Provisional translation

【Moonshot Goal 3】

R&D concept of “Realization of AI robots that autonomously learn, adapt to their environment, evolve itself in intelligence and act alongside human beings, by 2050.”

February 2020
Ministry of Education, Culture, Sports, Science and Technology

1. Moonshot Goals

Within the Moonshot Goals (decided on January 23rd, 2020, by Plenary session of Council for Science, Technology and Innovation), the Ministry of Education, Culture, Sports, Science and Technology (“MEXT”), with Japan Science and Technology Agency (“JST”) as a research and development promotion agency, will undertake research and development activities for achieving of the following Goal.

＜Moonshot Goal＞

"Realization of AI robots that autonomously learn, adapt to their environment, evolve itself in intelligence and act alongside human beings, by 2050."

- By 2050, development of AI robots that humans feel comfortable with, have physical abilities equivalent to or greater than humans, and grow in harmony with human life.
- By 2030, development of AI robots that behave well with humans under certain conditions, and allow over 90% of people to feel comfortable with them.

- By 2050, development of an automated AI robot system that aims to discover impactful scientific principles and solutions, by thinking and acting in the field of natural science
- By 2030, development of an automated AI robot system that aims to discover scientific principles and solutions for specific problems

- By 2050, development of AI robots that autonomously make judgements and act in environments where it is difficult for humans to act.
- By 2030, development of AI robots that operate unattended under human supervision in specific circumstances.

2. Direction of research and development

Based on the discussion and proposal made in the Moonshot International Symposium (held in December 17, 18, 2019), direction of research and development at present is shown as follows.

(1) Area and field to promote challenging R&D

Considering Japan's declining birthrate and aging population, it is important that robots can be used in all aspects of society - such as working in dangerous or understaffed sites, developing human frontiers, and supporting our lives. For that purpose, the key is to realize a robot that learns and acts on its own through co-evolution of AI and robots.

In order to realize an AI robot that learns and acts on its own, it is necessary to realize a series of cooperative actions between the AI and the robot as described below.

AI receives the sensory information, obtained by the robot through sensors, as emotion, caution, and empathy information. AI stores it as knowledge, intention, and learning. The AI performs recognition/decision/control accordingly, and outputs motion information. With this information, the robot performs the actuation.

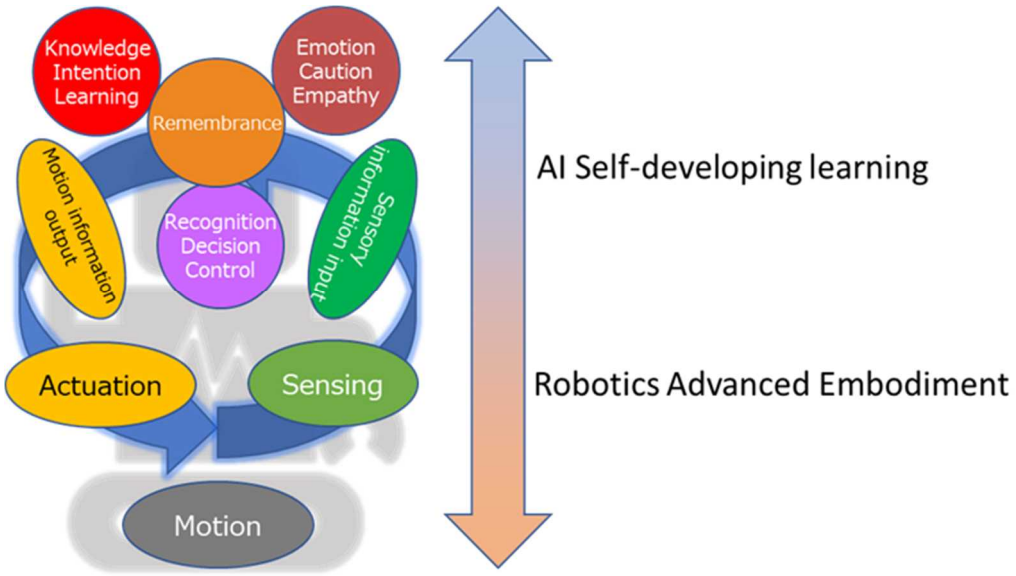


Fig.1 Concept of co-evolution AI and Robot

In order to achieve this, it is necessary to fuse and co-evolve the technological elements shown in Fig.2 while researching and developing them.

These are the fields for challenging R&D to be promoted in the Moonshot Research & Development Program.

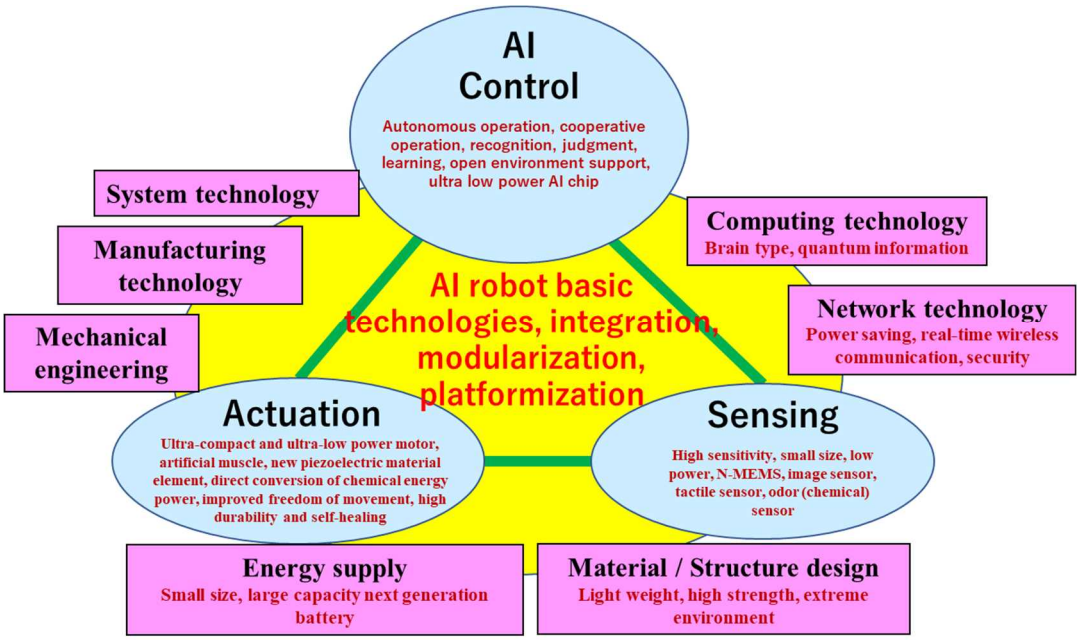


Fig.2 Main field and area of R&D that is required for Realization of a robot that can autonomously learn, adapt to the environment, evolve itself in intelligence

(2) Research subject for realization of MS Goal

The image in Fig.2 is the area and field for challenging R&D to be promoted under the Moonshot Research & Development Program. R&D that contribute to the achievement of this MS Goal ”realization of a robot can autonomously learn, adapt to the environment, evolve itself in intelligence and act with human beings” should proceed. In order to have the most effective and efficient countermeasure, the most cutting-edge scientific trends shall be researched and used for R&D.

Specifically, the following research and development will be promoted.

< [1] AI robots that humans feel comfortable with, have physical abilities equivalent to or greater than humans, and grow in harmony with human life.>

Develop AI robots that allow people to interact with them without any discomfort, that learn, act and grow on their own, provide optimal support for each individual, and improve human QOL.

< [2] An automated AI robot system that aims to discover impactful scientific

principles and solutions, by thinking and acting in the field of natural science.>

Develop an AI robot system that autonomously discovers scientific principles and solutions by exploring and selecting from a large range of possibilities very quickly, substituting the experiments and tasks traditionally done by humans. The AI technology developed here should be used to realize AI robots [1] and [3].

< [3] AI robots that autonomously make judgements and act in environments where it is difficult for humans to act.>

Develop AI robots that work on behalf of people in places that are dangerous for human activities (space, disaster sites, high places, deep seas, etc.) or places where human resources will become insufficient in the future (construction, agriculture, forestry, fisheries, etc.).

[1] to [3] are all research and development aimed at the fusion and co-evolution of AI and robots, and research and development of basic AI and robot technology should be advanced in full cooperation.

In conducting R&D, various sources and types of knowledge and ideas will be adopted, stage gates will be established. And evaluation will be conducted to promote R&D to achieve Goal.

In addition, from the viewpoint of smoothly implementing research results in society, a system that enables researchers in various fields to participate in ethical, legal, and social issues will be considered.

(3) Direction of research and development for realization of the Goals

○ By 2030

[1] Development of AI robots that behave well with humans under certain conditions and allow over 90% of people to feel comfortable with them.

[2] Development of AI robots that autonomously and exploratively propose solutions to specific problems and aim to discover scientific principles and solutions.

[3] Development of AI robots that can autonomously operate under human supervision in specific situations, such as outer space and disaster sites, and achieve given tasks.

○ By 2050

[1] Development of AI robots that humans feel comfortable with, have physical abilities equivalent to or greater than humans, and grow in harmony with human life.

[2] Development of an automated AI robot system that aims to discover scientific principles and solutions for specific problems

[3] Development of an AI robot that can make autonomous decisions, and act and grow by itself in an environment where it is difficult for people to work.

To realize a robot that learns and acts and grows by itself by 2050, it is necessary to develop technical elements and achieve modularization and systematization through their fusion and co-evolution.

In order to achieve these speedily, and in response to the demands on robot technology and robot functions required by service sites and industries, we gather technology elements that considered promising to realize them, promote R&D on their fusion and co-evolution and build a platform to confirm functionality.

Fig. 3 shows how to proceed with R&D to achieve the Moonshot target by realizing the R&D concept.

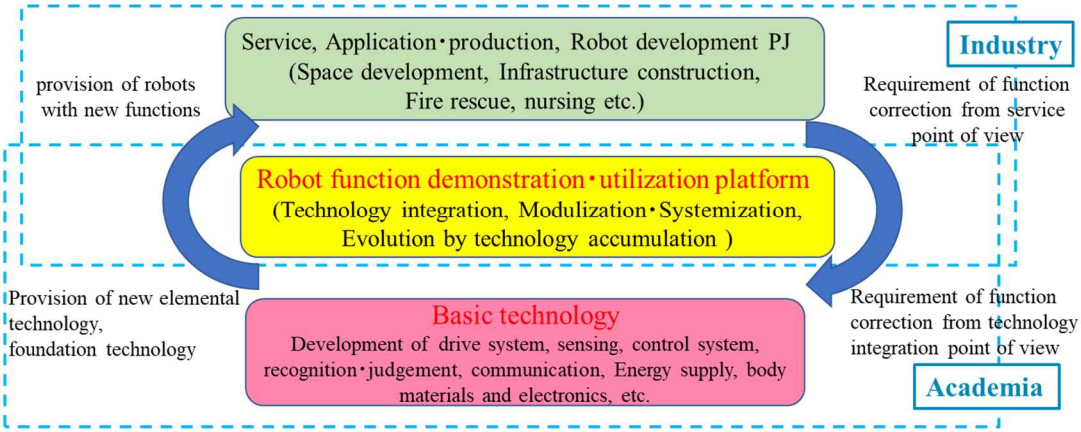


Fig.3 How to proceed with research and development to realize a robot can autonomously learn, adapt to the environment, evolve itself in intelligence

＜Reference : Analysis for realization of the Goals＞

Summary of content which is analyzed in the Initiative Report presented in Moonshot International Symposium is shown, as follows:

(1) Structure of research fields and technologies

Fig.4 shows a group of technologies related to the realization of an AI robot that learns and acts by itself.

In this Goal, it is necessary to conduct research and development of necessary technical elements and integrate and utilize them, requiring challenging R&D.

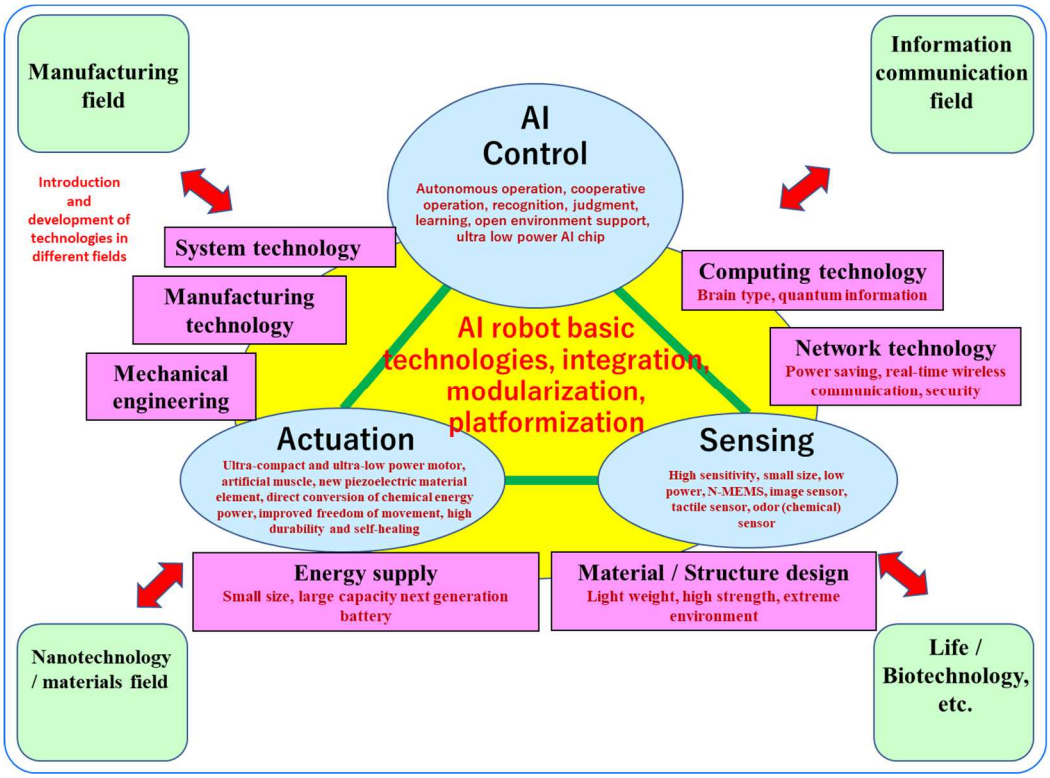


Fig.4 The structure of research fields and technologies mainly related to AI robots that learn and act on their own

(2) R&D trends in related fields

Fig. 5 shows the 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. Such real-world big data 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.

The Moonshot R&D program aims to achieve the Moonshot target by 2050 by promoting R&D in the fusion and co-evolution of AI and robot technologies.

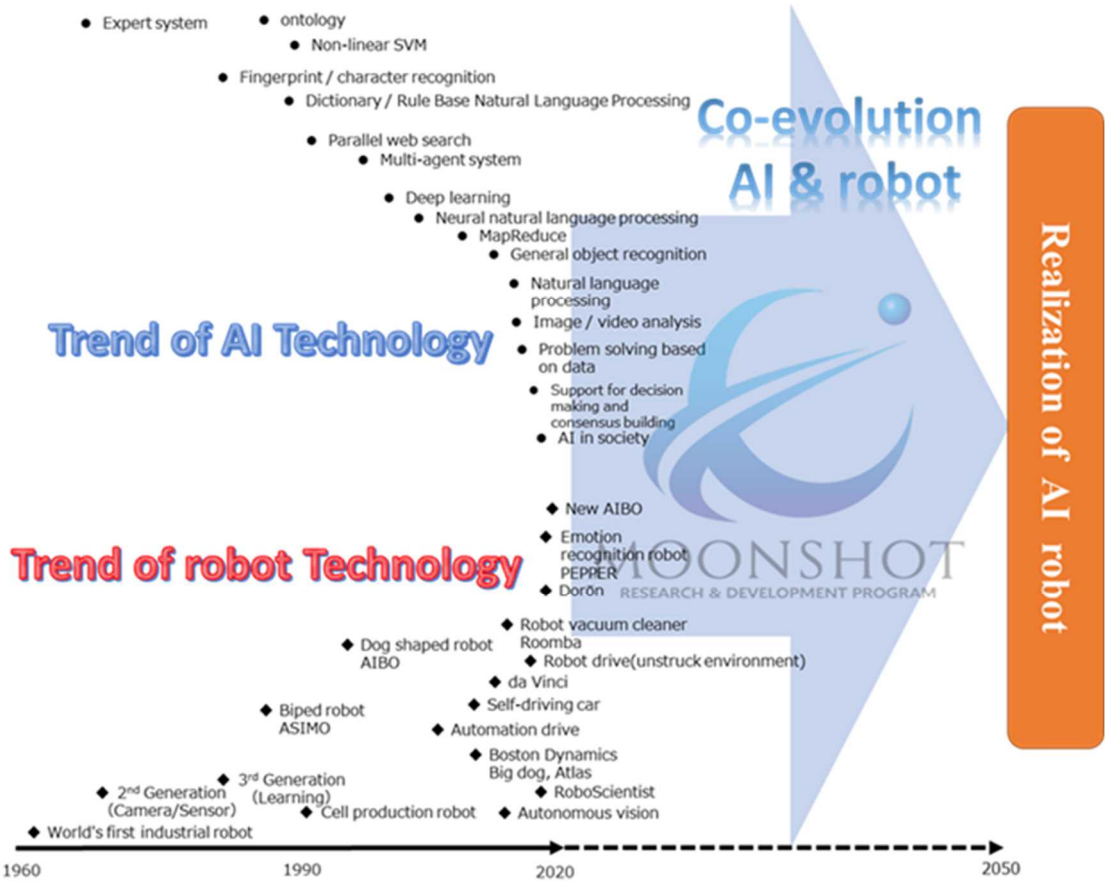


Fig.5 Technical trend related AI and robot
(Panoramic View of the Systems and Information Science and Technology Field(2019), produced by CRDS, JST)

(3) Strengths of Japan, trends in global research community

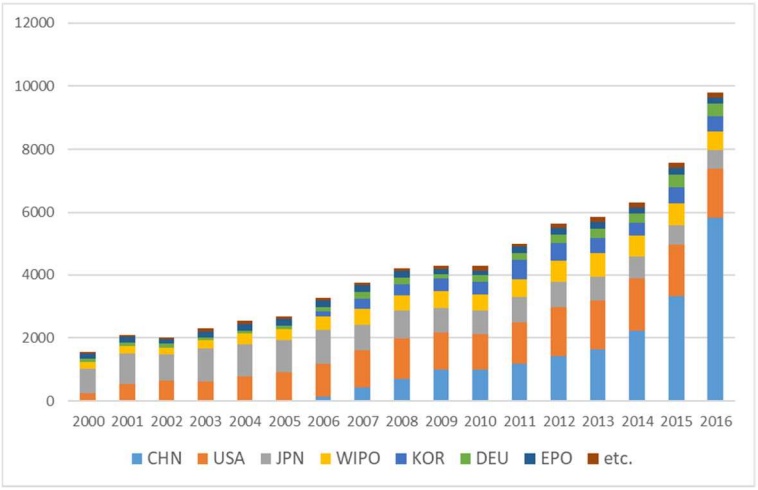
[1] Trends of patent applications and paper publications in the field of AI robot.

Fig.6 shows the number of patent applications by region including both AI and robot technologies.

The number of applications has been increasing globally since 2000. Looking at the number of applications in 2015 and 2016, the rate of increase is higher than in 2014.

Therefore, 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

Cumulative numbers from 2000 to 2016

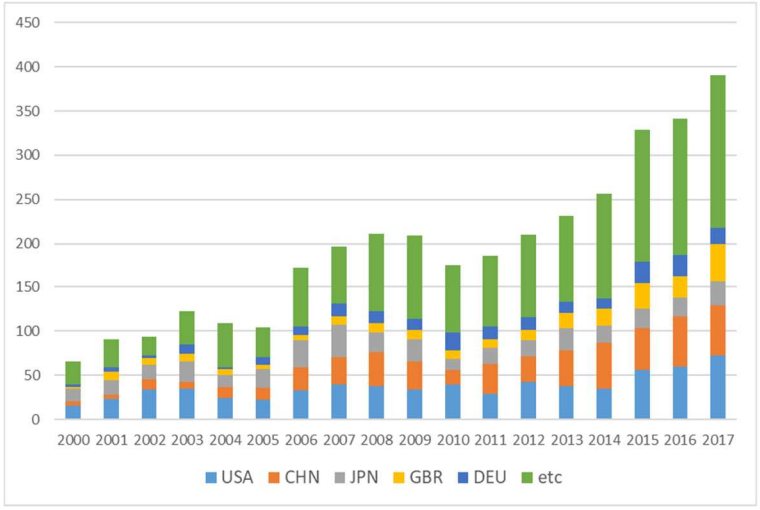
Fig.6 Number of patens by region

(Source) Created by NEDO TSC based on search results on Derwent Innovation™ (2018)

Figure 7 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

Cumulative numbers from 2000 to 2017

Fig.7 Number of papers by region

(Source) Created by NEDO TSC based on search results on Web of Science™ (2018)

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.

[2] International comparison of elemental technology

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 are 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.

On the other hand, it seems to be behind in terms of technological innovation in AI over recent years.

However, although not shown in this table, especially in the field of industrial robots and commercialization, these technologies are fine-tuned to each other to achieve their original performance, and through so-called combination technologies become overwhelmingly competitive.

Table 1 Technical trend for AI and Robot

		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	○↗	◎↗	◎↗	◎↗	◎↗	○↗	△→	○↗	△→

(Source) Panoramic View of the Systems and Information Science and Technology Field (2019), CRDS, JST(CRDS-FY2018-FR-02)

(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