Moonshot International Symposium
December 18, 2019

Working Group 3

Expanding frontiers through co-evolution of AI and robots

Initiative Report

Contents

EXECUTIVE SUMMARY

In WG3, we discussed MS Goal candidate based on the Area and Vision set by the visionary council. In the study, WG3 has been discussed from various points of view, as detailed below.

1) MS goal is accepted by the public as a goal for 2050.

2) Social demands and urgency for AI and robot technology

3) Global R&D trends and technical issues

As a result, WG3 proposes that "By 2050, a robot can autonomously learn, adapt to the environment, evolve itself in intelligence and act with human beings" is the MS Goal candidate.

In 2050, it is estimated that the aging rate will continue to increase, and the population will continue to decline in Japan. In such a situation, in order to eliminate work in places that are dangerous for humans and to avoid labor shortages associated with the decline in the workforce, it is possible to utilize AI technology and robot technology, which have been developing rapidly.

In addition, these AI and robot technologies could contribute greatly to frontier development (space development, discovery of new science, etc.) for humans.

By 2050, a variety of social issues will be solved by AI robots and human beings co-existing, and this is expected to contribute toward improving the lifestyle of human beings.

In WG3, for society in 2050, we set a goal where the "AI robot" is active. Even if a robot does not have a human command, it would be able to act as if it were autonomous. Furthermore, “AI robots” that can not only move autonomously but also learn autonomously like humans and evolve through self-learning.

Although the achievement of this goal has scientific and technological hurdles, we believe it can be realized by conducting research and development while expecting a synergistic effect to be a mutual fusion area between AI technology and robot technology.

To realize this goal through the Moonshot R&D program by 2050 is a timely challenge.

In addition, WG3 proposes the following three targets.

1. By 2050, development of AI robots, that humans do not feel uncomfortable, have physical abilities equivalent to or better than humans and grow with human life.

2. By 2050, the development of an automated AI robot system that aims to discover principles and solutions with great impact by thinking and acting in the field of natural science.

3. By 2050, development of AI robots that autonomously judge and act in environments where it is difficult for humans to act.

AI robot technology provides a great advantage to human society. On the other hand, because of its influence, appropriate development and social implementation are required. ELSI and other issues need to be discussed and carried out by stakeholders.

Ⅰ. VISION AND PHILOSOPHY

1. The Moonshot 「Area」「Vision」 for setting MS 「Goals」 candidate

The visionary council, which consists of experts, proposed 3 Areas, 13 Visions, and examples of 25 MS Goals that the Moonshot Research and Development Program should aim for. The aim is to set ambitious targets and concepts for the social agenda that are difficult to tackle but will have a profound impact once resolved. (See Fig.1)

Working Group 3 discusses the following Area and Visions for setting MS Goals.

[Area]

- Turning the aging society into the innovative and sustainable society by harnessing diversity through techno-social transformation
- Exploring frontiers with science and technology.

[Vision]

- Industrial transformation by complete automation
- Automation of Scientific Discovery (AI/Robotics)
- Permanent presence in space (space)

[Examples of MS Goal candidate to be used as reference]

7) Full automation of agriculture, forestry & fisheries (by 2040)

8) Full automation of construction work (by 2040)

18) Development of AI system for scientific discovery at the level worth Nobel Prize (by 2050)

25) Distributed and collective satellite constellations and space robotics (by 2035)

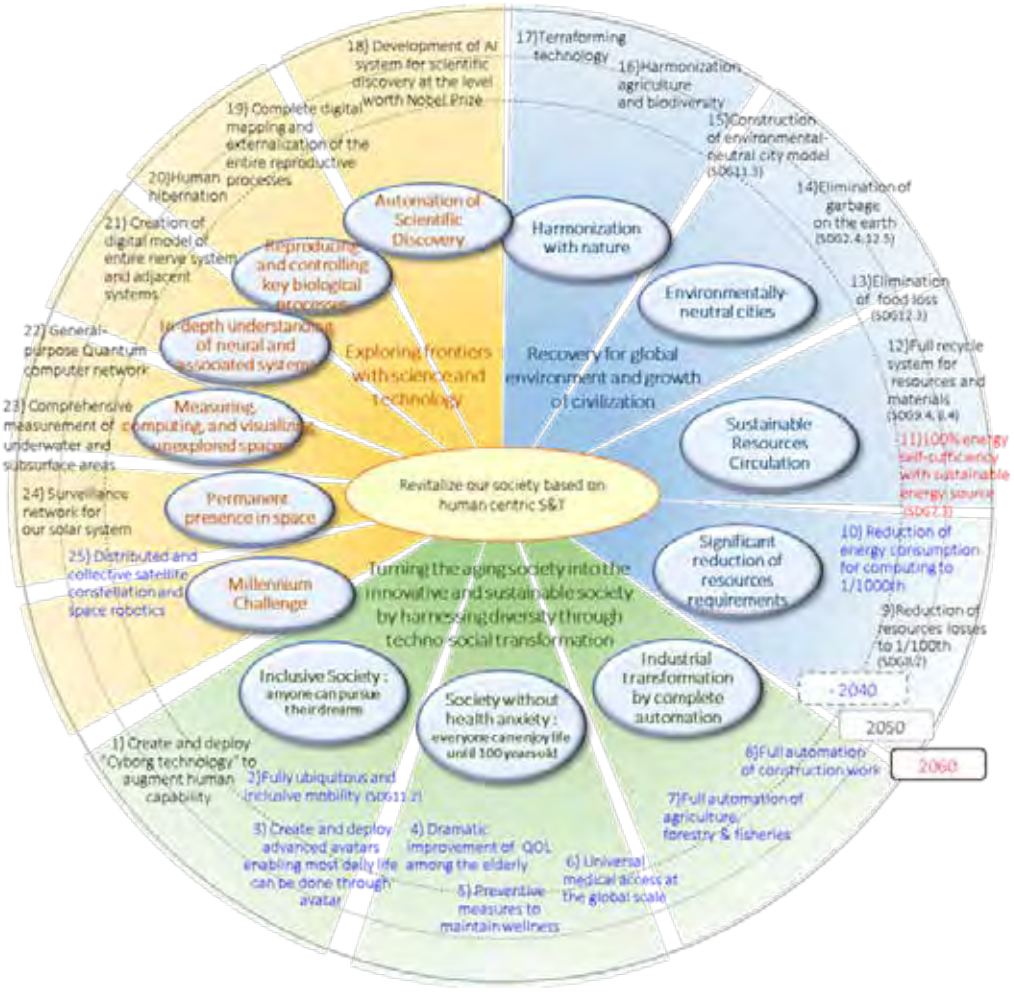


Fig.1. Future visions and 25 MS goal examples

2．Concept of MS Goal candidate

2.1【MS Goal candidate】

・By 2050, robot will be able to autonomously learn, adapt to the environment, evolve itself in intelligence and act alongside human beings.

2.2 Target

We set up 3 targets to achieve the MS goal.

1. By 2050, the development of AI robots, that humans do not feel uncomfortable with, have physical abilities equivalent to or better than humans, and can grow with human life.
2. By 2050, the development of an automated AI robot system that aims to discover principles and solutions with great impact by thinking and acting in the field of natural science.
3. By 2050, the development of AI robots that autonomously judge and act in environments where it is difficult for humans to act.

2.3 Concept

In 2050, AI technology and robot technology will have co-evolved, and the following society is coming. Even if a robot does not have a human command, it can act as if it were autonomous. Furthermore, “AI robots” will not only move autonomously but also learn autonomously like humans, and further develop through self-learning.

(Current robots only act through given commands. It is not possible to act autonomously by recognizing surrounding circumstances. Today robots cannot extract and combine the information by using results learned in the past.)

Instead of human, AI robots will work in places where are dangerous for human activities (space, disaster scenes, high places, deep seas, etc.), places where human resources are not enough, places where situations change from moment to moment, and places where irregular things happen.

People can spend time with robots comfortably. In addition, AI robots provide optimal support to individuals and improve human QoL by learning, acting, and developing themselves.(co-evolution AI robot and human)

In addition, AI technology can search and select enormous possibilities that humans cannot imagine, at a speed that humans cannot keep up with. The fusion of AI technology and robot technology allows AI robots to perform experiments and do work that has been done by humans, and it is possible to automate science such as the discovery of principles and solutions, as well as various other things. This will have several positive impacts on social.

The research policy for realizing the above concept is shown below.

In Society 5.0, as shown in Fig. 2, the connection between the real world (Physical space) and the virtual world (Cyber space) is achieved by making a feedback loop as detailed in the following steps. Sensors on robots can detect the Physical space situation, AI system can perform processing in Cyber space using the physical space information, and AI systems actuate the robot in physical space through the processing results.

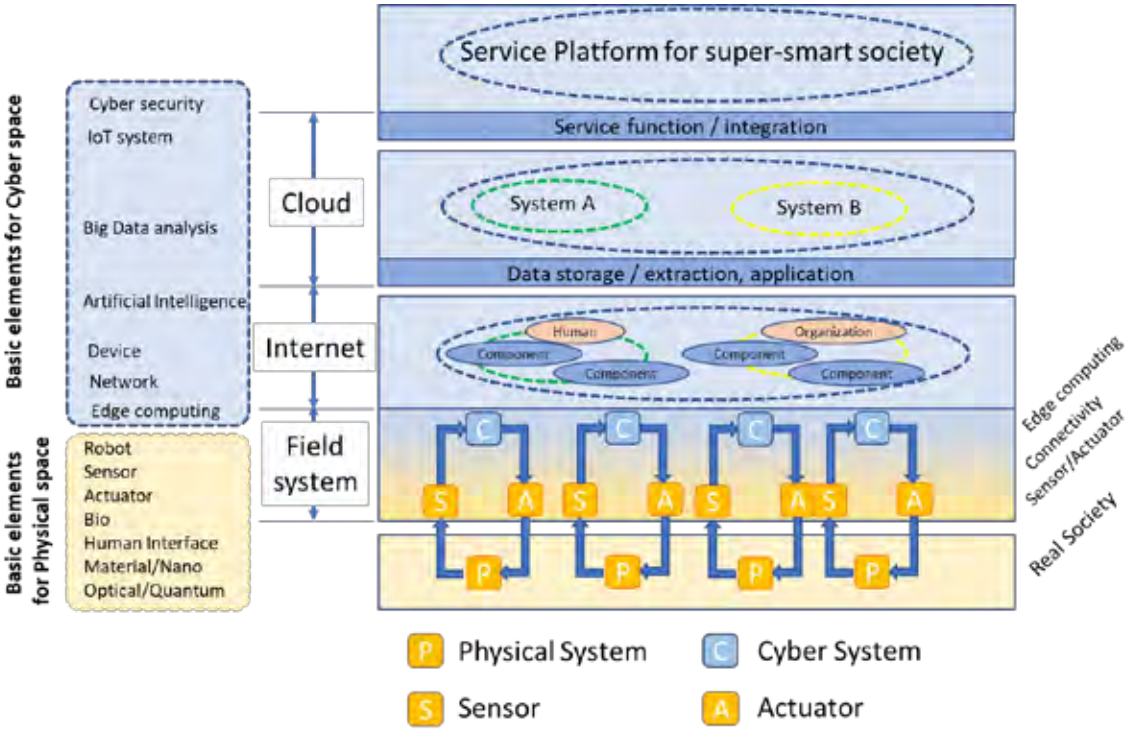


Fig.2 Platform designed by Society 5.0

(This figure is revised by JST based on "Fifth Basic Plan on Science and Technology (Related Materials))[1]

In the past, robot technology and AI technology were often developed independently.

AI technology has been mainly developed in Cyber space as a technology for communicating with humans via networks.

On the other hand, robot technology, which was initially operating in an environment completely isolated from humans like industrial robots, has recently been developed to operate in an environment closer to humans, such as pet-type robots.

Current robots perform programmed movements based on information obtained from various sensors, and can change movements depending on the situation, although they cannot autonomously think about new movements and act.

AI technology is very effective to afford such autonomy to robots.

Using external information obtained from robots equipped with various sensors that exceed human capabilities, AI technology can detect human emotions and empathy. Then, using the information from sensors and the stored information that has been learned previously, robots predict the motion and operate.

After that, the operation result is once again stored in the robot.

By repeating this loop, AI learns and stores the results in its memory.

In this way, by fusing and co-evolving robot technology and AI technology, we can build up "an autonomously evolving robot that learns and acts by itself," that is, an AI robot.

Specifically, as shown in Fig. 3, we aim to have "a robot that learns and acts by itself and evolves itself" by combining robot technology with AI technology, and adding elements such as safety, ELSI, international standardization, etc.

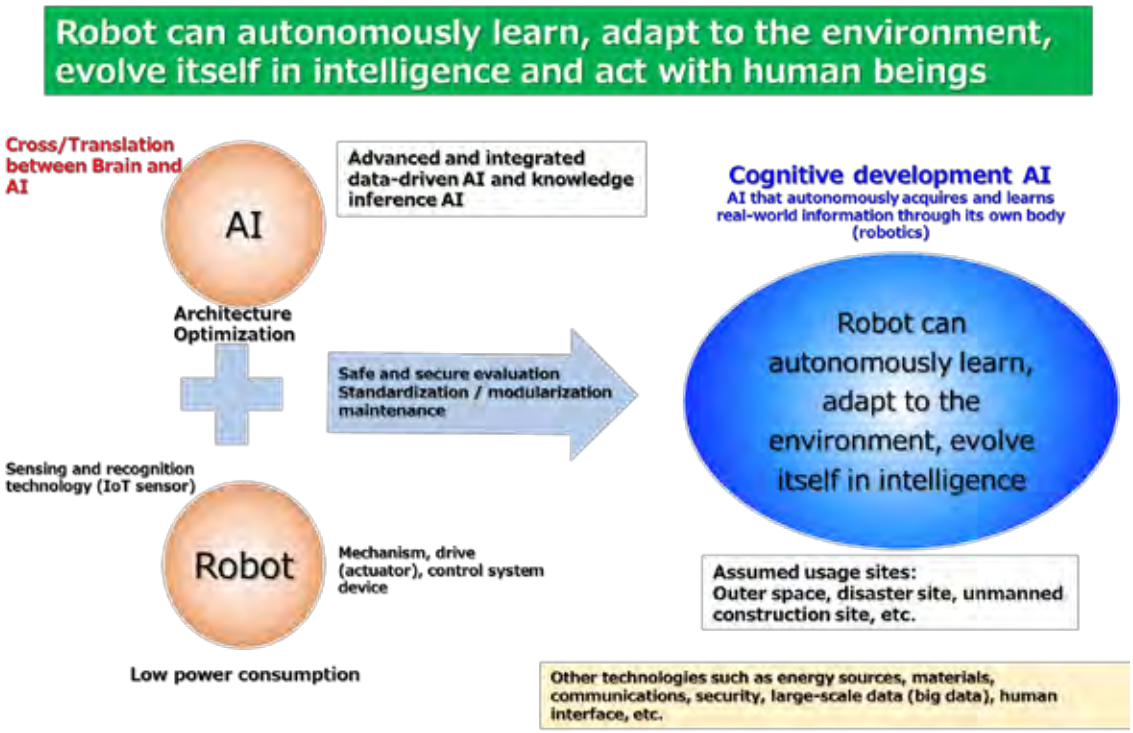


Fig.3 co-evolution AI and Robot

3. Why Now?

There are two aspects to the reason why the goal of realizing an “AI robot” in 2050 must be set now.

One is the social and environmental aspect, and the other is the scientific and technical aspect. Each is explained below.

(1) Social and environment aspects

If the declining birthrate and aging population continue into the future, the population will decrease to 101.92 million by 2050. Among them, the proportion of elderly people aged 65, that is currently 37.7%, is expected to rise to 38.41 million.

The working-age population is expected to decrease from 75.06 million to 52.75 million.

This issue of the declining birthrate, the aging population, and the population decline is inevitably a common issue in many advanced countries and countries around Asia that have the same demographics as Japan.

Japan, as an advanced country, should be at the forefront of solving this problem.

On the other hand, there is an overseas study that estimates that 50% of the children born in Japan in 2007 will live to be 107 years old. Japan has the longest life expectancy in the world meaning that a life support system for elderly people whose activities will decline is required.

Frontier development is a major goal of humanity. Recently, as a result of the development of various technologies, rockets have also been launched in large quantities by private enterprises, and space has become a market not only for communication satellites and meteorological satellites, but also for civilians to enter space, and there are great expectations for this market in the future.

In 2050, humans are expected to live in outer space, the moon, and planets in the same environment as on Earth.

(2) Scientific and technological aspects

With current AI and robot technology, AI has not reached the level of understanding and judgment that a human has. In addition, AI learning requires the assistance of humans. For example, it is necessary to collect data according to the purpose in a format that AI can easily understand. In addition, even though AI has recently been introduced in robot technology, it is not capable of wide-ranging activities in the real world, such as human-like movements and the regeneration of senses.

However, instead of waiting for the advancement of AI technology alone or the advancement of robot technology alone, Moonshot is set to establish a fusion area where AI technology and robot technology that have not yet become mainstream can co-evolve by 2050.

The speed of development of AI technology has been remarkably fast over recent years. However, it is thought that the development of AI capable of self-learning and self-evolution like humans will soon stall.

When co-developing AI technology and robot technology (for real-world issues), much time is spent in motion experiments and so on, so it is expected to take longer than conventional AI development alone.

Therefore, it is necessary to immediately start research and development of their co-evolution.

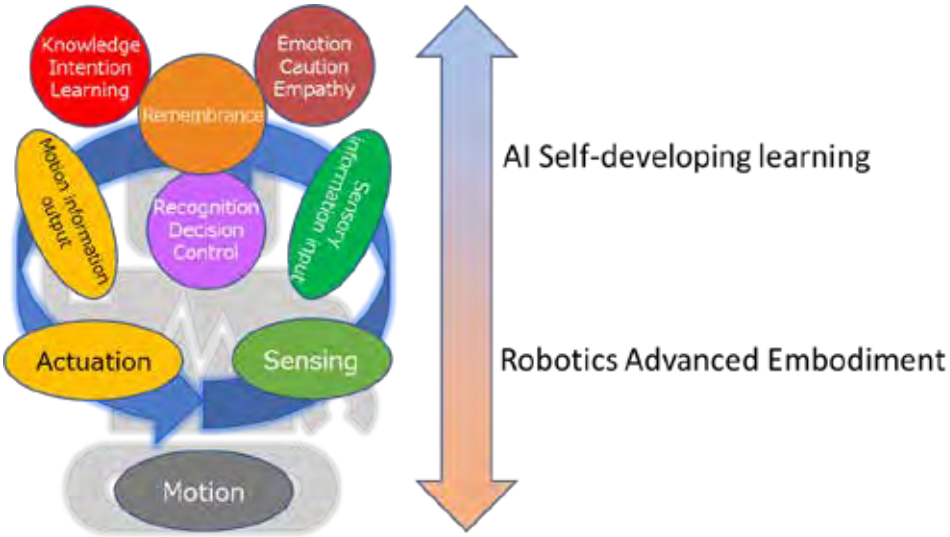


Fig.4 Concept of co-evolution AI and Robot[2]

Figure 4 shows the elemental technologies that make up the “self-evolve robot that learns and acts on its own”.

Based on the “sensory information” obtained from the environment through various sensors of the robot, the robot obtains information on “emotion, attention, empathy.”

Information such as “knowledge, intention, learning” learned through AI are stored as “memory.”

From these learning results, AI "recognizes" information, and utilizes the "memory" accumulated in the long-term to predict the situation, then determines the "judgment".

What and how to control the situation are decided according to this decision. The information is passed to the robot as “movement information output” and “actuation” is executed.

In this way, the AI robot operates based on the stored information learned so far, while obtaining information from the outside world and again storing the learned result.

It also develops a physicality that makes people feel comfortable with movements and gestures. For this purpose, we aim to realize AI robots that can autonomously learn, adapt to the environment, become more intelligent and act with human beings through the co-evolution of AI technology and robot technology.

To realize these, it is necessary to fuse various technologies as shown in Fig.5.

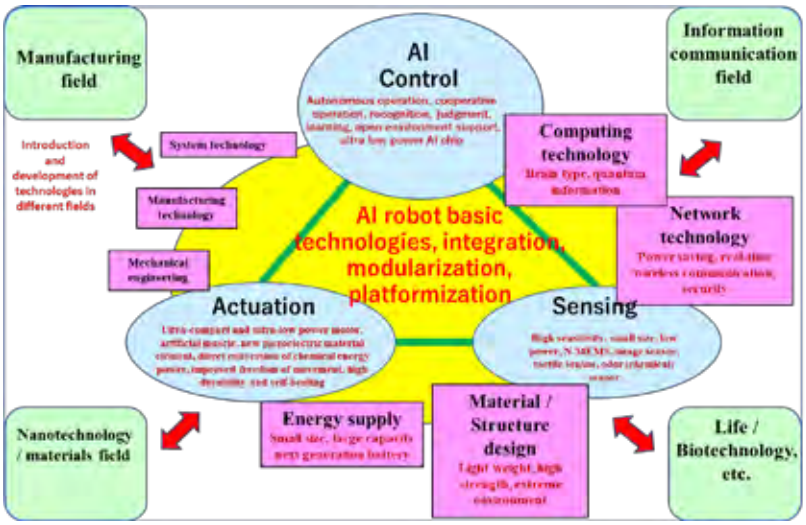


Fig.5 Basic technologies to achieve AI Robot[2]

4. Changes in industry and society

The following would be made possible by the coexistence of humans and AI robots in 2050:

- Realizing a society where people can live comfortably through their natural lifespans with the aid of unattended care AI robots in their homes.
- People can spend time with AI robots comfortably. In addition, AI robots provide optimal support to individuals and improve human QoL by learning, acting, and developing themselves.(co-evolution AI robot and human)
- Realizing an affluent lifestyle through the development of medicines and technologies based on discovery through the automation of science.
- Realizing life-partner robots that grows with us from the cradle to the grave, and provide a higher-quality living standard by sharing personal data.
- Mining extraterrestrial resources such as the moon, Mars and asteroids. Reaching planets outside the solar system.
- Strengthening the labor force and increasing the efficiency of agriculture, forestry, and fisheries. Realizing zero occupational accidents. Realizing a safe, secure, and comfortable society
- Establishing an environment where people can live comfortably by building a system from lifesaving to reconstruction in the event of a disaster.

Fig.6 Vision of a society

Ⅱ STATISTICAL ANALYSIS

1. Structuring of MS Goal

Fig. 7 shows a panoramic view of the technology groups necessary for realizing AI robots.

Fig. 7 shows 33 research and development areas that are strategically important in the Emerging Layer in the fields of systems and information science and technology based on the selection criteria of “emerging”, “social impact” and “vision and mission”.

The related technology in the Working Group 3 is the area shown in red letters in the figure below.

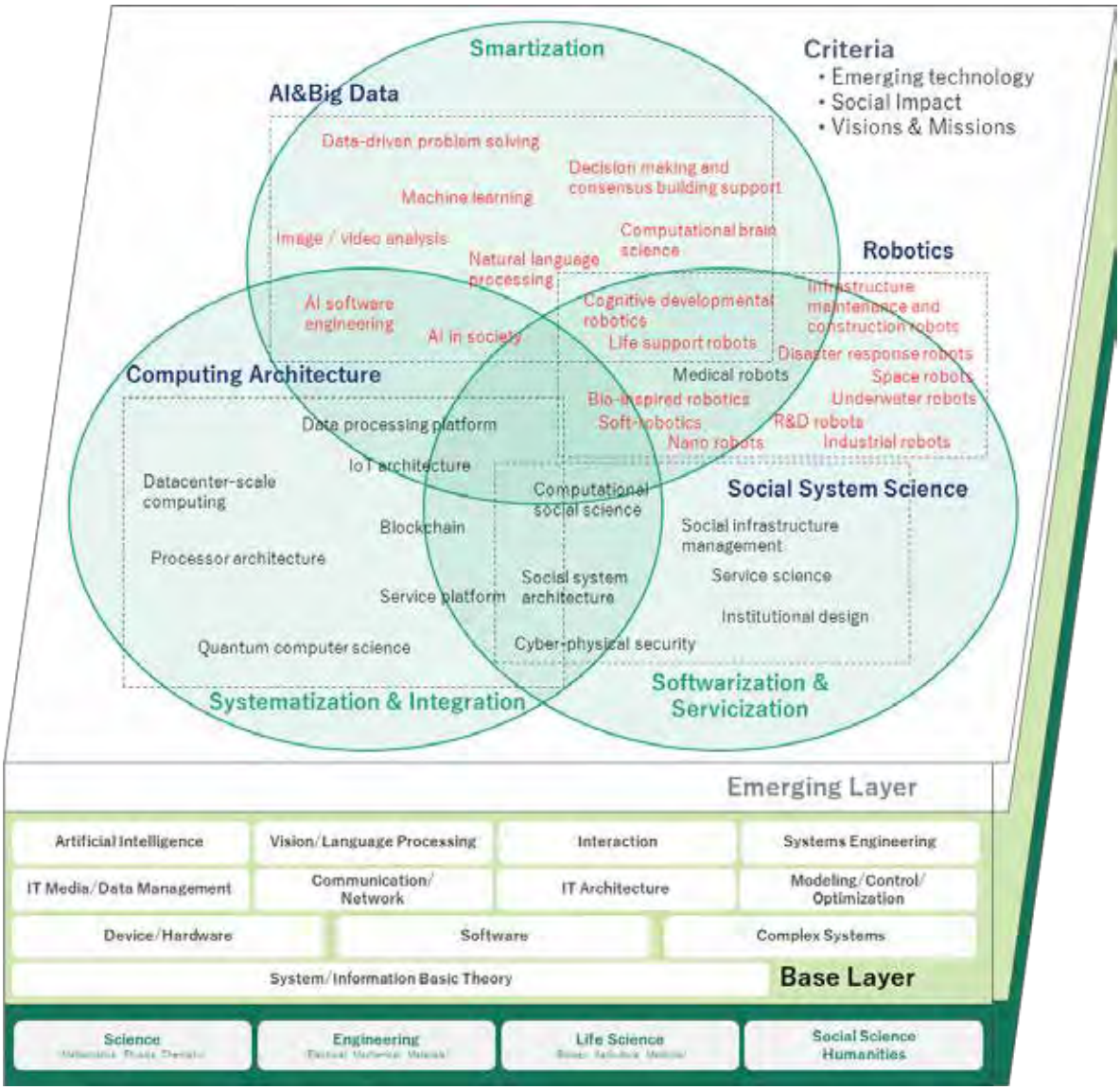


Fig.7 A panoramic view map of System and Information Science and Technology.
Red items are the scope of WG 3.
(Panoramic View of the Systems and Information Science and Technology Field (2019), CRDS, JST)[3]

2. **Progress in related science and technology**

Fig 8 shows progress of AI technology and robot technology.

Basic concepts related to AI were proposed in the first AI boom (from the late 1950s to the 1960s), and AI was launched as a new academic field. In the second AI boom (1980s), the approach to constructing and utilizing dictionaries and rules manually became the mainstream, and expert systems, fingerprints and character recognition, and dictionaries and rule-based natural language processing (kana-kanji conversion, etc.) were put into practical use. Currently, with the third AI boom, some tasks have been able to catch up with and outperform humans in the context of the expansion of the Internet and computing power, and have begun to spread to society as various AI application systems. In addition, with the advancement and spread of sensors and Internet of Things (IoT) devices, real-world big data can be obtained in various situations. Collection and analysis technology is being used to precisely grasp and predict the state of phenomena and activities occurring in the real world in real time.

Beginning with industrial robots in 1962, robots have reached the level where routine work can be carried out accurately and without a break, by implementing image recognition and learning functions with the aim of realizing automation of processes in the factor. In addition, robots that imitate the exercise capacity of humans and animals also appeared, and in the 90s, research and development of not only industrial robots but also intelligent robots that work in general society and the home became active. In the 2000s, the application of robots expanded further, and surgical support robots and robot cleaners were also developed. Moreover, intelligent robots that are equipped with artificial intelligence that judge, determine, and operate their own behaviors and are expected to intelligently interact with humans as home robots made further progress in the 2010s.

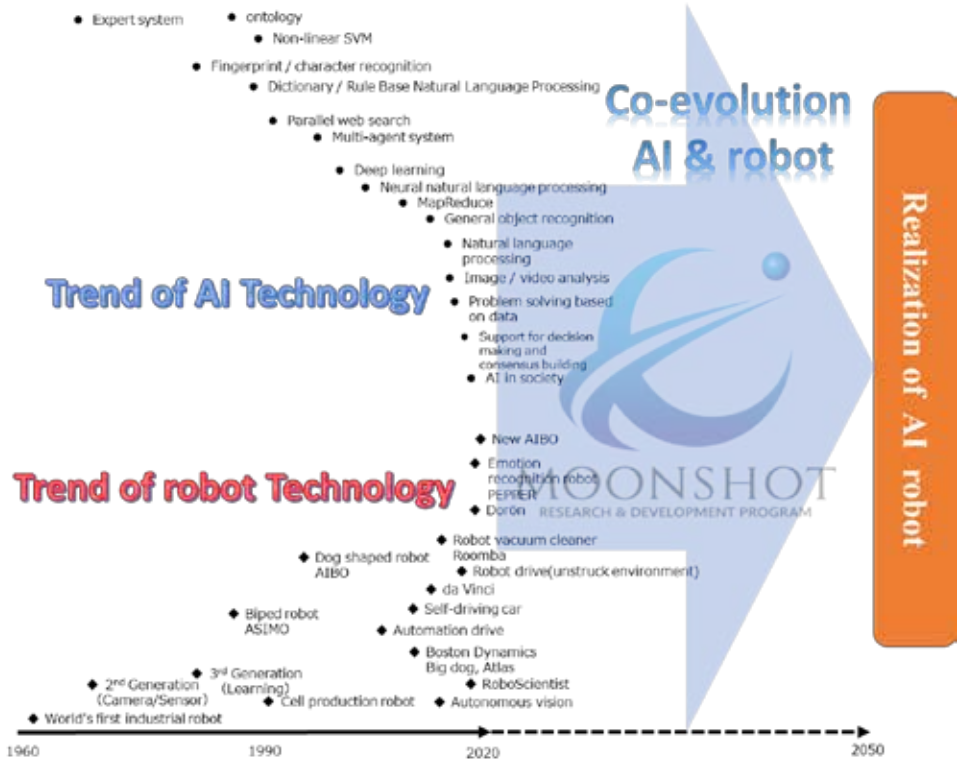


Fig.8 Technical trend related AI and robot[3]

(Panoramic View of the Systems and Information Science and Technology Field(2019), produced by CRDS, JST)

3. Strengths of Japan, overseas trends

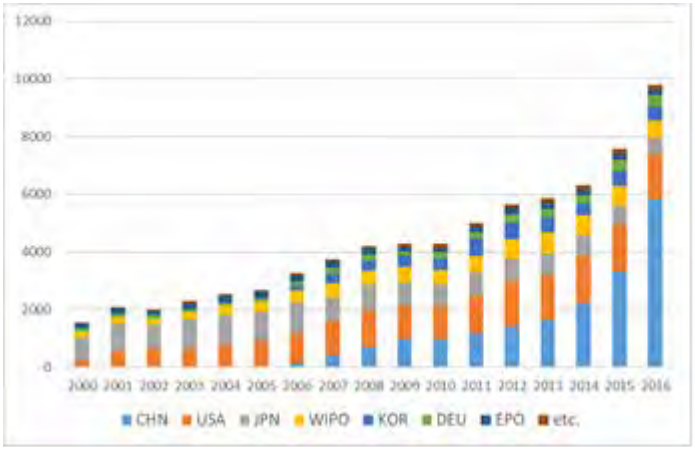
①Trends of patent applications and paper publications in the field of AI robot.

Fig.9 shows the number of patent applications by region including AI and robot.

The number of applications has been increasing globally since 2000, and increased at an almost constant rate until 2014

Looking at the number of applications in 2015 and 2016, the rate of increase is higher than in 2014. This field is attracting attention in industry.

In recent years, the number of applications in Japan has decreased, but Japan has the third largest number of patent applications after China and the United States, and it is thought that Japan's industrial competitiveness is still high in this field.



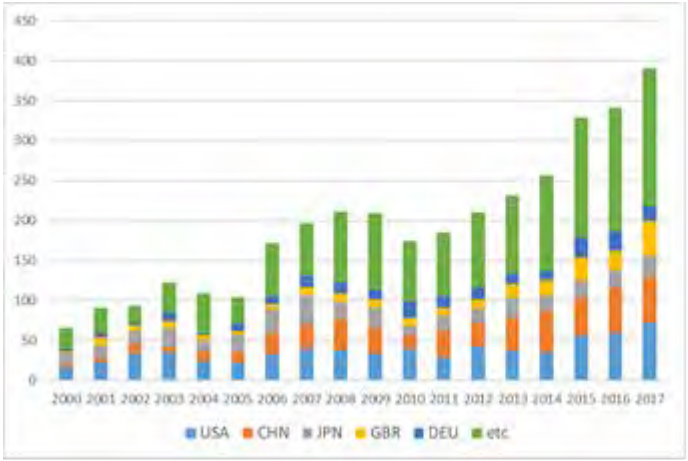
RANK	Country / Institution	Number
1	CHN	18,956
2	USA	18,721
3	JPN	14,255
4	WIPO	8,022
5	KOR	4,775
6	DEU	3,398
7	EPO	3,207

Fig.9 Number of patens by region[4]

Figure 10 shows the paper publication trends that include both AI and robot technologies. Although the number of papers began decreasing from 2007, it increased again from 2010.

As with intellectual property rights, this field is one that is attracting attention in the scientific community.

The cumulative number in Japan by region is the third as well as intellectual property rights.



RANK	Country / Institution	Number
1	USA	670
2	CHN	513
3	JPN	384
4	GBR	240
5	DEU	221

Fig.10 Number of papers by region[4]

Both the number of papers and the number of patent applications are increasing in the field of AI robots, and it can be said that this is one of the fields that is attracting worldwide attention.

②International comparison of elemental technology

Table 1 shows the current international comparison of the elemental technologies that make up the AI and

robot shown in Fig.4.

In the United States, it is remarkable that there is generally an advantage in both basic research and applied research and development. This seems to be because there are a large number of researchers who can receive large-scale research and development investments such as the industries centered on AI, DARPA, and NSF.

In Europe, basic research is strong albeit local. Applied research and development is weak, because there is no huge IT company like in the United States. In recent years, China's growth has been remarkable. Investments in research and development under the Chinese government's national policy and the domestic giant IT industry are steadily increasing capabilities in both basic research and applied research and development by sending foreign students to the United States. Japan boasts an overwhelming competitiveness in the field of industrial robots, especially with systemization and fitting technologies not shown in this table. On the other hand, it seems to be behind in terms of technological innovation in AI over recent years.

		Sensing	Sensory information input Emotion, attention, empathy		Knowledge / Intention / Learning		Recognition / Judgment Exercise information output		control	Actuation / Power
	Phase	MEMS	Image / video analysis	Natural language processing	Machine learning	Problem solving based on data	Biological normative robotics	Support for decision making and consensus building	System technology	Robot basic technology
JP	Basic research	○→	○↗	○→	○↗	○→	△↗	○↗	◎→	○→
	Applied research and development	○→	◎→	○↗	○↗	○↗	△→	○↗	○↗	○→
US	Basic research	◎→	◎→	◎→	◎↗	◎→	△↗	◎↗	◎→	◎↗
	Applied research and development	◎↗	◎↗	◎↗	◎↗	◎↗	○↗	◎↗	◎↗	◎→
EU	Basic research	○→	◎↗	○→	○→	○→	○↗	◎↗	◎→	○→
	Applied research and development	◎↗	○↗	○→	○↗	○→	○↗	◎↗	○→	○→
CN	Basic research	○↗	○↗	◎↗	○↗	○→	△→	○↗	○↗	△→
	Applied research and development	○↗	◎↗	◎↗	◎↗	◎↗	○↗	△→	○↗	△→
KR	Basic research	△↘	○→	△→	△→	△→	△→	△→	○→	○↗
	Applied research and development	△→	△↗	○↗	△↗	○→	△→	△→	◎↗	○→

Table 1 Technical trend for AI and Robot

Excerpt from technical overview of CRDS[3]

(Note:1) phase
Basic research phase ：Scope of basic research at universities and national research institutions
Applied research and development phase ：Scope of technology development (including prototype development)
(Note:2) current situation
※It is an absolute evaluation, not a relative evaluation based on the current situation in Japan.
◎ :Particularly remarkable activities and results are visible、○:Remarkable activities and results are visible,
△ ：I can't see any significant activities / results、×：I can't see the activity / results
(Note:3) Trend
↗ ：Upward trend、 →：Maintain the status quo、 ↘：Downward trend

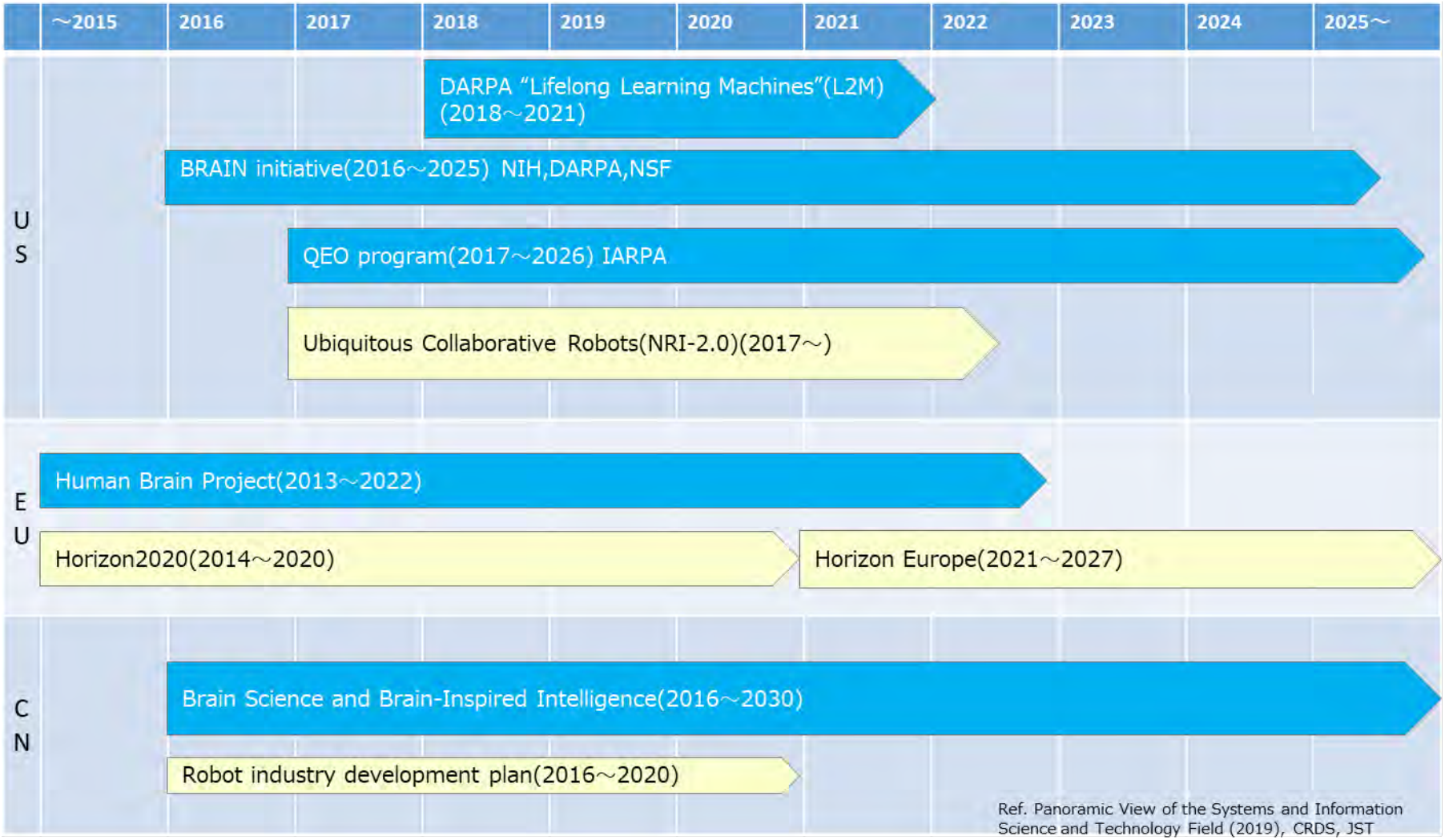


Fig.11 Trends in major AI- and robotics-related research projects in each country[3]

Announcement	Title	Overview
2017	Explainable AI, XAI	XAI aims to develop artificial intelligence that can present reasons for decision-making to people so that they can be used in areas where transparency and trust are required by users, such as medical, legal, financial, and national defense.
2018/5	L2M	Develop machine learning systems that continue to respond to new situations, inspired by biology systems In 2017, a public offering was launched, and a team was selected to work in two areas. One is to develop systems and components. The other is to study the learning mechanisms of bioorganisms and apply them to computing systems.
2018/7	Data reduction for learning and training	Today's major machine learning systems require vast amounts of teacher data individually labeled by humans. This is the cause of the cost and time of training deep neural networks (DNNs). In addition, machine learning systems have a problem that often learning becomes unstable. Therefore, in order to reduce the initial cost and time associated with training and adapting machine learning systems, we will start a program to learn with fewer labels. Artificial Intelligence Exploration: AIEprogram announced to maintain U.S. superiority in ai technology
2018/7	AIE(Contextual Adaptation)	We recognize the limitations of AI technology by regarding the progress of AI technology as "first wave (rule-based)" and "second wave (statistical machine learning)". We aim to construct and develop adaptive AI theory using AI, descriptiveness, and model (contextualmodel) with the ability to adapt as "third wave". Researchers will make efforts to establish the feasibility of a new AI concept within 18 months of receiving the grant.
2018/9	AI NEXT	AI applications have announced a research and development program that has common sense for more efficient communication with people. Take two approaches. 1, development of a computational model that mimics the core functions of basic cognition learned from experience as a child 2, Development of technology to learn from text data such as web repositories, to build knowledge repositories that shape common sense, and to answer questions.

Table 2 DARPA AI-related programs[5]

Table 2 shows a list of AI-related programs at DARPA. In September 2018, a project called “AI NEXT” was started. This is a project to develop AI with "common sense" for more efficient communication with people.

AI-related technology of DARPA is mainly aimed at the fusion with humans in Cyber space.

Programs in Europe and the United States are focused mainly on the “cooperation with people.”

This working group aims at an AI robot that has functions of self-learning, self-repairing, self-organization, and self-evolution, by giving the robot a physicality, and symbiosis with humans.

Regarding physicality, not much research has been done on the physicality of humanoid robots because there trends to be distaste for humanoid robots in Europe and the United States.

On the other hand, in Asia, there is not so much distaste for humanoid robots, and research on humanoids is progressing in Japan as a form of robot that snuggles up to people.

In this working group, in order to co-evolve robot technology and AI technology, as a new approach, we created the new concept of co-design, co-evolution, co-sensation and co-partner, aiming to conduct research and development while always synchronizing AI technology and robot technology.

Ⅲ. SCENARIO FOR REALIZATION

1. Realization of Goals

We set three targets to achieve the MS Goals.

1. By 2050, development of AI robots that humans feel comfortable with, have physical abilities equivalent to or better than humans and grow together with human life.
2. By 2050, development of an automated AI robot system that aims to discover principles and solutions with great impact by thinking and acting in the field of natural science.
3. By 2050, development of AI robots that autonomously judge and act in environments where it is difficult for humans to act.

The following are example of research and development scenarios to be triggered towards realization of targets.

【Scenario 1】By 2050, development of AI robots that humans feel comfortable with, have physical abilities equivalent to or better than humans and grow together with human life.

[Image of 2050]

<Milestone>

- Realization of a partner AI robot as a true member of the family(famirobo).

<Ripple effect>

- AI robots that can get close to people can also be used in nursing care sites.

[Image of 2040]

<Milestone>

- A robot that human can trust will be introduced.

[Image of 2030]

<Milestone>

- Develop AI robots that people will behave with AI robots under certain rules and feel comfortable for over 90% of people .

[Additional Technical issues to overcome]

- Development of five-sense sensors that exceed human sensitivity, which captures facial expressions and gestures, and the development of AI software and hardware that quickly process and learn such information.
- Development of AI robots that record human growth and grow on their own.
- Development of design and reproduce memory(remembrance).

【Scenario 2】By 2050, development of an automated AI robot system that aims to discover principles and solutions with great impact by thinking and acting in the field of natural science.

[Image of 2050]

<Milestone>

- AI robots can automate the discovery of scientific principles and solutions with great impact.

<Ripple effect>

- Obtaining the means of automation and speeding up the discovery of scientific principles and solutions with great impact leads to greater competitiveness of all industries. Technology for automation and high speed creates a new industry.

[Image of 2040]

<Milestone>

- AI robots can automate discovery of scientific principles and solutions.

[Image of 2030]

<Milestone>

- Achieved automation of the discovery process of scientific principles and solutions for specific problems

[Additional Technical issues to overcome]

- Develop the method to use indicators or technologies to evaluate what contributes greatly to problem solving by verifying hypotheses and evaluating experimental results for large-scale complex social issues and scientific problems.
- Development of a method that is thought to be effective for solving one problem can be diverted to be applied to other problems.
- Even if a huge paper, analysis of experimental data, and inference are carried out by AI technology, human hands are necessary to demonstrate experiments. By using AI robots, we significantly reduce the time of problem-solving by learning and inferring with AI, building and experimenting with experimental systems ourselves, and feeding back the results to AI. Develop the method to feed back the Inference method , which AI build , to humans.
- Develop the method to quickly collect, analyze, and correlate research results (papers, experimental data, etc.) that have already been conducted and published around the world. In addition, develop the method to generate a new hypothesis from there, or to detect the contradiction automatically.
- Develop the method to automatically construct experimental design and construction of experimental equipment for verification of hypotheses and the comparison of options.
- Development of AI scientists for hypothesis generation, experiment planning, automatic execution of experiments, verification of results, etc. for limited experiment verification.

【Scenario 3】By 2050, development of AI robots that autonomously judge and act in environments where it is difficult for humans to act .

[Image of 2050]

<Milestone>

- Development of an AI robot that works autonomously regardless of the weather 24 hours per day, analyzing surrounding physical space in places where people find it hard to work .

<Ripple effect>

- Mankind stays on the moon for a long time and performs various activities such as resource exploration and sightseeing which can be supported through AI robots.
- AI robot that works autonomously in areas including civil engineering and building work in any weather for 24 hours per day, judging the situation at the construction site
- AI robots that autonomously remove rubble and help in disaster recovery.
- AI robots that can perform nursing care level 5 at home.

[Image of 2040]

<Milestone>

- Development of an AI robot that operates unattended in certain circumstance.

<Ripple effect>

- A base infrastructure is built on the moon, and astronauts stay there.
- Things that require human experience, such as civil engineering works, can be used in cooperation with AI robots while being monitored by humans.
- Fire-fighting AI robots that can be used anywhere and AI robots to check confirmation of human survival.
- AI robots that can be unattended for 24 hours and help those that require level 5 nursing care at care facilities, hospitals, etc.

[Image of 2030]

<Milestone>

- Development of an AI robot that operates unattended under human supervision in the limited circumstance.

<Ripple effect>

- Demonstration of simple base construction on the moon
- Humans work on the foundations and AI robots perform simple construction.
- AI robots that collect information and guides evacuation at the time of disaster
- AI robots that support nursing care level 2

In order to achieve targets and example of scenarios, three categories of technologies are required for instance.([6],[7])

1. Technology for fusing AI and robots.

- **Co-design**
  Designing how to promote co-evolution of AI technology and robot technology.

- **Co-evolution**
  Development such as fault tolerance, self-repair, self-organization, and self-evolution.
  AI control the robot by using outside information sensors, and AI learns the results of action. In this way, AI learns and the robot motion becomes closer to humans.

- **Co-sensation**
  When robots and people live together, robot should be able to understand human emotions and gestures. Develop sensor technology and AI technology to understand human emotions and gestures, we will also develop a function to store this information in remembrance.

- **Co-partner**
  Together with individuals, we will develop functions that allow AI and robots to grow.
  AI learns with individuals, and robots develop functions that can change their physicality according to individuals.

2. NEXT AI technologies

Below is a step-by-step description of the technologies to be achieved in 2050 for each basic technology. The upper part of the down arrow(↓) is the technologies to be achieved by around 2030. The lower row shows the technologies for 2050. (Items without arrows indicate the technologies for 2050.)

- **AI theory/technology**
  - Development of Trusted Quality AI that has quality assurance of results from AI and has explainable.
  - Development of architecture that realizes information processing imitating the brain in a practical time
  - AI algorithm capable of various information processing that mimics the information processing process of the brain

    ↓
  - Development of small, low-power AI architecture and AI devices for Edge processing.

- **Thoughtful AI**
  - Extract task structure and dynamics to be adapted from motion learning by induction of movement. Motion learning through direct observation of human behavior.
  - To perform real-world learning through interaction, appropriate estimation from uncertain systems, sparse learning, fusion of model-based reasoning and deep learning, etc.

    ↓
  - AI that can understand the emotion of the human and communicate with them with compassion.

- AI with ethics like human.

- **Self-sustained**
  - Current AI system wastes great power and cost, so green AI chip which have low power consumption and high-performance at same time is required. In order to realize this chip, hardware and software architecture should be developed.

- **Anti-compromise**
  - If the learning environment is bad, the learning results will be strange. There are problems such as risk of information leakage due to external hacking, virus contamination, etc., and hijacking of operations due to hijacking. Implement a function that can counter this.

- **AI control**
  - Real-time algorithms that perform realistic tasks in an unstructured environment
  - Effective optimization of tasks by reflecting constraints due to dynamic environmental changes in the motion planning algorithm

↓

  - Development of motion planning method for multiple robots to cooperate and execute complex tasks

- **Design of remembrance**
  - A method of providing categorized information to individuals. Development of recording methods such as information hierarchies, common sense, and emotions. Also, develop the playback method.

3．NEXT robot technologies

Below is a step-by-step description of the technologies to be achieved in 2050 for each basic technology. The upper part of the down arrow(↓) is the technologies to be achieved by around 2030. The lower row shows the technologies for 2050. (Items without arrows indicate the technologies for 2050.)

- **Mobility**
  - Realize human-like walking.

↓

  - Development of technology that can move around the house freely.
  - Development of technology that can move freely on rough surfaces such as rubble.

- **Actuator/manipulation.**
  - Integrate new sensors, actuators, motion transmission mechanisms. Dynamics using robotic materials and robot motion control methods should be developed.

↓

  - Development of new principles and materials for maintenance-free actuators over a long period of several decades
  - A robot that operates quickly and accurately like a living thing.

- **Motion/task planning**
  - Development of real-time algorithms that perform realistic tasks in unstructured environments

↓

- Robots free from frame problems

- **Material/structure**
  - Development of new sensors, actuators, and power transmission mechanisms using soft materials. Advanced integration of dynamics and robot motion control methods using soft materials

    ↓
  - Development of lightweight, high-strength, and non-breakable material to realize an endoskeleton robot with a living body-like housing that has a soft outer shell and a strong skeleton. Development of optimal body structure using these new materials.

- **Sensors**
  - Advanced sensing system with higher accuracy and lower cost

    ↓
  - Development of five-sensors (visual, auditory, tactile, gustatory, and olfactory) that exceed humans
  - Ultra sensory sensor (Mounting of sensors that capture information that cannot be captured by humans such as electromagnetic waves, ultrasonic waves, low frequencies, brain waves, etc. on robots. Miniaturization, weight reduction, low power consumption)

- **Fault tolerant**
  - Self-healing function (In case of breakage, using a universal 3D printer, etc. to materialize design information using self obtained material.)

- **Power control device/system**
  - Power supply method and low power consumption technology that can operate for a long time without a power cable in extreme environments

- **Embodiment**
  - Robust grasping and manipulation of complex and flexible objects by recognition of surrounding environment by tactile sense and grasping motion planning based on it

    ↓
  - In order to live in harmony with humans, AI robots are made the same size and weight as humans, and the freedom of movement of the body is improved beyond the level of humans.
  - A robot that has an appearance that allows people to feel comfortable.

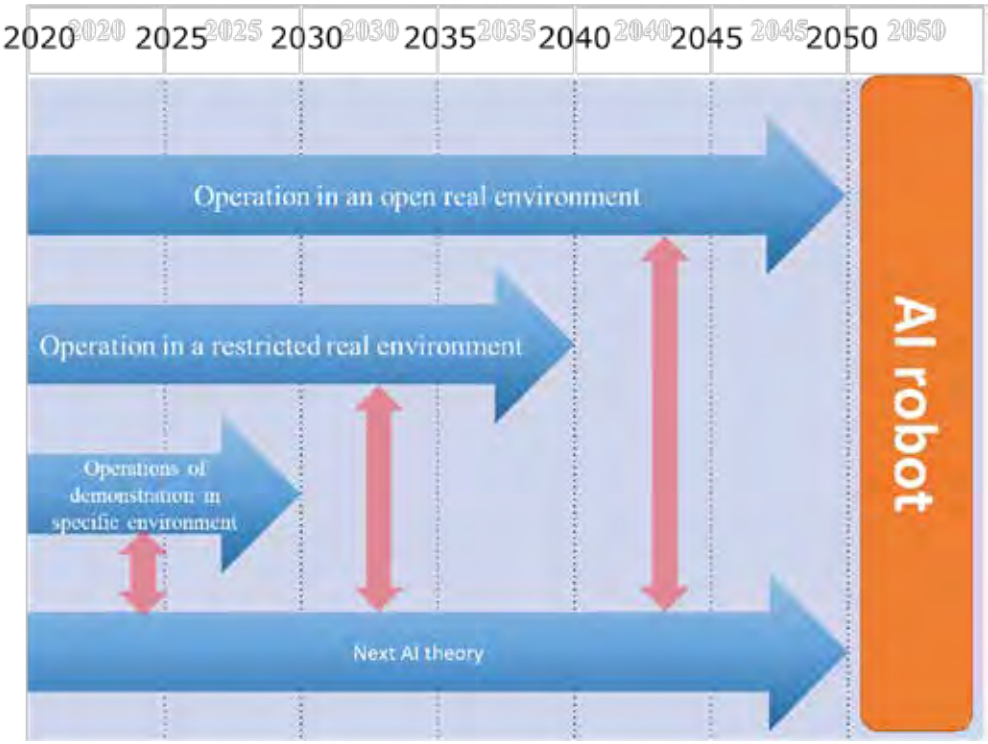


Fig.12 Conceptual scenario

By 2030, AI robot that operates in a specific environment and conditions will be developed

By 2040, develop an AI robot that operates in a restricted real environment.

By 2050, develop AI robots that operate in an open real environment.

Figure 13 shows R&D promotion method for robot using a platform enabling function demonstration and utilization.

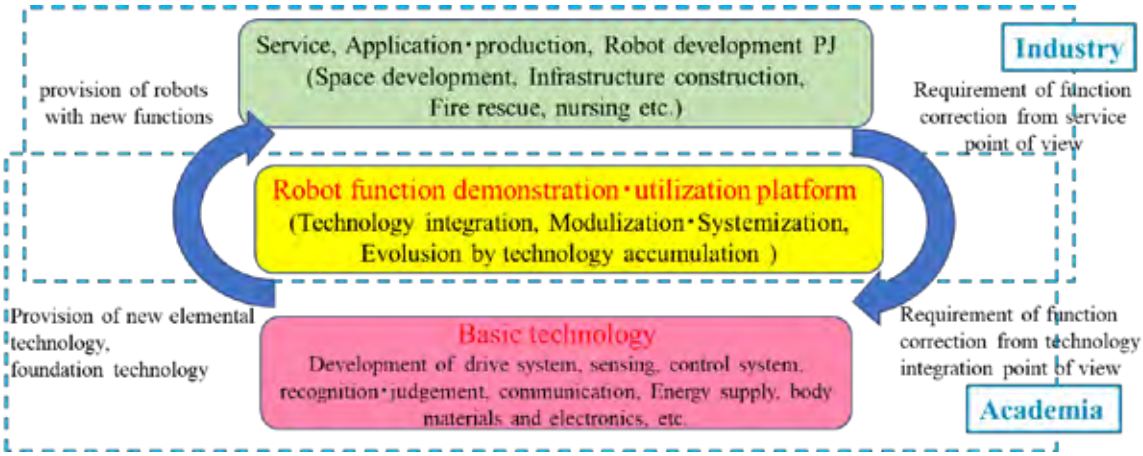


Fig.13 R&D promotion method[2]

Fig.13 shows such a robot function demonstration and use platform.

In this platform, we collect elemental and fundamental technologies that are considered promising to realize the demands of robot technologies and robot functions required by service sites and industry and promote the development of technologies for fusion and integration of these technologies to confirm their functionality. As a result, users and industry who want to use new robot technologies and modules can provide feedback to module development and elemental technology and fundamental technology development. By making such loops go smoothly, it will not be only an elemental technology or a fundamental technology development, but it will be refined as a technology that can be used in practice. That will be bring the accumulation of new technologies and knowledge for Academia which advances this platform, basic technology development. In addition, by experiencing such a place, we can acquire a wide range of knowledge through exchanges with people in other fields, and industries, and it is thought that human resource development will also be advanced.

In addition, as show in figure 5, integration, modularization, and platformization are necessary to build AI robot. Therefore, due to achieve above rapidly, AI development and robot development should be executed while looking at mutual research results and simultaneously.

With these, it is also necessary to develop functions such as autonomous learning, self-evolve, self-healing, and self-organization required for AI robots in order to realize "robots that learn and act on their own and develop themselves" by 2050.

2. International Collaboration

In order for AI robot technology and infrastructure to be used globally, it is important that hardware / software, their interfaces, and the common infrastructure on which they operate are in mutual with the world, such as international standardization.

In terms of regulations and systems, it is also important to build common principles, regulations and systems that can spread throughout the world by harmonizing the legal framework of Japan and the world.

Therefore, it is necessary to promote international cooperation from the beginning.

In addition, the robot and AI community is spreading all over the world, and it is possible to speed up research and development by collaborating with excellent institutions, scientists, engineers, etc.

3. Cooperation with other WG

Regarding as development of AI robot, some technologies as common one among WG1 and WG5. Therefore, WG3 plans to cooperate closely and to proceed with development by sharing information with WG1 and WG5.

4. Security

Ensuring security is essential in the current ICT system. Systems that utilize AI and robot technology, it is inevitable to work on ensuring security from the research and development stage. Also, since there are technologies in common with other WGs in this effort, it should be crossed across WGs.

Especially for AI robot development, it is essential to research and develop safety and reliability based on coexistence with humans. It is very important to consider at what level the mechanism of safely stopping is, when parts are broken or malfunctioning so as not to cause harm to a human being.

It is also crucial to incorporate double and triple safety measures from service systems to robot systems, functional modules, components, and material levels, and consider them at each level. It is also needed for the interface of the module to be compatible with a standard robot OS and consider the overall architecture (platform) so that they are able to work in cooperation with the environment and system around the robot.

When thinking about the platform, it is difficult to do it by industry and academia alone. This is because the development of basic technologies with a view to social implementation is important.

5. ELSI

While AI will bring many great benefits to society, its large impact on society calls for appropriate development and implementation. In order to avoid or reduce the negative aspects in advance while making effective use of AI to benefit society, we should promote the continued research and development (R&D) of technologies related to AI, a transformation into an "AI-Ready Society" where AI can be used effectively and safely. We need to redesign society in every way including Japan's human potential, social systems, industrial structures, innovation systems, and governance. (Partial excerpt from Cabinet Office "Human-Centered AI Social Principles[8])

In developing AI robot technology, it is necessary to always be aware of ELSI.

For example, there is a possibility that a robot may become antisocial due to contamination of a learning environment, external hacking, viruses, or the like.

Therefore, it is necessary to always develop technology such as tamper resistance (a state in which analysis of internal structures of software and hardware and stored data is difficult), etc.

In order for AI robots to be used in society, human dignity, rights, and the like must be maintained in line with existing laws and regulations (such as occupational safety, medical care, road traffic, radio waves) while incorporating ethical considerations such as freedom and cultural diversity. After that, make recommendations to the relevant ministries. Initiate dialogue and collaboration among diverse stakeholders, link various activities to further research, innovation and policy formation, and work to solve social issues.

Ⅳ. CONCLUSION

WG3 started the study with the following example of goals as its starting points, chosen from among the 25 related example of Moonshot goals shown at the visionary council: 7) Full automation of agriculture, forestry & fisheries by 2040, 8)Full automation of construction work by 2040, 18) Development of AI system for scientific discovery at the level Nobel Prize by 2050 and 25) Distributed and collective satellite constellation and space robotics by 2035.

In the study, we have discussed from a multifaceted perspective so that MS Goal candidates will be accepted by many people as targets around 2050. It is to clarify the expected milestones and image of research and development and the spin-off expected in the process of research and development taking into consideration international trends and the status of projects under development in Japan.

WG3 proposes "By 2050, robots can learn autonomously, adapt to the environment, evolve itself in intelligence and act with human beings."

REFERENCES

[1]Cabinet Office 5th Basic Plan for Science and Technology (Related Materials)
[2]STRATEGIC PROPOSAL Innovations of Basic Technology for Robots Through Integration of Nanotechnology, Information Technology, and Mechanics. CRDS, JST(CRDS-FY2015-SP-03)
[3] Panoramic View of the Systems and Information Science and Technology Field (2019), CRDS, JST(CRDS-FY2018-FR-02)
[4] TSC Foresight Vol.29 New Energy and Industrial Technology Development Organization.
[5]AI white paper 2018、Information- Technology Promotion Agency, JAPAN
[6]2016 Robotics Roadmap and the National Robotics Initiative 2.0
https://cra.org/crn/2017/02/2016-robotics-roadmap-national-robotics-initiative-2-0/
https://www8.cao.go.jp/cstp/kihonkeikaku/5siryo/5siryo.html
[7]Cabinet Office AI Strategy 2019
https://www.kantei.go.jp/jp/singi/tougou-innovation/pdf/aisenryaku2019.pdf
[8]Cabinet Office Human-Centered AI Social Principles (Decision of the Council for the Promotion of Integrated Innovation Strategy) https://www.cas.go.jp/jp/seisaku/jinkouchinou/pdf/aigensoku.pdf