots for scouting and a wall cleaning robot.
- Medical robots-surgical assisting holder, passive and active positioning robot for minimally invasive surgery.
- Elderly and disabled assistive robots – multi-function walking-aided wheelchair, self-help feeding robot.
- Edu-tainment robots – modular robot, wheeled mobile educational robot.
- Controller and driver – embedded robot control board, 2-axis motor servo driver, etc.

… and different creature

Business models

- Governmental investment to build research platform
- Identifying the needs of local enterprises to then de-velop the technology
- Establish venture capital to incubate enterprises and encourage R&D personnel to do pioneer work

4.19.3. Funding modes and statements regarding funding

Over RMB 300 million of fiscal expenditures have been invested in KSITRI by the Kunshan city government. It has already attained more than RMB 200 million in financial support for talents and R&D projects. Currently, more than 20 percent of KSITRI funding comes from the Kunshan industrial base and its surrounding areas.

4.19.4. Knowledge Transfer, Cooperation, and IP handling

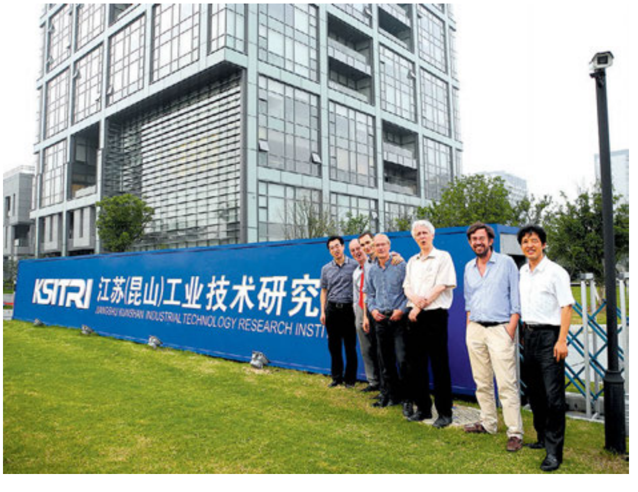
The university-industry platform represented by the Institute of Microelectronics, Chinese Academy of Sciences, provides technological projects and intellectual resources. It brings together the following institutions: the Institute of Microelectronics (Kunshan Branch, Chinese Academy of Sciences), Peking University Science Park in Kunshan, Nanjing University Innovation Institute, the Xidian University Kunshan Innovation Research Institute and the Kunshan Institute of Enterprise Innovation.

The technology transfer and incubation center bridges the gap between universities and enterprises as well as between research institutes and enterprises. The center is committed to the industrialization of research results and has successfully started more than 30 enterprises and projects.

KSITRI
Shanghai, China

Cooperation modes

The National Level Industrial Development Zone KSND is an important platform in Kunshan which actively encourage independent innovation by fostering favorable conditions, accelerates clustering of hi-tech industry, and promotes the improvement of economic development methods. KSND is in downtown Kunshan and is the central industrial park of the city. All kinds of resources are integrated in KSND. The construction of a robot industrial park with a planned campus of 500 acres has already begun, with a total investment of RMB 360 million for the first planning phase. The main R&D and production areas are industrial robot bodies, controllers, vision sensors, and offline programming and other robot related technology.



The group in front of KSITRI

KSITRI's laboratory

Commercial activities

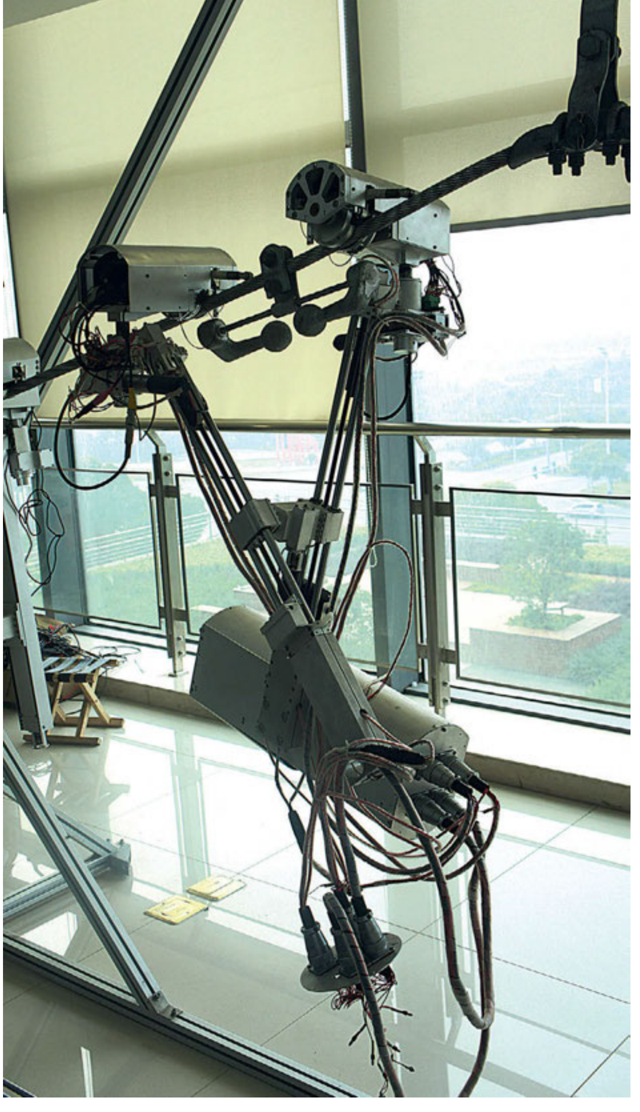
KSITRI has set up a venture capital firm and an 'angel fund' to provide financial support for enterprises and innovative and entrepreneurial groups in the institute.

Spin-offs

KSITRI has spun-off nearly 10 companies in the robotics and automation fields: Robotechn, Ameditec, Tami, Kuke, etc.

IP handling

An IPR and patent management and trade platform will provide legal services.



A power line inspection robot

4.19.5. Education

The center wants to become a national-level 'post-doctoral work station', an academic place with studios for professionals recruited from the Thousand Talents Program. A comprehensive human resources management platform will provide talent support.

4.19.6. Statements by the people visited

KSITRI is extremely interested in international cooperations, especially with the EU. Based on the strong manufacturing capabilities in mechatronics and IT, there is potential for a mutually beneficial cooperation, particularly because of KSITRI's contacts to the local industry. KSITRI wants to take the role of a technology transfer institute, bridging the gap between research and commercialization.

5. Conclusions and Recommendations

Based on the insights gained during the trip, several main conclusions can be extracted which can be summarized as follows:

Major triggers of robotics in Asia

In all three Asian countries, the aging population is the major trigger of investments in robotics. The demographic changes will impact both the labor market and the need for institutional elderly care. Despite the financial crisis and its consequences, there is still a relatively high degree of curiosity-driven research in academic Japanese labs.

Market information and funding

In Korea, robotics has been selected as one of the ten areas of technology for economic growth. Also in China robotics is seen as part of the industrial growth strategy. Korea has a fairly high degree of military funding which pushes innovative research (like in the United States), while Japan does not have any military funding at all.

In 2010, for the first time, Japan was only the second largest robot market in the world. The top position is now held by Korea. China is the fastest growing market in robotics, and by 2014 it will head up the global market.

However, despite significant research funds going into the area of service robots in the countries visited (particularly healthcare), none of these countries has gained a significant share of the world market, with only 1 % of professional service robots originating from the whole of the Far East and Australasia. Korea, though, was reported to have recently made a switch of investment in service robots from primarily domestic robots to its current professional service robots orientation.

Funding schemes and major projects

In Japan, the Humanoid Robot Project (HRP) has triggered a trend towards prestige-driven research on humanoids (originally pushed by the HRP project) mainly conducted in academic labs, but it has gained a more application-driven connotation with intended applications for elderly people, waiting services, education, language teaching, playing, entertainment, etc. Today, the NEDO project is the driving force behind robotics research funded on the government level. It involves many of the big players in Japanese industry, several funding agencies, as well as some universities.

The major share of the Korean government's robotics funding originates from the Ministry of Knowledge Economy (MKE), which channels robotics funding through a specially set up agency, the Korean Institute for Robot Industry Advancement (KIRIA). The Ministry of National Defense does fund sizable military related robotics developments as well as joint projects with MKE. Some of KIRIA's funding is made available through direct rants, but much of the funding is channeled through other agencies such as the Korean Institute of Science and Technology (KIST) via specific programs, like the Frontier 21 program. Smaller amounts come from other branches of the government, such as the Ministry of Environment. University infrastructure and staff support is available through the Ministry of Education. Lastly, some regional R&D funding is available for robotics companies.

In China, the overall science and technology policy is decided by MOST (Ministry of Science and Technology). Two programs are of major importance in robotics: the National High-tech R&D Program (863 Program) and the National Basic Research Program of China (973

Program). Additional ministries are involved (e.g. the State Planning and Development Commission, the State Economic and Trade Commission, the State Environmental Protection Agency, the Ministries of Agriculture and Health). The Chinese Academy of Science is the main provider of fundamental and applied research in China. The Academy manages a network of more than 100 research institutes. The National Natural Science Foundation is China's research council. Additional support is granted by the Chinese provinces.

Scientific research, trends and R&D spending

The United States still leads worldwide R&D spending, but particularly China is increasing its spending on R&D. Another indicator for the focus on research is the educational output of scientists and engineers: Asia's share of the global researcher pool has increased, while the US share has declined. In Asia, though, not all countries are growing. Japan's share dropped from 17 % to 12 %. The number of scientific publications confirms this trend. In the eight largest countries in Asia, the number of publications is growing by 9 % annually (while in Europe the level is just 1 %).

Academic research has the lowest level in China and the highest level in Japan, which indicates a high percentage of fundamental research in Japan. This statement could be confirmed after the tour. In general, the role of the universities in Japan is to show the possibilities and to concentrate on basic research. The situation in robotics seems to be a bit different, though, as robotics has not been successful in industry for very long. Therefore, universities get more involved in application-orientated research and in the analysis of customer/user needs than in other areas of research.

Korea is in-between. The scientific research in robotics undertaken by higher education labs in Korea can be very application-orientated.

The tour revealed that despite the crisis and the financial constraints for Japanese firms, there are very large companies that are still willing to invest in 'marketing-orientated' research and development with non-product defined outcome to show technological leadership. This attitude and the pride of the technological leadership inspired by academic research pushes the research on humanoids in Japan.

The growth of Korean robotics is supported by a special 'robot law' aimed at facilitating the development and take-up of intelligent robotics in 2008. In Korea, robotics has been selected as one of the ten areas of technology for economic growth.

The Chinese government wants to push its technological progress beyond low-cost manufacturing towards innovative R&D (especially in emerging sectors). MOST wants to pave the way from mass production in China to an advanced manufacturing society. Driven by an increased need for education and elderly care, service robotics is taking off.

Medical applications, in particular surgery, are a main aspect in China's robot endeavor. The degree of clinical testing that is carried out to obtain data on real-life applications in China is particularly noteworthy. There is a strong push to test assistive technologies in the real world, e.g. in homes for the elderly. Supported by the legal framework, which allows for a high degree of clinical testing, significant progress in the area of assistive technologies and medial surgery can be expected from China.

Intellectual Property rights, spin-offs and SMEs

IPR have a long tradition in Japan, but seem to be a relatively new phenomenon in Korea and particularly in China.

The industrial landscape in Japan is dominated by a few major players. This makes it difficult for spin-offs in Japan to stand their ground. It appears that they can only have commercial success if they profile as suppliers for these large enterprises. Due to the decrease in industrial funding, there has been a stronger initiative by universities to found spin-offs in the last two years. In general, there is a strong initiative in Japan to change the industrial infrastructure and to facilitate the foundation of SMEs. This was triggered by the nuclear disaster in Fukushima and by the Lehman Brothers failure. Just like in Europe, however, one of the major problems for young SMEs is to generate venture capital.

Despite the short history, patents and licensing fees are managed in a very sophisticated manner in Korea, implemented by different academic institutions. Patents (when held by academic institutions) are implemented as an instrument to generate additional funds, not to serve protectionism. As academic institutions want to transfer their scientific results into products, they are willing to compromise with their industrial partners, even if they own the rights.

Compared to other countries, the protection of IPR in China is fairly low. This fact causes problems in terms of imitation, reliability and quality. There is a huge variation among the different regions in China in terms of benefits from positive developments. Over 98 percent of Chinese businesses function without patents. While in some areas such as Beijing, Shanghai and Guangdong the regional technological innovation is effective through the successful implementation of IPR diffusion, in central China there is obviously a lack of this kind of diffusion. The Chinese industry is dominated by many state-owned as well as private companies. A number of such large companies are established in the world market. It does not seem to be common in China to found spin-off companies.

The Asian countries visited on the tour also suggest that IPR can shape or at least preserve the industrial structure of a specific country. IPR can keep SMEs from innovation. Innovation (if any) then takes place outside the IPR system, which can actually become a barrier to technological creativity. In this case, most of the SMEs and their competitiveness rely on marketing and niche opportunities.

Technology transfer and academia-industry collaboration

Despite the flexible management of IPR in Korea, large companies seem to have a preference for developing their products in-house, while smaller companies seem to be more open to intensively cooperate with universities. For larger companies, universities act as the long arm of industry for R&D, where it is too expensive and too time-consuming for the industrial stakeholders to carry out themselves. The major problem in academia-industry cooperation – particularly for large companies – when it comes to hardware development, is the completeness of technology, liability of the system and robustness, which cannot be taken for granted when hardware is supplied by universities, despite the comparative application orientation of many universities in Korea.

When commercializing personal service robots in Korea, the price and the aftersales service are the crucial problem. Concerning international trade, the different certificates for robots are considered to be one of the major trade barriers. From the industry's point of view, it would be desirable to have just one certification worldwide because having to cope with various certificates is expensive.

Conferences are a good medium in Korea to present scientific findings to industry and to find industrial partners for the commercialization of products. In addition, there are strong ties with industry due to the graduates that take senior positions in companies.

In Japan, there is little evidence of support mechanisms and experience with small, high-technology businesses. Japanese companies like to develop their technologies by themselves. It is difficult to found high-tech start-ups in Japan due to a lack of private investment, a lack of trust in safety and a lack of venture-capitalism. The ROI in robotics takes much longer than in other areas. The idea of service robotics is not well understood. The business models are not clear to the parties involved. In addition to this, the technology is not transparent to the investors.

Last but not least, here are the highlights, in a nutshell on a country-by-country basis:

Japan

- Good technology development but limited ability to enter niche markets which (exist and are emerging) because their big vertically integrated companies need mass markets
- No route via military development
- Less government support for humanoid robotics research than in the past
- Strong industrial robot market with further potential for innovative developments
- Universities are still focused on humanoids but realize the need to change paradigm towards service and rescue robotics

Korea

- Excellent development with strong government support. In particular KIST and KAIST seem to be at the same level as leading European labs.
- Mix of large (LG Electronics, Samsung in service, Hyundai in industrial) and small companies are able to discover niche markets and develop them.
- Korea is moving towards becoming a strong leader in technology in Asia, which has been facilitated in recent years by support from the government
- Interesting funding scheme: the government funds customers who buy pilot products in final prototype stage
- Straight funding scheme
- Change of emphasis to professional service market
- Also significant interest/support from defense sector
- 'Robotics Law' to foster societal transformation through robotics

- 'Fusion technologies programs': they did not disclose, but the experts understood it aims to converge nano, bio and robotics (similar to IIT and RCC flagship)
- Evidence of strong interest in collaboration within Horizon 2020

China

- Already manufactures most of the world's domestic robots (vacuum cleaner included)
- Generally in catch-up mode but with significant advantages in certain areas (e.g. healthcare)
- Supports interaction between universities and industry (e.g. KSITRI in Yangcheng Lake Science Park), public and private venture capital
- Significant developments in industrial robotics, which could become a significant worldwide player in this area quite soon
- China targets massive deployment of conventional industrial robot arms to be sold at a fraction of current prices. This may pose a significant future threat to European and Japanese industrial robotics sector.
- Strong focus on medical robotics (taking advantage of the less rigorous regulatory framework), manufacturing and elderly care

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