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MESSAGES FROM THE EDITORIAL BOARD

There has been a wide gap between science and society. The last three hundred years of the history of modern science indicates to us that many research results disappeared or took a long time to become useful to society. Due to the difficulties of bridging this gap, this stage has been recently called the valley of death or the nightmare stage (Note 1). Rather than passively waiting, therefore, researchers and engineers who understand the potential of the research should actively try to bridge the gap.

To bridge the gap, technology integration (i.e. *Type 2 Basic Research* – Note 2) of scientific findings for utilizing them in society, in addition to analytical research, has been one of the wheels of progress (i.e. *Full Research* – Note 3). Traditional journals, have been collecting much analytical type knowledge that is factual knowledge and establishing many scientific disciplines (i.e. *Type 1 Basic Research* – Note 4). Technology integration research activities, on the other hand, have been kept as personal know-how. They have not been formalized as universal knowledge of what ought to be done.

As there must be common theories, principles, and practices in the methodologies of technology integration, we regard it as basic research. This is the reason why we have decided to publish "*Synthesiology*", a new academic journal. *Synthesiology* is a coined word combining "synthesis" and "ology". Synthesis which has its origin in Greek means integration. Ology is a suffix attached to scientific disciplines.

Each paper in this journal will present scenarios selected for their societal value, identify elemental knowledge and/or technologies to be integrated, and describe the procedures and processes to achieve this goal. Through the publishing of papers in this journal, researchers and engineers can enhance the transformation of scientific outputs into the societal prosperity and make technical contributions to sustainable development. Efforts such as this will serve to increase the significance of research activities to society.

We look forward to your active contributions of papers on technology integration to the journal.

Addendum to Synthesiology-English edition,

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Papers or articles published in "Synthesiology-English edition" appear approximately four months after the publication of the original "Synthesiology". Those published in Japanese are translated into English, so the views expressed in translated versions are exclusively those of the Japanese authors and editors. The Japanese authors are generally consulted regarding the translation of their papers, but are not responsible for the published English version.

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Synthesiology Editorial Board
(written in January, 2008)

Note 1 : The period was named "nightmare stage" by Hiroyuki Yoshikawa, the then President of AIST, and historical scientist Joseph Hatvany. The "valley of death" was used by Vernon Ehlers in 1998 when he was Vice Chairman of US Congress, Science and Technology Committee. Lewis Branscomb, Professor emeritus of Harvard University, called this gap as "Darwinian sea" where natural selection takes place.
Note 2 : *Type 2 Basic Research*
This is a research type where various known and new knowledge is combined and integrated in order to achieve the specific goal that has social value. It also includes research activities that develop common theories or principles in technology integration.
Note 3 : *Full Research*
This is a research type where the theme is placed within the scenario toward the future society, and where framework is developed in which researchers from wide range of research fields can participate in studying actual issues. This research is done continuously and concurrently from *Type 1 Basic Research* (Note 4) to *Product Realization Research* (Note 5), centered by *Type 2 Basic Research* (Note 2).
Note 4 : *Type 1 Basic Research*
This is an analytical research type where unknown phenomena are analyzed, by observation, experimentation, and theoretical calculation, to establish universal principles and theories.
Note 5 : *Product Realization Research*
This is a research where the results and knowledge from *Type 1 Basic Research* and *Type 2 Basic Research* are applied to embody use of a new technology in the society.

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Contents

Training technology for auditory orientation by the persons with visual impairment

— Toward practical use in rehabilitation facilities —

Yoshikazu SEKI

[Translation from *Synthesiology*, Vol.6, No.2, p.66-74 (2013)]

People with visual impairments require training to perceive their surroundings from ambient sounds. The author developed a system, introduced to rehabilitation facilities, that allows training to be conducted in a safe virtual environment. To realize this system, the author carried out fundamental research on the mechanism of auditory orientation; developed basic technologies to simulate 3-D sound; and designed hardware and software to calculate 3-D sound, as well as head position and direction. A training curriculum was also developed. The effectiveness of the training system was evaluated, and certified as being more effective than the existing real-environmental training system. However, some problems with calculating head position and direction must be addressed before this system can be completely introduced to rehabilitation facilities. While we are currently working to resolve this problem, the training system in its present state is being distributed as a simplified version to the people concerned since September, 2010, and is being actively used.

Keywords **:** Visual impairment, auditory orientation, rehabilitation, 3-D sound, position and direction measurement

1 Training in the past

It is essential for people who have lost their sight, due to injuries, disorders, or other reasons, to develop an ability to recognize their surroundings based on sound (auditory spatial orientation), instead of light, and improve their ability to walk and daily living skills. Auditory spatial orientation required by visually impaired people includes both "sound localization," the ability to identify the location of a sound-producing object such as a car, and "obstacle perception,[Term 1]" the ability to determine the position of an object that does not produce sound such as a wall or pillar, using reflected sound.

Practice to improve auditory spatial orientation currently implemented in education and rehabilitation settings for visually impaired people only focuses on training in which they are repeatedly tested for their ability to recognize their surroundings by listening to auditory information while actually walking in a real-life environment.[1] However, training in an actual environment with moving vehicles poses a risk to visually impaired people "who have just started undergoing training." It may also be very difficult for them to distinguish auditory clues required for auditory spatial orientation from a mixture of noises in the actual environment. Training in auditory spatial orientation should be conducted in a safe and structured manner to improve its safety and efficiency and shorten the rehabilitation period, instead of only emphasizing training to distinguish different sounds in the actual environment. In this context, a few studies were conducted in Japan and other countries to develop systems designed to help implement training in auditory spatial orientation in a structured manner.[2] Most of these training systems created virtual reality environments for auditory training, using acoustic technology. However, these systems were only designed to help conduct training in sound localization and not obstacle perception, and no findings of the studies were put into practical use.

On the other hand, during the period between 1998 and 2002, the authors developed a training method focusing only on basic training to improve obstacle perception, which was put into practice.[3] As people who have just started undergoing training have difficulty identifying an approach to learn obstacle perception, the training method, which involves creating a virtual environment using acoustic technology, aimed to help visually impaired people understand and learn it. However, the method does not cover training to improve sound localization, which suggests that there is no appropriate system for training in auditory spatial orientation.

In this context, I conducted research to develop a system for training in auditory spatial orientation, including sound localization and obstacle perception, and put it into practice. The present paper presents the results of a series of studies conducted to develop the system for auditory spatial orientation training.

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2 Constructive scenario required to develop the training system

As described in the previous chapter, currently, there is no method to implement training in auditory spatial orientation in a safe and structured manner, and people with visual impairment undergo training in a real-life environment to add to their experience of distinguishing different sounds. It is desirable that they receive training and learn in a safe, virtual environment. To conduct training in a structured manner, the level of difficulty of training materials should be changeable. The most realistic approach is the adoption of virtual reality technology, which can simulate factors associated with sounds to be learned in auditory spatial orientation training. However, to implement this training method, knowledge on the mechanism of auditory spatial orientation in terms of acoustics is required, and the use of virtual reality technology requires techniques to produce three-dimensional sound and monitor the movement of the heads of trainees.

To develop the training system, it is necessary to create a scenario by integrating elements of interdisciplinary studies in a structured manner, as described in previous paragraphs. To this end, I created the following scenario: clarify the mechanism of auditory spatial orientation, develop a training method based on the mechanism (which simulates safe, virtual training environment), seek ways to reduce costs, and introduce the method to rehabilitation and education settings for visually impaired people.

This scenario consists of the following elements:
1) Knowledge on the mechanism of auditory spatial orientation required by visually impaired people while walking (psychoacoustics)
2) Three-dimensional acoustic technology to simulate the above-mentioned mechanism (acoustic technology)
3) Hardware/software to conduct real-time calculations required for 3-D acoustics (signal processing technology)
4) Technology to monitor and record the position and direction of the head, used to create a virtual reality environment based on 3-D acoustic technology (sensor technology)
5) Training schedule implemented using the developed training system (rehabilitation science)

Figure 1 shows the principle of the training system. A trainer in charge of conducting training for visually impaired people first develops a training schedule, and then creates a training environment required to implement it. For example, “a training environment in which automobiles drive on roads” should be designed, if a trainee is to “develop the ability to recognize the position and direction of a road by listening to the sound of a vehicle passing on it.”

Following this, the training system simulates the stereophonic environment designed by the instructor for the trainee, using the 3-D acoustic technology, hardware, and software. It ensures that even trainees with little experience of undergoing the training can clearly hear and understand sound information, a part of the mechanism of the system, when the environment is simulated. The system allows trainees to feel as if they are in the actual environment, hear sounds coming from the surroundings more clearly than in the actual environment, and effectively learn the mechanism of auditory spatial orientation.

When the head of a trainee turns or moves in the training environment, changes in the position and direction will be identified by the system for monitoring them and conveyed to the 3-D acoustic system, and, based on this information, the sound images will be changed. When trainees move their heads in the training environment, they can experience changes in the sound similar to those in the real environment.

3 Solutions to problems in the development of a training system

3.1 Development of a prototype training system

A prototype training system was developed based on findings acquired by clarifying the mechanism of auditory spatial orientation required by visually impaired people while walking (Fig. 2).[8] Research and development were conducted in collaboration with the Department of Visual Impairment, National Rehabilitation Center for Persons with Disabilities, with the support of a Grant-in-Aid for Scientific Research from the Ministry of Health, Labour and Welfare.

3.1.1 Development of training methods based on perception of obstacles

Between the 1990s and early 2000s, I conducted

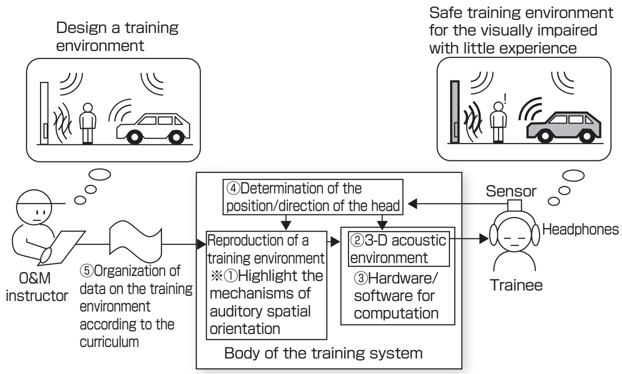


Fig. 1 Concept of the auditory spatial orientation training system

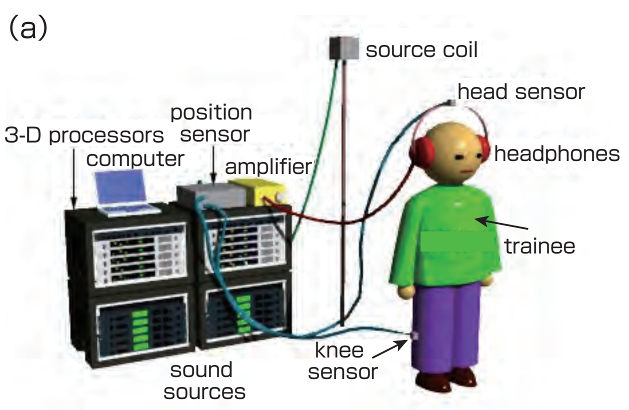
A trainer first develops a training schedule, and then creates a training environment required to implement it. Following this, the training system simulates the stereophonic environment for the trainee, using the 3-D acoustic technology, and ensures that even trainees with little experience in rehabilitation can clearly hear and understand sound information. The technology to determine the head position/direction moves the position of the sound image when the trainee moves or turns his/her head in the training environment. The trainee feels as if he/she is in the actual environment.

psychoacoustic research and experiments, involving human subjects, to examine the mechanisms of “obstacle perception” included in “auditory spatial orientation,” which had not been clarified.[3]-[7] In the process of the study, it became clear that people involved in rehabilitation and education for visually impaired people had to rely on experience-based training methods because the mechanisms of obstacle perception had not been clarified, and that it was necessary to develop training methods based on the clarified mechanisms. The results suggested that visually impaired people used the following acoustic phenomena as “clues” in obstacle perception: changes in the image[4][5] and tone[6] of direct and reflected sounds, and decays[7] of sound due to sound insulation and diffraction. When these “clues” were simulated using acoustic technology, people who had developed obstacle perception skills felt as if specific objects were present.[3] Figure 3 shows an example of an examination of obstacle perception training. In this example, speakers positioned in front of and behind a person produced direct and reflected sounds similar to those heard in the actual environment, and the body movements were examined when the virtual walls approached the person. The subjects in the experiment, who had developed obstacle perception skills, involuntarily moved to avoid the virtual wall when it approached them. This demonstrates that factors associated with obstacle perception can be identified by simulating direct and reflected sounds using speakers. The finding is the basis for obstacle perception training in the system. Factors associated with obstacle perception are highlighted in the training system, so that even trainees with little experience of undergoing the training can clearly understand them. For example, fully-reflected sound was used (no decrease in the sound pressure level); sound was completely insulated when obstacles were placed; direct sound vertically striking the reflecting surface of an obstacle was used; and there was no noise, excluding direct and reflected sounds.

3.1.2 Technology to create a 3-D acoustic environment

As the auditory system of humans has a mechanism that allows them to perceive three-dimensionally-formed sounds, the training system adopted a technology that produces a variety of 3-D sounds based on this mechanism[9] and presents them to trainees wearing headphones. The technology assigns a sound image to a position in 3-D space by convolving the head-related transfer function (HRTF), which represents the acoustic transfer characteristics of the head, auricle, and ear canal, into signals transmitted by the original sound. It creates a 3-D virtual auditory environment for trainees wearing stereo headphones. However, the technology has a drawback: the position of the sound image produced in 3-D space varies depending on the person due to individual differences in the HRTF. Therefore, the technology cannot be used to accurately simulate an auditory environment unless calibration is conducted for each person. The training system developed based on the scenario should be used as an educational material to help trainees with little experience of undergoing this type of training learn the basics of auditory spatial orientation, and not for official training.

To create the above-mentioned 3-D acoustic environment, hardware and software designed for high-speed computing were needed that can convolve the HRTF and signals transmitted by the original sound on a real-time basis; therefore, sound effectors with integrated circuits for digital signal processing (DSP) were commonly used in the early 2000s. The prototype training system was operated by ten



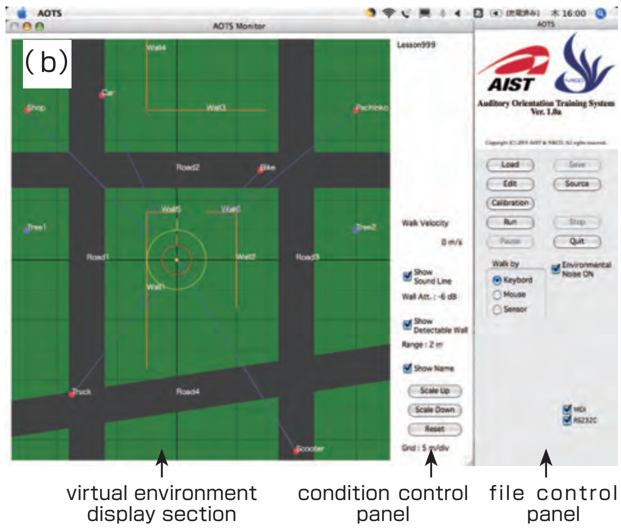


Fig. 2 Prototype training system

(a) Structure of the system

(b) Training environment displayed on the screen

Positions of the trainee (at the center of the circle), sound sources (such as cars, trucks, stores), walls, roads, and landmarks are displayed in the virtual environment display section on the left of the screen. The condition control panel in the center of the screen is for setting conditions regarding the virtual environment (e.g., with or without noise) and the display mode (e.g., enlarge and reduce). The file control panel on the right of the screen is for operating files regarding the virtual environment and starting/stopping its display.

commercially available 3-D sound effectors (RSS-10 by Roland) connected in parallel, equipped with dedicated DSP integrated circuits, to create a 3-D acoustic environment for ten sound sources.

3.1.3 Technology to identify the position and direction

In the development of the prototype training system, commercially available magnetic position sensors (3SPACE Fastrak, Polhemus) were adopted to monitor and record the position and direction of the head. The magnetic position sensor identifies the position and direction of an object with high accuracy; the sensor coil attached to an object detects a magnetic field generated by the source coil. Although its price is over one million yen, the sensor is used for research purposes, and readings can be obtained with an accuracy of 1 mm (position) and 1 degree (direction). As the position and direction were identified only within an approximately one-meter area, or the magnetic field was generated by the source coil, trainees could not walk in the actual environment. Therefore, they marched in place without moving forward in the training environment. The sensor coils were attached to both the head and knees of a trainee to detect stepping movements. Vertical movements of the knee detected by the knee sensor were determined as steps made by a trainee; the walking rate was determined according to the speed and range of vertical movements.

3.1.4 Training schedule

In the training schedule, four components were positioned in the training environment: 1) sound sources, 2) walls, 3) roads, and 4) landmarks. Point sources of sound (1) were used as components to represent sound-producing objects in the training environment such as automobiles and stores. Therefore, "sound sources" could be used for training to identify their positions. In addition to this, environmental sound was produced by four sources in the training environment, which were equivalent to north, south, east, and west, so that trainees could feel as if they were in a real outdoor environment. (2) "Walls," which do not produce any sound, were used to reflect and insulate sound produced by the above-mentioned sources. "Walls" were prepared to be used for obstacle perception training. Although the third and fourth elements, "roads" and "landmarks," had no acoustic function, they were added so that an instructor designing the training environment could use them to create an image of streets as real as possible. Finally, I asked an instructor from the Department of Visual Impairment, National Rehabilitation Center for Persons with Disabilities, to create a common environment to be used for walking training, using the four above-mentioned components. As the prototype training system is equipped with an interface that allows users to freely edit a training environment, the instructor customized the environment using it.

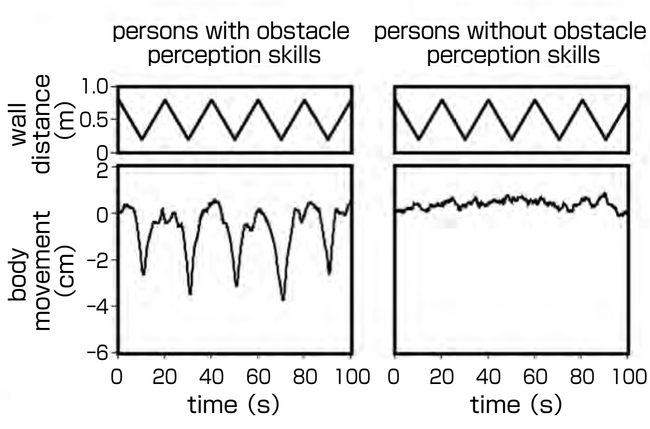


Fig. 3 An example of validation of obstacle perception training

The body movement of the trainee when he/she thinks he/she is approaching a virtual wall created by reflected sounds (left: person who has acquired obstacle perception orientation, right: person who has not). The upper figures show the movement of the wall. Persons who had acquired obstacle perception involuntarily moved to avoid the virtual wall when it approached them.

3.2 Effectiveness of the training system

In 2005, when the prototype training system was completed, an experiment to examine its effectiveness was conducted in the National Rehabilitation Center for Persons with Disabilities.[10]

To simulate visually impaired people with no or little experience of rehabilitation, the researcher recruited 30 sighted people without knowledge of auditory spatial orientation, rather than those with visual impairment, and asked them to wear eye masks and participate in the experiment. The subjects were divided into three groups, each consisting of ten people. The first group underwent no training, and the second group underwent training conducted using the present system. The third group underwent conventional training. Forty-minute training sessions were conducted by a skilled walking trainer for five days. Assessment items as the effects of the training were reduction of the following: (a) veering[Term 2] while walking (unable to walk in a straight line), and (b) stress while walking (psychological burden experienced by being unable to see while walking). Two objective assessment tests from the viewpoints of the subjects were also conducted: (c) skill assessment[Term 3] (consisting of 50 self-assessment items on walking skills) and (d) assessment on anxiety[Term 3] (consisting of 50 self-assessment items on anxiety while walking). In Assessment (a), the trajectory recorded by GPS and the walking routes were compared to calculate the maximum and mean differences. In Assessment (b), the stress pulse ratio (SPR), rate of increase in the heart rate, was calculated. In Assessments (c) and (d), surveys on walking skills and anxiety while walking were conducted using questionnaires consisting of 50 items each developed by the National Rehabilitation Center for Persons with Disabilities.

Regarding (b), (c), and (d), there were no significant differences in the effects of training between Group II (prototype training system) and Group III (actual environment), although the effects for the two groups were significantly higher compared to Group I (no training) (Fig. 4 (b), (c), and (d)). This suggests that the effects of training conducted in safe virtual training environments were comparable to those of training implemented in the real environment associated with risks. Regarding (a), the effects of training conducted under the present training system were significantly higher, compared to the other two groups. This suggests that walking training using sound as clues conducted in the virtual environment was more effective than training in the actual environment (Fig. 4 (a)). These results support the effectiveness of the training system developed by the researcher.

The training system was patented in 2010 in Japan.[11]

3.3 Obstacles to the practical use of the training system (problems)

The efficacy of the developed prototype training system has been established in the preceding paragraphs. However, some challenges remained to be overcome “to introduce the system to rehabilitation settings for visually impaired people,” the final part of the scenario.

The first obstacle was the cost of the system. The price of the effector equipped with dedicated DSP integrated circuits to simulate a 3-D acoustic environment was approximately 300,000 yen at that time, and the prototype training system used ten effectors for ten sound sources; the cost of these components alone amounted to approximately three million yen. The magnetic sensors used to identify the position and direction of the head were over one million yen, and the total cost of the system, including equipment to record the original sound and controlling computers, was approximately five million yen. Different from medical settings, “sections involved in welfare services,” including rehabilitation for visually impaired people, cannot afford to purchase expensive systems. Efforts to reduce the cost of the system were essential to introduce it to welfare settings.

Furthermore, the body of the system was too large to be carried. Some visually impaired people attend training facilities to undergo rehabilitation, while others receive “home-visit-based training” or rehabilitation at home with trainers. As the system, being too heavy to be carried, could not be used for home-visit-based training, it was necessary to develop a downsized system.

As explained in the preceding paragraphs, the magnetic

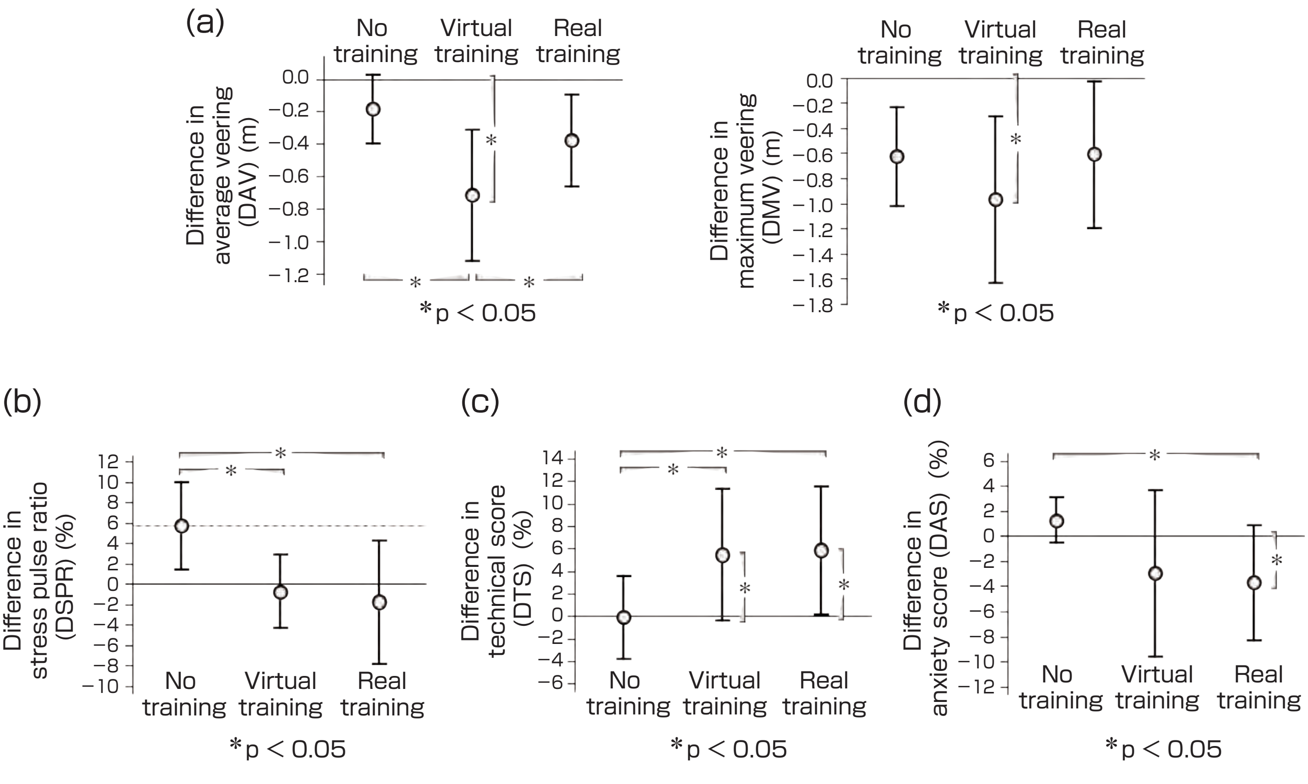


Fig. 4 Results of an experiment to assess the training system (Seki *et al*., 2011[10])

(a) Changes in veering while walking as a result of training (left: mean value, right: maximum value). The smaller the value on the vertical axis, the higher the veering-reducing effect of training.
(b) Changes in stress while walking as a result of training. The smaller the value on the vertical axis, the higher the stress-reducing effect of training.
(c) Changes in skills as a result of training. The larger the value on the vertical axis, the greater the effect of training to improve skills.
(d) Changes in anxiety as a result of training. The smaller the value on the vertical axis, the greater the anxiety-reducing effect of training.

positional/directional sensor used in the prototype training system only reacts to an object placed within approximately one meter of it, trainees were asked to march in place without moving forward. Therefore, trainees in this experiment did not feel that they accelerated, a feeling they would have experienced while actually walking. It was necessary to expand the area covered by the sensor so that trainees could actually walk and move forward.

New approaches were implemented to address the above-mentioned difficulties and to put the system into practical use.

3.4 Reexamination to put the training system into practical use

The development of a practical training system was initiated in 2006, including reexaminations of some elements of the scenario. Research and development were conducted in collaboration with the Research Institute of Electrical Communication, Tohoku University, Tohoku Fukushi University, and other research institutions with the support of research grants from Tohoku University Research Institute of Electrical Communication (Collaborative Project Research) and the Okawa Foundation for Information and Telecommunications.

Regarding hardware/software employed in this type of system, dedicated DSP integrated circuits were mainly used in the early 2000s when I developed the prototype training system. However, due to the advancement of computer technology, even the central processing unit (CPU) of a general-purpose computer can now perform convolution integral calculations, or convolve the head-related transfer function (HRTF) on a real-time basis.[12] Since most rehabilitation facilities for visually impaired people had already adopted general-purpose PCs as a tool to ensure information accessibility, these institutions did not have to purchase new equipment if general-purpose PCs could be used for calculations. Moreover, the body of the system, which was too large and heavy to be carried, could be downsized using laptop PCs. For a practical training system, it was decided to introduce SiFASo (simulative environment for 3-D acoustic software) [13] for general-purpose PCs, developed by a research group of Tohoku University Research Institute of Electrical Communication. SiFASo has an excellent capability to reproduce sound, although the number of sound sources that can be produced depends on the processing speed of the CPU. Up to eight sounds can be reproduced using Pentium IV 2 GHz or other CPUs of a similar class, and the present mainstream CPUs of Core 2 Duo 2 GHz class are expected to produce an even larger number of sound sources. This means that the new system was expected to deliver the same level of performance as the prototype training system.

As a technology to identify the position and direction of the head, the introduction of commercially available, or mass-produced, GPS equipment and MEMS gyro acceleration sensors into the practical training system was decided to replace expensive and high-precision magnetic sensors that covered narrow areas. As these were low-priced costing thousands to tens of thousands of yen, they could reduce financial burdens. Furthermore, since there were no restrictions on the area covered by the sensor, trainees would not have to march in place, as they did with the prototype training system, and the new system would allow them to actually walk in the real environment. The new system helps conduct safe training and allows trainees to walk around a large area without buildings, such as the grounds of a school for the visually impaired, while feeling that they are accelerating the walking speed. However, commercially available, low-priced sensors, which cover wide areas, are usually inaccurate, often produce noise, and measurements using them include significant errors. Therefore, to adopt these sensors into the training system, it is necessary to introduce new technologies to improve their accuracy. Currently, methods for reducing noise-induced errors are being considered.[14] It has been suggested that a Kalman filter-based algorithm is effective for reducing noise-induced errors, and that low-priced sensors covering wide areas may be adopted into the system.

4 A simplified version of the training system

A practical training system was developed based on the above-mentioned reexamination results (Fig. 5).

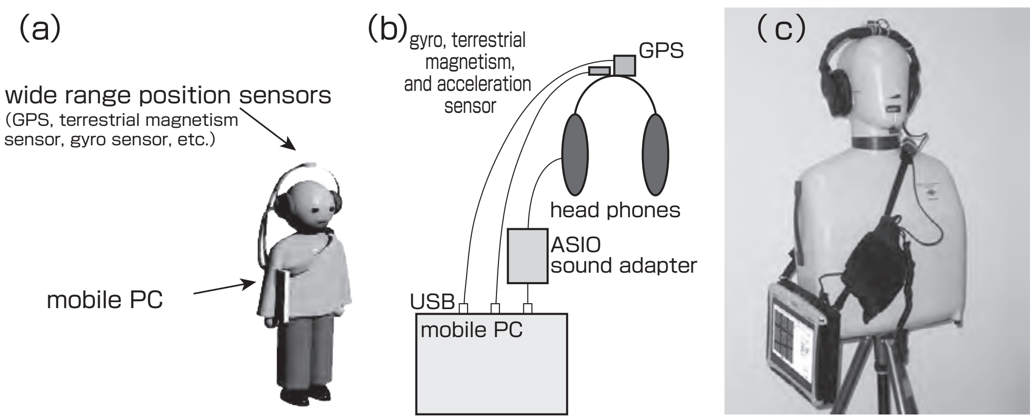


Fig. 5 Practical training system
(a) Structure of the system
(b) Diagram of components (blocks)
(c) A picture of a model with the equipment

The practical training system consists of a laptop PC, headphone set (and a sound adapter), and position/direction sensors. The small and light body of the system (the weight of the PC and headphone set together is approximately 3 kg) allows trainees to walk while carrying it.

The simplified version of the practical training system is currently available, although the accuracy of the sensors for identifying the position and direction of the head has not yet been improved. The simplified version, which has not adopted GPS equipment and gyro acceleration sensors, allows users (e.g. instructors) to operate the image of a trainee displayed on the PC screen while the trainee is moving around in the training environment (Fig. 6). Although the simplified version still has a drawback that trainees cannot walk around in a real environment, a problem also shared by the prototype training system, people involved in rehabilitation can afford to introduce the system because of its low price and small size. The table shows a comparison of the prototype and practical training systems and the simplified version. In September 2010, we started to distribute the simplified version of software free of charge (AIST Intellectual Property Management Number: H22PRO1182) to the visually impaired and relevant people in Japan and other countries to obtain feedback for improvement. The software system consists of the core 3-D acoustic technology and other software to determine the position and direction of the head, to generate data on the training environment and reproduce it, and to control the user interface for trainers. In 2010, the Department of Visual Impairment, National Rehabilitation Center for Persons with Disabilities introduced the software system to its instructor training course. The introduction of the training system to the instructor training course has increased efficiency in teaching, including simulating a variety of walking environments in the classroom.

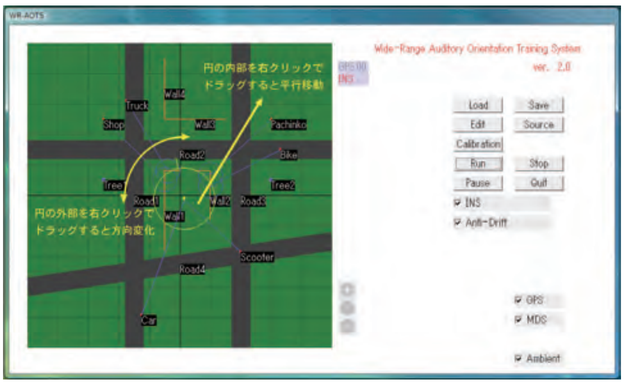


Fig. 6 User interface of the simplified version of the practical training system
Instead of a sensor to identify the position and direction of the head, the operator can use the mouse to move the image of a trainee around in the training environment.
- Right-click in the circle and drag the image in the direction you want it to move
- Right-click outside the circle and drag the image in the direction you want it to turn

Table. A comparison of the prototype and practical training systems and simplified version

	Prototype training system	Practical training system	Simplified version of the practical training system
Price (excluding that of the PC)	Five million yen	Tens of thousands of yen	Tens of thousands of yen
Size	Large (four times the size of the 0.6 m (H) x 0.6 m (W) x 0.6 m (D) rack)	Small (Laptop PC + headphones)	Small (Laptop PC + headphones)
Portability	Stationary-type	Portable	Portable
Determination of the position /direction of the head	High accuracy (direction: 1 degree, distance: 1 mm)	Low accuracy (direction: 10 degrees, distance: several dozen centimeters to a few meters)	Replaced by a mouse
	Narrow range (with an approximately one-meter radius)	Wide range (unlimited)	
	Expensive (one million yen or higher)	Inexpensive (a few thousand to tens of thousands of yen)	

5 Summary and future development

The present paper has described the development of a system for auditory spatial orientation training and research to put it into practical use.

To develop the training system, it was necessary to integrate the following elements of interdisciplinary studies in a structured manner: 1) mechanisms of auditory spatial orientation, 2) 3-D acoustic technology to reproduce the mechanisms, 3) hardware/software for computation regarding 3-D acoustic environments, 4) technology to determine the position/direction of the head, and 5) a training schedule. Therefore, research and development were conducted according to the following scenario: clarify the mechanism of auditory spatial orientation, develop a training method based on the mechanism (which simulates a safe, virtual training environment), seek ways to reduce costs, and introduce the method to rehabilitation and education settings for visually impaired people.

In the 1990s, I started a study to clarify the mechanisms of obstacle perception in humans. In 2003, I considered the introduction of 3-D acoustic technology, hardware and software to reproduce a 3-D acoustic environment, technology to determine the position and direction of the head of a trainee, and a training curriculum including training procedures, and a prototype training system was developed in 2005. Although the results of experiments supported the validity of the training system, some obstacles to its practical use still remained to be overcome. Following reexaminations of hardware/software to reproduce 3-D acoustic environments and technology to determine the position/direction of the head, the practical training system was completed. It is necessary to establish the validity of the system in practical settings as soon as possible. Since 2010, the simplified version of software has been distributed to the visually impaired and relevant people and used in courses to train instructors.

I plan to improve the technology to determine the position/direction of the head and publish a paper on the revised version. As the controller of a commercially available home video game device was considered to be best suited for the sensor to determine the position/direction of the head in terms of the balance between the cost and positioning performance, I am hoping to publish a paper on a revised version of the system adopting an algorithm to reduce errors in measurements obtained from the sensor. I am also planning activities to further promote the training system. I will distribute the training system software free of charge through the website of the National Institute of Advanced Industrial Science and Technology (AIST), and ask academic organizations involved with visual impairment to distribute it. I also plan to teach training methods using the newly developed training system to people on instructor training courses, and develop a system to assess the training results.

Acknowledgement

The present study was conducted with the support of the Department of Visual Impairment of the National Rehabilitation Center for Persons with Disabilities, Tohoku University Research Institute of Electrical Communication, Tohoku Fukushi University, and Mr. Takahiro Miura who completed the 2011 AIST Innovation School program. The study was partially supported by a Grant-in-Aid for Scientific Research, from the Ministry of Health, Labour and Welfare (2003 to 2005), the Tohoku University Research Institute of Electrical Communication Collaborative Project Research (2007 to 2012 (scheduled)), and the Okawa Foundation for Information and Telecommunications. I would like to express my appreciation to them.

Terminology

Term 1. Obstacle perception: An auditory ability to identify objects that do not produce sound, including walls and pillars, using clues such as reflected sound from objects, sound insulation, and their changes. An important environmental perception for the visually impaired.

Term 2. Veering: A visually impaired person's behavior of walking off a predetermined route

Term 3. Assessment of skills and anxiety while walking: Assessment using a questionnaire consisting of 50 items developed by the National Rehabilitation Center for Persons with Disabilities. Question items for assessment of skills include, “You can walk without veering much,” “You can walk while touching the side of a wall or building,” and “You can walk in parallel with automobiles running on the road.” Question items for assessment of anxiety include, “You worry about being hit by a car,” “You feel uneasy when walking in an unfamiliar place,” and “You worry about hitting a sign board.”

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Author

Yoshikazu SEKI

Complete the doctorate course at the Graduate School of Engineering, Hokkaido University in 1994. Doctor of Engineering. Entered the National Institute of Biosciences and Human-Technology of the Agency of Industrial Science and Technology in 1994. Principal researcher of Special Division for Human Life Technology, AIST, currently involved in clarification of the mechanisms of auditory spatial perception by the visually impaired and the development of technologies to implement training for them to learn spatial perception. Part-time instructor at the National Rehabilitation Center for Persons with Disabilities, Department of Visual Impairment, teaching trainers specializing in life training for the visually impaired based on the research results.

Discussions with Reviewers

1 Overall structure

Comment (Hideto Taya: Public Relations Department, AIST)

The present paper describes research on a training system for auditory spatial perception, developed and implemented using 3-D acoustic, signal processing, sensor, and other element technologies, and a training schedule, based on the author's knowledge of the mechanisms of auditory spatial perception, the subject of his long-term study. The paper is worthy of publishing in this journal.

Comment (Yasushi Kubo: Evaluation Department, AIST)

The present scientific study is excellent, and I think this paper complies with the objectives of *Synthesiology*.

2 Obstacle perception

Question (Hideto Taya)

Please describe problems that were solved in the development of methods for basic training in obstacle perception, and how the solutions have been utilized in the training system.

A description of the examination results of "obstacle perception" training for the visually impaired may be required.

Answer (Yoshikazu Seki)

Regarding "problems that were solved in the development of methods for basic training on obstacle perception," they are described in the paper as follows: "When these "clues" were simulated using acoustic technology, people who had developed obstacle perception skills felt as if specific objects were present." The description, "Fully-reflected sound was used (no decrease in the sound pressure level)" in the paper explains "how the solutions have been incorporated into the training system."

As the examination results of "obstacle perception" training for the visually impaired, records of visually impaired people's movements to avoid virtual walls (data shown in Fig. 3) created using 3-D auditory technology were added.

3 Experiment for validation

Question (Yasushi Kubo)

As the experiment for validation described in "3.2 Effectiveness of the training system" is very important to establish the effectiveness of the system, shouldn't actual data be included?

Since the effects are considered to vary depending on the number of training sessions implemented, it is necessary to state the number, isn't it?

Answer (Yoshikazu Seki)

Yes, it is. Experimental data, quoted from Reference 10, are in Figs. 4 (a) to (d). Information on the number of training sessions has also been added to the second paragraph of 3.2.

Additional question (Yasushi Kubo)

Figure 4 adds to the objectivity of assessment of the developed system. On the other hand, it may be difficult for non-specialists to understand the meaning of the labels on the vertical axis. Can supplemental descriptions be added to explain what an increase or decrease in the number indicates?

Answer (Yoshikazu Seki)

Captions to Figs. 4 (a) to (d) state the meanings of positive and negative numbers and an increase or decrease in the number.

Question (Hideto Taya)

The subjects of the experiment for validation were sighted people, instead of the visually impaired.

—Do you think that the validation experiment has limitations because the subjects were sighted people?

—Has a validation experiment involving the visually impaired been established?

Answer (Yoshikazu Seki)

I do not think that the validation experiment has limitations because the subjects were sighted people; in fact, I consider that the system has satisfied stricter criteria. If the system was designed for the visually impaired who had already learned daily life skills, the assessment using blindfolded sighted people as subjects would have been inadequate. However, as the system is used to conduct training for visually impaired "people who have not learned those skills," an assessment involving those with much experience of living as visually impaired people would have been rather inappropriate.

The effectiveness of the system when "the subjects are actual visually impaired people with little experience of rehabilitation" has not been established. This is because it is difficult to conduct an experiment involving people who have lost their sight recently to examine the validity of a system under development from an ethical point of view.

These are also explained in Reference 10.

4 Future challenges

Question (Hideto Taya)

I think there are technological development and promotional issues in promoting the system in the future. Please explain these two issues. What activity plan for promotion do you have?

Answer (Yoshikazu Seki)

As challenges in technological development, descriptions on the results of reexamination of the balance between cost reduction and positioning performance were added. As for promotion activities, the training system software will be distributed, free of charge, through the website of AIST, and I will also ask academic organizations related to visual impairment to distribute or help distribute it. I plan to teach training methods using the newly developed training system to people taking instructor training courses. I implemented the promotion of a CD called "Acoustic environment for obstacle perception training," a training material developed ten years earlier than this training system, and it was adopted by more than 300 facilities.

Separation of carbon nanotubes (CNTs) by the separation method for biomolecules

— Towards large-scale, low-cost separation of metallic and semiconducting CNTs —

Takeshi TANAKA* and Hiromichi KATAURA

[Translation from *Synthesiology*, Vol.6, No.2, p.75-83 (2013)]

There are two types of carbon nanotubes (CNTs): metallic and semiconducting. To exploit their superior electric properties, mixtures of these two types of CNTs should be separated. For industrial applications, a large-scale, low-cost separation method is required. We successfully developed novel separation methods for CNTs by applying separation methods for biomolecules. We first applied agarose gel electrophoresis, and finally achieved large-scale, low-cost separation by the column method. Using this method, we provided separated CNT samples. A separation method for single structure semiconducting CNTs was also developed by overloading CNTs into tandemly arranged multi-columns. The point of timing of patent application, publication of research results, and budget application to carry out this research effectively is also presented in this paper.

Keywords **:** Carbon nanotubes, metallic/semiconducting, separation, gel, biomolecules

1 Introduction

1.1 Background – Expectation and issues for the application of CNTs to electronics

Carbon nanotubes (CNTs) have structures where a sheet composed of hexagonal arrangement of carbon atoms is rolled into a cylindrical shape. They are extremely thin and long materials with diameter of several nanometers to tens of nanometer (nanometer is one-millionth of millimeter), and with length over micrometer (Fig. 1). In 1991, the “multi-wall CNTs” in which the CNTs are stacked coaxially in multiple layers were observed under the electron microscope[1] by Iijima of the Fundamental Research Laboratories, NEC Corporation (Iijima currently works as the director of Nanotube Research Center, AIST).

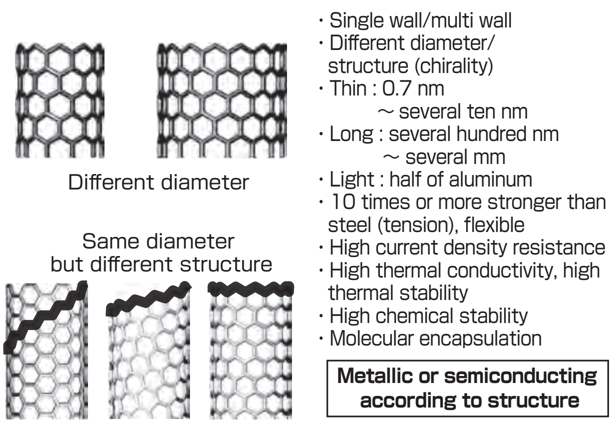

Fig. 1 Structure and characteristics of CNTs

Then, in 1993, “single-wall CNTs” were discovered.[2][3] In CNT research, the theoretical calculations were done actively due to their relatively simple molecular structure. From the calculations, it was predicted that, despite being a substance consisting solely of carbon atoms, CNTs would have extremely excellent properties such as lighter weight and lower density than aluminum, over 10 times the strength of steel, higher electroconductivity than copper, as well as diverse properties including high thermal conductivity, high thermal stability, and high chemical stability. Also, the theoretical calculation predicted that they would behave like metals or semiconductors due to their arrangement (structure) of the carbon atoms.[4] As mentioned above, since CNTs are nanomaterials with excellent potential, expectation is increasing for their new applications that cannot be achieved by other materials. Particularly looking at the electronics application, metallic CNTs, when made into thin film, do not require rare metal like the current transparent conductive film, and can be used as a transparent conductive film that can be bent due to their high mechanical strength. For semiconducting CNTs, high-speed transistor can be fabricated easily by coating, and a transparent and flexible film can be created in this case also. However, there are barriers in the electronic application of CNTs. That is, using the conventional CNT synthesis method, the selective synthesis of metallic CNTs or semiconducting CNTs is not possible, and the result obtained is a mixture of metallic and semiconducting products (normally, ratio of metallic:semiconducting is 1:2). Therefore, research for the separation of metallic and semiconducting CNTs is crucial.

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1.2 Objective – Supply of large-scale, low-cost separated CNTs

The metallic and semiconducting CNTs are both materials with uniform hydrophobic surface where the sheet consisting only of carbon atoms is rolled into a tube. Both are similar in appearance and are difficult to tell apart. As CNTs after synthesis form extremely strong bundles, and as they are difficult to separate into individual CNTs, this inhibited their separation research. After more than ten years since the prediction of the metallic and semiconducting CNTs by theoretical studies,[4] the research for the extraction and separation of the metallic and semiconducting CNTs started to be published.[5]-[10] For example, they included methods such as selective oxidation,[5] dielectrophoresis,[6] extraction using amines,[7] extraction using polymers,[8] DNA dispersion and chromatographic separation,[9] density gradient ultracentrifugation,[10] and others. These methods can be divided roughly as follows: (1) “selective destruction” where either the metallic or semiconducting CNTs are obtained by selectively destroying the other, (2) “selective extraction” where either the metallic or conducting CNTs are extracted selectively, and (3) “separation” where the metallic and semiconducting CNTs are separated and both CNTs are recovered. Among these methods, the density gradient ultracentrifugation published by Hersam *et al.* in 2006[10] was an innovative method where highly pure metallic and semiconducting CNTs could be obtained. However, there was some room for improvement such as the ultracentrifuge was extremely expensive and not suitable for mass processing, and it required a long time for separation (12 hours). Inexpensive separation of CNTs in large amounts is necessary for the industrial utilization of the metallic and semiconducting CNTs. Although it is possible to lower the cost by mass-production, it is first necessary to accomplish mass processing. While it is possible to conduct some researches with a small amount of samples, large amounts are needed in other cases. Therefore, we decided to conduct the CNT separation research with the objective of developing a method to supply large-scale, low-cost separated metallic and semiconducting CNTs.

2 Scenario for realizing the objective

2.1 Application of the biomolecular separation method to CNTs (fusion of different fields)

The aforementioned density gradient ultracentrifugation is a method used frequently in the field of life science to extract substances such as DNA. By processing the dispersed CNTs using DNA in column chromatography, relatively good results were obtained for separating the metallic and semiconducting CNTs.[9] For the separation of nanomaterial CNTs, good results were obtained by using the biomolecule-separation method or by using the biomolecules themselves. Tanaka, one of the authors, originally specialized in biochemistry and was knowledgeable in the separation and purification of biomolecules such as DNA and protein. When Tanaka joined AIST, he was assigned to a position to promote the fusion of different fields (biotechnology and nanotechnology), and was looking for a new research topic. He learned from Kataura, the other author, that CNTs were mixtures with various thickness, length, and electric properties, and that the separation was a major issue. Therefore, the two decided to conduct joint research on CNT separation. Kataura, who has a background in physics with a specialty in solid state spectroscopy and materials science, and Tanaka, who has a background in biology, started the collaborative research fusing different fields. When the fields differ, the terminologies and common knowledge differ greatly, and that often prevents smooth communication. However, totally different points of view may result in ideas never conceived before, and this becomes the driving force that propels the research toward a good direction. With the joint research by the researchers of different fields as the starting point, the research for the separation of metallic and semiconducting CNTs progressed from the agarose gel electrophoresis,[11] the separation using gel but no electric field (e.g. freeze-thaw-squeeze method, etc.),[12] the column method,[13] and further to the separation of single-structure semiconducting CNTs using the multicolumn method[14] (Fig. 2). These could be categorized as *Type 1 Basic Research*. The column method was suitable for low-cost, large-scale separation, and this was *Type 2 Basic Research* where massive amount of CNTs was actually separated. Currently, we are able to supply the samples of separated metallic and semiconducting CNTs. The details of the development of the separation method will be explained.

2.2 Discovery of the original separation method using gel (gel electrophoresis)

Before starting the research for CNT separation using gel, we tried to separate the CNTs using the molecular recognition ability of protein, a biomolecule. However, a long time was required before the result could be obtained in this method, and we experienced long periods without any good results. Then, the separation of metallic and semiconducting CNTs

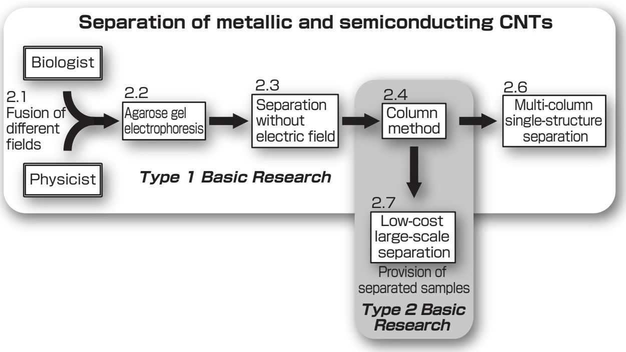

Fig. 2 Scenario for the development of large-scale, low-cost separation method for metallic and semiconducting CNTs

using the density gradient ultracentrifugation was published.[10] Thinking that if the metallic and semiconducting CNTs could be separated by slight density difference, then the separation could be also done easily by charge difference, we stopped the research for separation using protein and started the research for separation by gel electrophoresis. In biological experiments, agarose gel electrophoresis is used for DNA separation while acrylamide gel electrophoresis is used frequently for protein separation. Since the thickness and length of CNTs resembled DNA, we applied the agarose electrophoresis to CNT separation. The agarose gel electrophoresis is a simple and frequently used separation technique used in undergraduate lab courses. For DNA separation, the ordinary method used was the submarine gel electrophoresis (method where gel with thickness 5~10 mm is submerged in the electrophoresis buffer solution, and the 10~20 μl sample is injected in the small wells made in the gel). However, for CNT separation, we used the electrophoresis using the agarose gel inside a glass tube, and this was an uncommon method for DNA separation. This method allows over ten times more sample supply compared to the submarine gel electrophoresis, and even slight differences can be detected. By preparing the CNT dispersion using sodium dodecyl sulfate (SDS) that is a general surfactant used in toothpaste and shampoo, and then applying this to the agarose gel electrophoresis using a glass tube, we were able to separate the metallic and semiconducting CNTs (Fig. 3a).[11] The metallic and semiconducting CNTs were separated at the forefront and tail end of electrophoresis, respectively. This method can be done in about one hour using extremely inexpensive equipment. However, the yield was not high, and about 80 % of CNTs remained unseparated in the center.

The agarose electrophoresis was originally a method for separating DNA according to the length difference, and it was thought that the length-distribution of the CNTs worked negatively in the separation of metallic and semiconducting CNTs in the above gel electrophoresis method. To solve this problem, we applied the two-dimensional electrophoresis in which the electrophoresis was conducted by combining different separating conditions. The two-dimensional electrophoresis is a method used in the proteome analysis where the total proteins of cells or tissues are separated. By conducting the second run perpendicularly to the direction of the first run, it is possible to separate the proteins that could not be separated on the first run of gel electrophoresis. In the CNT separation, the first separation by length was done by agarose gel electrophoresis using sodium cholate as the dispersant, and the second electrophoresis (for separation of metallic and semiconducting) was done by replacing the surfactant to SDS in the gel. Then, a strange phenomenon occurred where the semiconducting CNTs did not move from the first gel and only the metallic CNTs moved and separated. The same phenomenon was confirmed when the "CNT-containing gel," where the CNT/SDS dispersion and melted agarose gel were mixed and gelated, was used from the beginning as the sample of electrophoresis, instead of replacing with SDS in the gel (Fig. 3b). Compared to the situation where the CNT dispersant was used as the sample, in the electrophoresis using the "CNT-containing gel," the yield improved dramatically to almost 100 %, the separation purity improved, the separation time was shortened to within 30 min, and this turned out to be an extremely efficient separation method. This was the first report in which the metallic and semiconducting CNTs were separated efficiently by gel electrophoresis.[11] The above separation is a specific phenomenon observed only in the combination of a specific gel and a surfactant, i.e. agarose and SDS. This combination is important in the separation method shown in subchapters 2.3 and 2.4.

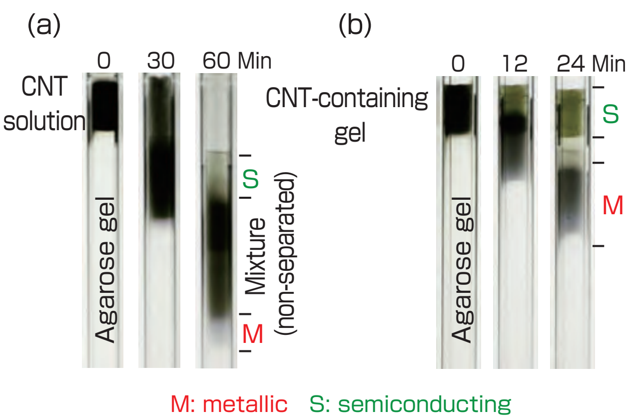

Fig. 3 Separation of the metallic and semiconducting CNTs by agarose gel electrophoresis (a: solution sample, b: gel sample)

The CNT mixture before separation is black in color, but the CNTs assume different colors upon separation because the metallic and semiconducting CNTs have different optical absorption wavelengths.

2.3 Improvement for simpler, larger-scale, and lower-cost separation method (separation without electric field)

In the electrophoresis using the CNT-containing gel, a strange phenomenon occurred where the semiconducting CNTs did not move at all and only the metallic CNTs moved. Since it involved the metallic and semiconducting CNTs that had different electric properties, it was thought that the electric field played an important role. Therefore, to investigate the necessity of the electric field, we conducted an experiment to see whether the separation occurred without an electric field. As a result, it was found that the electric field was not necessary. For example, the metallic CNTs eluted from the gel simply by immersing the CNT-containing gel in the SDS aqueous solution, and were separated from the semiconducting CNTs remaining in the gel. Also, it was possible to separate by directly centrifuging the CNT-containing gel and obtaining the solution containing the metallic CNTs. As a result of analyzing the transistor fabricated by the separated semiconducting CNTs, the separation was confirmed from the observation of electrical properties.[15]

Freeze-thaw-squeeze method is a method for recovering the DNA that was separated by agarose gel electrophoresis.[16] While this method is extremely simple, the recovery rate of DNA is not very high, and it has become obsolete in the biological experiments. However, from the viewpoint of the researchers of the physics field, the separation "just by squeezing with hands" was amazing beyond imagination, and the freeze-thaw-squeeze method was applied to the separation of metallic and semiconducting CNTs. When the CNT-containing gel after freezing and thawing was squeezed by hand, the solution containing the metallic CNTs was squeezed out of the gel, and could be separated easily from the gel residue containing the semiconducting CNTs (Fig. 4). This was an extremely simple separation method of metallic and semiconducting CNTs that could be done using a home refrigerator. The paper featuring the result of this "simple separation without electric field" was published in a major international journal.[12] This is a good example of fusion of different fields, where a method that is commonplace in a certain field is taken up from a different viewpoint in a different field.

When the CNT/SDS dispersion and agarose gel beads were mixed, the semiconducting CNTs were adsorbed selectively by the gel and could be separated from the metallic CNTs remaining in the solution (batch separation). While this is simple, it shows an important point in considering the separation principle: the selective adsorption of semiconducting CNTs to the gel. Initially, we selected the agarose gel due to the size similarity of CNTs and DNA, and we found there was not much significance in the size of the mesh structure of the agarose gel, but the most important point was the selective adsorption when the SDS was used. The separation of metallic and semiconducting CNTs was accomplished by the combination of agarose gel and SDS that was discovered by coincidence. In gel electrophoresis, the separation efficiency was greatly improved by using the CNT-containing gel as the sample, but the CNT-containing gel was not necessary for separation. We believe the separation was improved as a result of increased area where the agarose and CNTs could interact, as the agarose was already dissolved when the CNT-containing gel was prepared. In the batch separation using the CNT dispersion, when the surface area is increased by decreasing the size of gel beads, the separation time shortens, the binding capacity increases greatly, and the separation is improved greatly.

2.4 Column separation method

The final form of the separation of metallic and semiconducting CNTs using agarose gel is the column separation (Fig. 5). This stemmed from the thinking that if the batch separation where the aforementioned CNT dispersion and gel beads are mixed could be done, then a continuous separation using a column should be possible. The agarose gel beads used for the column separation were originally made for the purpose of separation of the biomolecule protein. Here again, Tanaka's biochemistry background became useful. When the CNT/SDS dispersion was poured in the column filled with agarose gel beads, the semiconducting CNTs were adsorbed on the gel while the metallic CNTs were recovered in the non-adsorbed fraction. The semiconducting CNTs adsorbed on the gel were recovered as a solution after washing with an elution solution containing different types of surfactants. The separation purity improved, the gel did not have to be removed from the semiconducting CNTs, and the gel could be used repeatedly. The chromatography technique is applicable to scale-up and automation, and it is an appropriate method for low-cost mass-production of the metallic and semiconducting CNTs.[13]

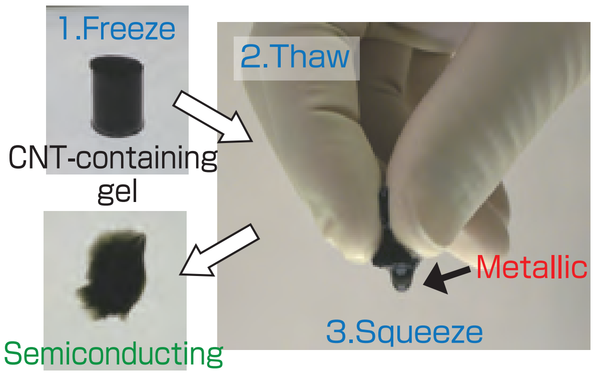

Fig. 4 Separation of the metallic and semiconducting CNTs by freeze-thaw-squeeze method using the CNT-containing gel

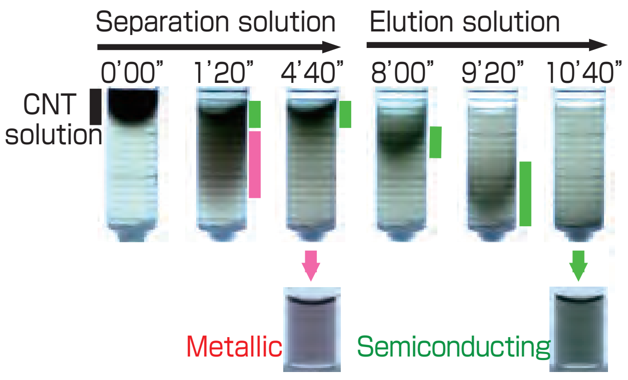

Fig. 5 Separation of the metallic and semiconducting CNTs by column using agarose gel beads

When the diameters of CNTs differ, the absorption wavelength range changes in metallic (or semiconducting) CNTs, and the colors become different from the colors of CNTs in Figs. 3 and 4.

2.5 Research promotion strategy (intellectual property, timing of publication, obtainment of research funds)

While we have discussed the research development, we shall discuss this research from a different angle or the ways of conducting research in terms of intellectual property, timing of publication, and obtainment of research funds (Fig. 6). Although, as researchers, we wanted to publish our discovery of this simple and efficient separation method of the metallic and semiconducting CNTs by gel electrophoresis, we could not publish immediately. Since the separation by gel electrophoresis was so simple and did not require expensive equipment, we feared that late-coming researchers might take the lead once this was published. Therefore, for some time after the discovery of the gel electrophoresis separation, we continued the research discreetly without publication. At the point we obtained full experimental data on the gel electrophoresis separation, we first applied for patent, and then confirmed that the separation without electric field was possible. To accelerate the research it was necessary to obtain research funds, but it was difficult for a researcher who only had experience in the biology field but no results in the CNT research to be granted funding. Although not shown in Fig. 6, I actually applied for grant immediately after the discovery of gel electrophoresis separation but failed to receive any grants. Although there was over half a year until the patent publication, we publicized the results widely through a press release at the same time we were presenting the result of gel electrophoresis in the academic society. The responses to the press release were positive, and it was covered by several newspapers including major papers, and we also were consulted by many companies. The timing of the press release was set to match the screening for external funds to which I applied earlier, and perhaps due to this strategy, relatively large funding was granted to me despite being a young researcher. The important point was that at that point, the key conditions of the experiment were not publicized in the press release, academic society presentation, or funding application. In the funding application at the beginning of 2008, the large-scale, low-cost column separation, which was the final form of the separation without electric field, was our research topic. In the summer and autumn of the same year, we received the poster award and gave our first presentation of this research topic at the academic society. As a result, we succeeded in signing a contract for joint research with funding, as well as obtained new external funding to clarify the separation principle. These further accelerated the speed of research. The first paper that described the details of gel electrophoresis[11] was published at the same time as the patent publication that was a year and half after the patent application. This series of development was done under extremely useful advice from Kataura who had abundant experience in intellectual property and press releases.

2.6 Separation of the single-structure semiconducting CNTs

We discussed the separation of metallic and semiconducting CNTs. However, strictly categorized, there are many structures among the semiconducting CNTs, and they are mixtures of different electrical properties called band gaps depending on the structure of the individual CNT. Completely uniform band gaps may be required in certain applications of CNTs using its semiconducting property, and

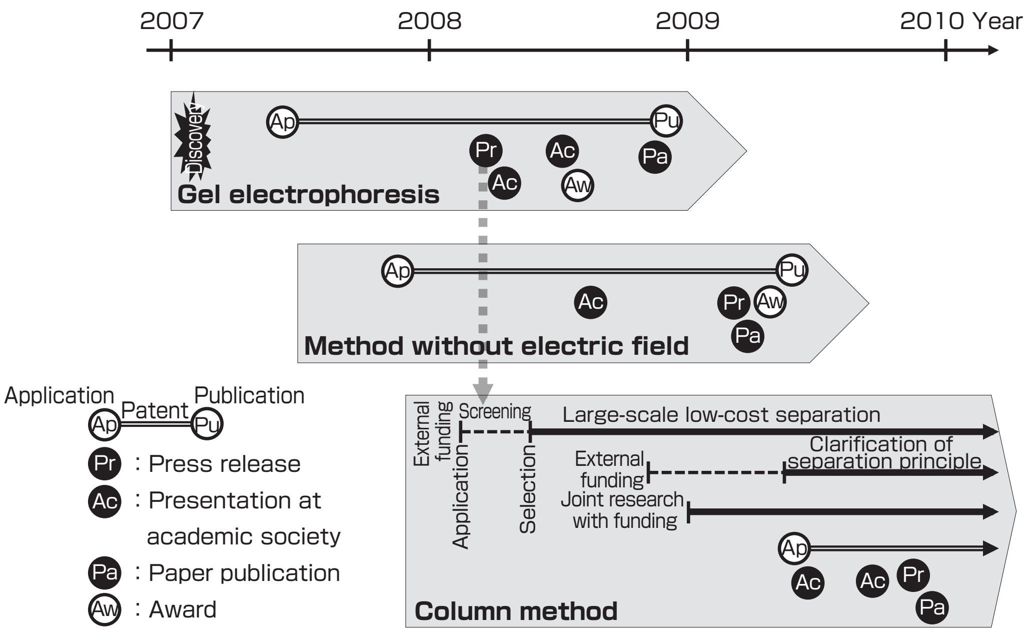

Fig. 6 Intellectual property strategy, timing of publication, and funding to effectively conduct the research, starting with the discovery of the separation of metallic and semiconducting CNTs using gel

the separation of single-structure semiconducting CNTs was an important topic. We were successful in roughly separating the different types of semiconducting CNTs by gradually changing the elution condition for the semiconducting CNTs in the column separation using agarose gel.[17][18] However, there was a limit to the separation precision, and a separation method with higher precision was in demand. Zheng *et al.* developed a method of separating the CNTs dispersed using DNA by chromatography, and succeeded in separating the single-structure semiconducting CNTs by using DNA with specific sequences.[19] This paper was extremely innovative because there had been no previous report of separating 12 types of highly pure single-structure CNTs. However, the method required expensive synthesized DNA, the efficiency was not good since only one type of CNT could be extracted from the CNT mixture, and there was room for improvement. Then, we found that the single-structure CNT could be separated by column separation using the commercially available gel called Sephacryl, a polysaccharide like agarose (this gel was originally developed for biomolecule separation).[14] When we were investigating the amount of CNT dispersant that should be used for the gel, we added a large amount of the sample to the column, and found that only certain types of CNTs adsorbed on the gel and were separated. Normally, to improve the purity in column separation, the amount of sample is reduced or the column is elongated, but in this case, a totally opposite way of thinking was employed, and we obtained highly pure CNT structural separation by adding excessive amount of the sample to a small amount of gel. When a large amount of CNT dispersant was added to the column, competitive adsorption occurred among different types of CNTs, and as a result, only a few CNTs with the strongest adsorption were adsorbed to the gel. Using multiple columns arranged in line, we were able to separate several semiconducting CNTs with different adsorbability at one time (Fig. 7). The important point is this method does not require expensive reagent, and several CNTs of different structures can be obtained from the CNT mixture. The column method is appropriate for the large-scale, low-cost separation. As shown in Fig. 7, we succeeded in separating 13 types of single-structure semiconducting CNTs with different bright colors.[14]

2.7 Scaling-up the separation of metallic and semiconducting CNTs

The researches up to now were the *Type 1 Basic Research* conducted to gain fundamental knowledge such as the discovery of a new phenomenon or the development of a new separation method. In the *Type 2 Basic Research*, the research focuses on the ways to scale-up and to lower the cost of separation to enable the large-scale, low-cost separation of metallic and semiconducting CNTs. It is one step before the *Product Realization Research*. Although the metallic and semiconducting CNTs separated by density gradient ultracentrifugation method were already commercially available, we aimed to boost the processing amount to 10 or 100 times using the gel column separation method. We succeeded in dramatically lowering the cost of separation by replacing the reagent with an inexpensive one and developing a new gel. We also scaled-up the separation by connecting the column that had several thousand times more capacity than the one shown in Fig. 5 to the large chromatography device. We also engaged in the research on the large-scale preparation of the CNT dispersant used for separation, concurrently with the separation scaling-up. The scaling-up and high throughput were obtained for separation with no problem, and the system to separate the metallic and semiconducting CNTs at a daily production of 1 g was established. The separated CNTs are now distributed as samples through the Technology Research Association for Single Wall Carbon Nanotubes (TASC), a consortium of companies and AIST. Hence, we were able to accomplish the initial goal of “sending the separated metallic and semiconducting CNTs into society.”

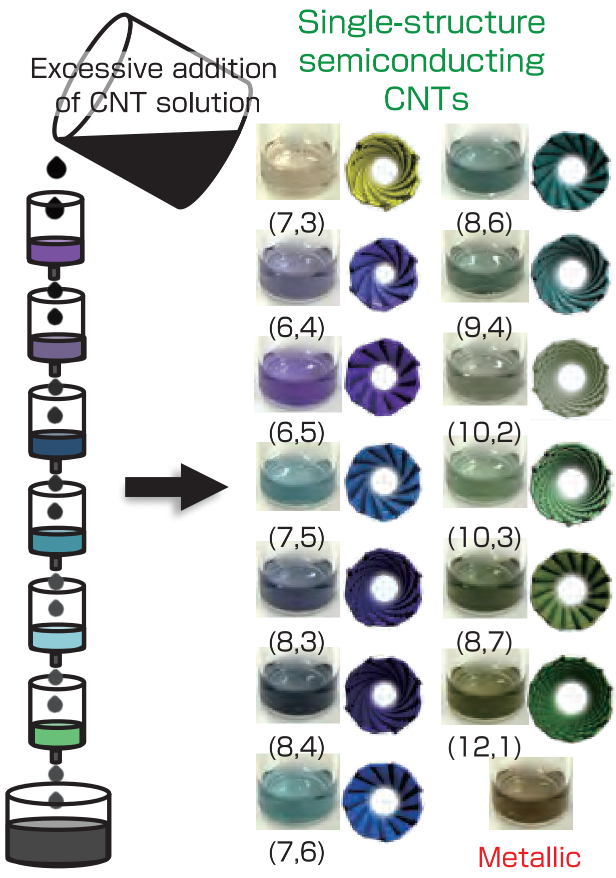

Fig. 7 Schematic diagram of the separation of single-structure semiconducting CNTs by multi-column method (left) and obtained dispersions (right)
The numbers (n, m) in the diagram are indices that represent the CNT structure. Brilliant colors are assumed when the separation is done to the single-structure semiconducting CNTs.

3 Future issues and prospects

3.1 Large-scale, long-length, and low-defect CNT dispersion method

In the column separation, the throughput of a daily production of 1 g has been realized, and currently, the daily production of 100 g is possible if the separation procedure is scaled-up. The issue is no longer “separation,” but the bottleneck of the throughput is the preparation of the “CNT dispersion.” There is also a major issue of loss of excellent properties of CNTs due to defects and breakages in the dispersion process. How to avoid defects in the CNTs, how not to cut them (to maintain length), and how to prepare the dispersion in large amounts are the major issues, and the researches are now being done to solve those issues.

3.2 Development of devices that maximize the property of CNTs

The initial objective “to send the separated CNTs into society” that we set at the beginning of the research was achieved in the form of sample distribution by TASC. We achieved the throughput of a daily production of 1 g, and the daily production of 10 g or 100 g is becoming possible. While we are able to contribute to both the basic and application researches of CNTs, separating large amounts of CNTs will not be useful unless there is a prospect of their use. It does not follow that once a new material is developed, some new application will be found instantly, and it is difficult to proceed to the next step unless we can show excellence of the property of our new material over the existing materials. Currently, we have set a new goal of developing a device that maximizes the excellent property of the separated CNTs, without stopping at “sending the separated CNTs into society.”

3.3 Clarification of the separation principle

The separation of metallic and semiconducting CNTs using gel occurs when the semiconducting CNTs are selectively adsorbed to the gel when SDS is used as the dispersant in the agarose or Sephacryl gel. Separation was not confirmed in starch or gellan gum gels that are polysaccharides as in agarose, other than acrylamide gels.[11][12] It is thought that selective adsorption occurs due to the fine balance of the interaction of the four factors including metallic CNTs, semiconducting CNTs, gel, and SDS, when combining the specific gel and the dispersant. Recently, it was indicated that surfactants that could be used for the separation, other than SDS, could be found by large-scale screening, and the surfactants with appropriate dispersion property could be found based on the common structure.[20] That is, surfactant with high dispersibility (such as cholate or deoxycholate) disperses both the CNTs regardless of metallic or semiconducting, and do not cause separation. On the other hand, surfactant with moderate dispersibility (does not have high dispersibility) recognizes the slight difference between the metallic and semiconducting CNTs, enhances selective adsorption of the semiconducting CNTs to the gel, and causes the separation. However, the essential principle of the exact differences that lead to the separation of metallic and semiconducting CNTs is unclear, and this is a subject for future study.

3.4 Safety

Nanomaterials have been newly synthesized recently, and many have inadequate safety evaluation due to their short history. Today, there is a requirement for safety confirmation before starting to use a new material, and CNTs, which are representative nanomaterials, are no exception. Currently, many research institutions are gathering data on safety, but time is required for complete understanding. It is necessary to conduct the development of application and safety evaluation concurrently.

4 Summary

We succeeded in developing the low-cost and mass-producible separation method for metallic and semiconducting CNTs using agarose gel. We also developed a mass separation method for single-structure semiconducting CNTs using the Sephacryl gel. The mass separation of metallic and semiconducting CNTs was started and the samples are being supplied. The separation method was originally devised by AIST, and was born from the results of joint research among researchers of different fields. In conducting research effectively, it is necessary to make integrated decisions for funding, intellectual property strategy, and timing of academic publication. Development of application is essential for the industrial application of CNTs. We hope to contribute to the industrial application of CNTs by accelerating the development of application by using large-scale, low-cost separated metallic and semiconducting CNTs.

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Part of the research described herein was conducted by the funds granted by: Grant for Industrial Technology Research, New Energy and Industrial Technology Development Organization (NEDO); Grant-in-Aid for Scientific Research, Japan Society for the Promotion of Science (JSPS); Core Research for Evolutionary Science and Technology, Japan Science and Technology Association (JST-CREST); and Grant for Developing Innovative CNT Composite Material to Realize a Low-Carbon Society, NEDO.

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Discussions with Reviewers

1 Thought process for the fusion of different fields

Question (Toshimi Shimizu: Nanotechnology, Materials and Manufacturing, AIST; Yasushi Mitsuishi: AIST Tsukuba)

When the researchers of totally different fields engage in trial experiments that are considered lacking in common sense (though often unperceived) in their community, they may run into serendipitous innovative findings. I think the greatest factor that led to the success of this research is the thought process that transpired in the fusion of different fields, where the separation and purification methods of biomolecules such as DNA that are used regularly in biochemistry were applied to carbon nanotubes (CNTs). Therefore, for the scenario of this paper, I would like you to organize and describe thoroughly the thought processes of how you evaluated the various elemental technologies to solve the problems and how they were selected and assembled.

Answer (Takeshi Tanaka)

The reason we selected electrophoresis was because we thought if the separation could be accomplished by density gradient centrifugation due to slight density differences, then the separation must also be possible by charge differences. Because the sizes of DNA and CNTs are similar, we selected the agarose electrophoresis used frequently in DNA separation. However, we found that rather than the size of gel mesh, the combination of the randomly selected agarose and SDS was important for separation. This means that the course was different from what we were thinking in the beginning, but we were able to obtain excellent results. As you indicated, I attempted to describe in detail the thought process and how the research policy was built around it.

2 Elemental technology

Question (Toshimi Shimizu)

In relation to the integration of elemental technologies, I don't think the progression from agarose electrophoresis → column method → multicolumn method is particularly an upgrade in life science research. However, when you used CNTs as the samples, I imagine that you ran into unique difficulties that you did not encounter in DNA. If you have any specific examples, please describe them. In some cases, it may become new elemental technologies. As a result, you will be able to appeal to the readers that it is not simply a biochemistry research method added to the elemental technology integration in the latter half.

Answer (Takeshi Tanaka)

The breakthroughs in the separation research for metallic and semiconducting CNTs using gel include the discovery of the combination of agarose gel and SDS, the improvement of yield by using the CNT-containing gel, the discovery of structure separation by excessive addition of sample, and others.

3 Side development of the gel material

Question (Toshimi Shimizu)

In the biomolecule separation, other than agarose gels, the polyacrylamide gel is widely used. In optimizing the gel material, were you engaged in any side development of the gel material?

Answer (Takeshi Tanaka)

The characteristic of the agarose gel is that the mesh structure is extremely large. This large mesh structure allows the separation of DNA, which is a giant biomolecule, by gel electrophoresis. Because CNT is similar to DNA in thickness and length, we used the agarose gel for CNT separation. On the other hand, the mesh of the acrylamide gel used frequently in protein separation is relatively small, and something extremely big like CNT is not likely to pass through the gel mesh. In fact, we conducted electrophoresis using the acrylamide gel, but failed to obtain separation. However, although we focused on the size of the agarose gel mesh at first, we found that the mesh size was not the essence of the separation, but rather, what was important was the specific interaction between the semiconducting CNTs and the gel when the combination of a certain gel and a dispersant was used. In fact, in column separation, the CNTs are separated by adsorbing on to the gel beads surface, even if we used the gel beads with high agarose concentration and therefore have dense mesh structure. However, in such a high concentration gel, adsorption to the gel decreases since the adsorption area is limited to the surface.

4 Separation mechanism

Question (Toshimi Shimizu)

When an unexpected result with good reproducibility is obtained, there must be some scientific basis. I think the value of this paper will be enhanced if you add the scientific explanation for the mechanism of separation.

Answer (Takeshi Tanaka)

Detailed explanations were added to subchapters 2.3 and 3.3 for the separation mechanism. As a phenomenon, we know that a selective adsorption of the gel and semiconducting CNTs occurs in the combination of a certain gel and a dispersant; however, the basic principle that causes the separation is not clear. This is an important research topic in the future.

5 Scaling-up

Question (Toshimi Shimizu)

The daily production of CNTs differs greatly depending on the types, from multiple to single wall. It is now on the order of several hundred grams to tons, but the order of kilograms or more will be necessary in the current separation and purification process. In that sense, is the scaling-up of over 1000 times the current state possible? Or, can the industrial demand be satisfied with the one-gram order of purified metallic or semiconducting carbon nanotubes? Please describe the social and industrial demands of scaling-up.

Answer (Takeshi Tanaka)

As described in subchapter 3.1, there is no scale-up limit for column separation itself, and I think the separation of 1,000 times more than the current state is possible. The bottleneck of throughput is the preparation of the dispersant, and we are engaging in research to improve this. However, as described in subchapter 3.2, without the development of application there will be no use, even if it can be separated in large volumes. Since the volume demand changes according to how the CNTs are used, it is still unclear how much throughput is necessary. Yet I feel that the abundant supply of large-scale, low-cost separated metallic and semiconducting CNTs will accelerate the development of applications. I added the relevant description in chapter 4 "Summary."

Construction of the Ceramic Color Database

— Database of more than 300,000 glaze test pieces and its application to industrial research —

Toyohiko SUGIYAMA

[Translation from *Synthesiology*, Vol.6, No.2, p.84-92 (2013)]

AIST has more than 300,000 glaze test pieces, from over 80 years of ceramic studies by the Imperial Ceramic Experimental Institute and the Government Industrial Research Institute of Nagoya. These pieces are the physical evidence of the processes and the results of glaze test experiments. As such, they provide valuable information for glaze and ceramic research. The Ceramic Color Database has been constructed to make this fundamentally important information widely accessible in support of R&D in the ceramics industry. The database includes: glaze name, firing temperature, firing atmosphere, coloring, chemical composition, recipe, physical state, and other information, as well as images of the glaze pieces. The database has been used in recent ceramics research, and its effectiveness has been verified.

Keywords **:** Glaze, ceramics, color, database, test piece

1 Introduction

There are over 300 thousand test pieces for ceramic glaze stored at AIST. They were created in the 80 plus years of ceramics research activities. While the research objectives and research phases may vary, the individual test pieces are basic data that represent the experimental results in a visible manner. By systemically organizing these test pieces, we constructed a database that was made available to the industry and the academia, so the pieces would be useful for new R&D.

As the database construction progressed and specific use started, we made improvements to accommodate specific usages. The glaze test pieces are actual samples of the experimental results, and are different from simple numerical data. It is necessary to predict the users and the users' activities to determine what kind of information should be extracted and organized from the test pieces. This is also related to the future direction of the research in this field, or what its direction should be.

Unlike a normal case of research that progresses from the results of basic research to practical application, the main usage expected for this database is that the researcher engaging in product realization research searches the basic data that match the research objective from the vast sea of information. The target of search may be direct, single information, group of information, collateral data, or information that provides a hint for the research. To respond to such usage, it is important to understand the values and characteristics of the original data, and systematically organize them accordingly. In this paper, the construction and the use of the Ceramic Color Database are described, and the new developments that may be possible from such database will be considered.

2 Construction of the database

2.1 Objective of the database

The glaze test pieces were accumulated in the research processes that started at the Imperial Ceramic Experimental Institute. The ICEI was established in Kyoto in 1919 for the purpose of conducting R&D "through the research of applied state-of-the-art basic science" with "close linkage with practical use." Various researches were conducted to lead the industry, with emphasis on prototype construction.[1] At the Government Industrial Research Institute of Nagoya that succeeded the ICEI, many new pigments were developed and advanced glaze researches were conducted, and the glaze test pieces were created in the course of such researches. Some of the researches are known worldwide, and the R&Ds were high level even according to the current standards. The test pieces are valuable source materials in terms of academic and scientific history, from the perspective that the research processes and the results are preserved in a visible manner. The test pieces are disclosed to the public and are used by the manufacturers and researchers of ceramics and glazes. With the attention given to the high value of the pieces, creation of the database was planned to further promote their use. The test pieces are considered directly useful to industry because of the following points:

(1) In the development and manufacture of the glaze, the

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work of fabricating the glaze test piece and improving the recipe is repeated. By using the information of the huge amount of existing glaze test pieces, the time required for testing may be shortened.

(2) They can be used for searching the glaze and glass materials to be used for certain ceramics or ceramic products under certain conditions.

(3) They provide technical information such as the relationship between the color and colored elements, glass composition, and firing condition.

Considering the universal applicability to items other than ceramics, the name "Ceramic Color Database" was used, and the systematic organization of the vast amount of material was started in 1997.

2.2 Design philosophy of the database

The primary objective of the database is to provide fundamental information to the manufacturers of ceramics and glaze. The ways in which the test pieces have been used are covered, and their use is promoted through added convenience. Figure 1 shows the scenario of the Ceramic Color Database construction.

The size of an average test piece is 30×45×5 mm. The pieces are affixed on mounting boards in groups of pieces per test, and the information such as the firing temperature and percentage of formulae are written on the board (Fig. 2). In many cases, the information is insufficient because preservation was not considered when the test pieces were made. The written information is different for each test piece. For the purpose of the database, it is desirable to include all information for all test pieces. However, from the aspect of workload and efficiency, the number of items entered and data were narrowed down. There are over 300 thousand test pieces and about 10,000 mounting boards. The database design was started assuming about five test pieces would be selected and entered per board. We thought the information of the entire group of test pieces could be utilized based on this data entry.

The structure of the data item was based on general, important information for glazes, and the content and search functions were designed assuming use by the researchers and engineers of ceramics. To understand the usage status, the logs for search and other activities were kept. The database also had images. The details of the data item structure and search functions will be discussed in the next chapter. The following two points were considered in organizing the large amount of test pieces that contain various kinds of information, and these two points are the foundation of the concept of the entire database design.

The original data that are the subjects of the database consist of the test result samples in the form of glaze test pieces, and a variety of information can be extracted from them. It is necessary to determine which information should be extracted in what format, considering the characteristic of the original data and the future usage. In designing the data items and the database structure, we tried to set up a guideline by considering the present situation of ceramics and glaze and the future direction of their R&D. For example, in glaze recipe, importance was placed on the type of raw materials. Due to the characteristics of natural raw materials, even if the chemical composition of the main ingredient is the same, the result may vary due to the trace elements and mineral composition (such as type and degree of crystallization) of the raw material. Considering the current practical use in industry, organization based on the name of the raw material seemed to be beneficial. However, the chemical composition was emphasized for this database, and the items for element

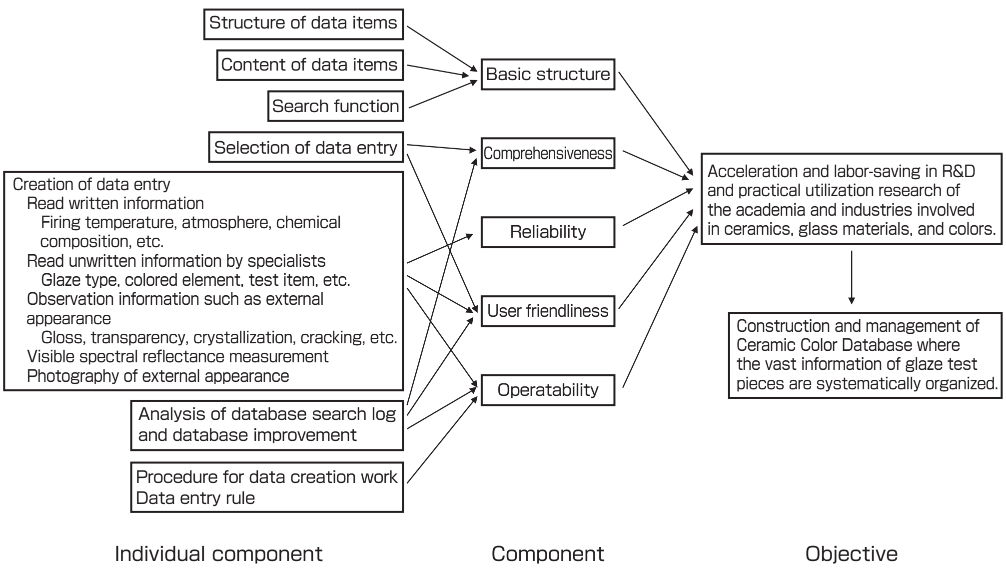

Fig. 1 Scenario for Ceramic Color Database construction

content were fortified. This was done because the natural resources change according to age and their stable supply is not guaranteed in the future. Also, there are possibilities that the database may be used widely by different fields in the future.

Another important perspective was the value of test piece information. In glaze firing, there are many factors for the test condition because the reaction may be stopped in the non-equilibrium state during the melting process. For example, the starting material may be affected not only by chemical composition but also by the mineral composition, grain size, mixing state, and other factors. Firing is also affected by the uneven temperature and the cooling process. This is one reason that a glaze that cannot be reproduced easily exists as a work of art. Normally, in a glaze test, comparisons are made by selecting target factors rather than trying to control all the factors. On the other hand, many of the stored glaze test pieces may not have written description of the main text data. Therefore, the information may be insufficient or there may be problems in reproducibility if the test pieces are seen individually. In contrast, the information that can be obtained from the series of test pieces affixed on one or several mounting boards can be highly useful because they present the information of a test result conducted with an objective. However, it is necessary to set the unit of data to individual test pieces when searching the database. Therefore, the database was designed by setting the individual test pieces as the basic data unit, but access to the information of the group of test pieces was allowed.

At the same time the database construction started, it was decided this database would be publicized on the Internet (as research information open database RIO-DB). Therefore two databases were constructed, one to be constructed within the research institute and the other to be publicized on the Internet. The characteristics of the two databases are shown in Table 1. The open database on the Internet assumed a variety of users. We emphasized ease of operation for people who did not have expertise in glaze or those not used to working with computers. Therefore, the open database was designed so the search result could be obtained in a short time, by selecting only the typical test pieces from the original database. Due to the communication speed and memory capacity of the Internet at the time, the data items were simplified for easy navigation. Unlike the original database set in proximity to the test pieces, the original test piece cannot be seen on the open database. Therefore, in the open database, we worked on the method of searching the test pieces related to the search-target test piece using the catalog number.

Table 1. Original database and open database

	Original database	Open database
Subject to be entered	All test pieces	Typical test pieces
Entry data	Detailed	Simple
Operator, user	User + Personnel	General user
Environment in which DB is provided	Specific place	On Internet
Objective of use	Specialty	Universality
Characteristic	Based on test pieces	Independent from test pieces
Goal of number of entries	50,000 entries	10,000 entries
Completed number of entries (*)	About 33,000 entries	3,826 entries

(*) As of November 2012, the original database includes the data that are in the process of being entered.

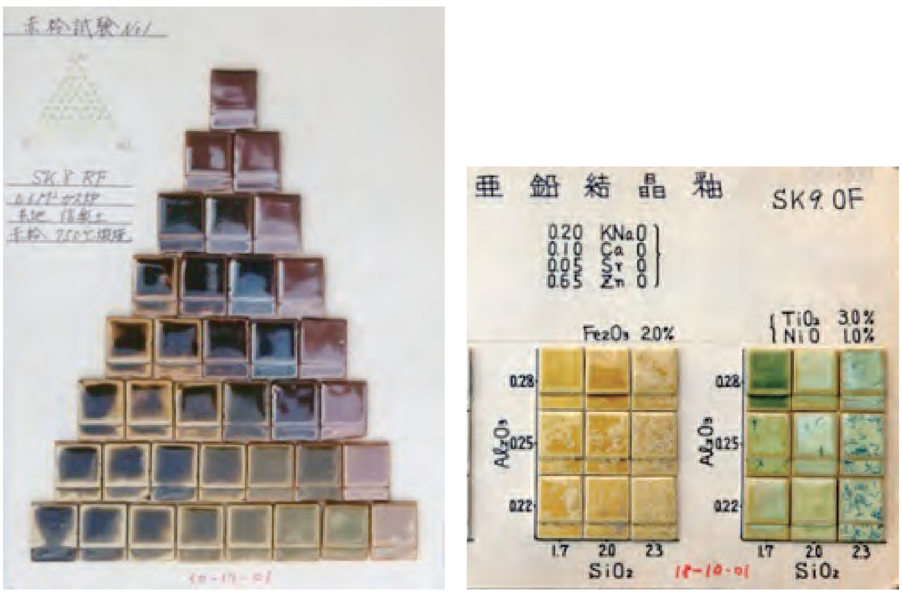

Fig. 2 Examples of glaze test pieces

2.3 Design of the database items and data entry

2.3.1 Overall composition of the data items

The following data items are set for the database. Items marked with "*1" have a format where the selection is made from the candidate list and the data are stored by code numbers. "*2" is numerical data and "*3" is text data.

(1) Information written on the mounting board: recipe*3, chemical composition*2, firing temperature*2, firing condition*1, body*1, manufacture date*2, manufacturer*3, experimental objective*3
(2) Information obtained from the test pieces by specialists: glossiness*1, transparency*1, color*2, physical appearance*3, glaze type (glaze name)*1, surface condition*1, crystallization*3, cracking*3, colored element*1, constituent element*3, body type*1, characteristic*3
(3) Information obtained by instrumental measurements: (visible spectral reflectance), color number according to color system*2, image of external appearance

Figure 3 shows an example of the screen of the original database. Since the written information left with the glaze test pieces did not have uniform format or content, we set several data items in comment format to allow entry of a variety of information to the database. The open database on the Internet has similar basic structure for the data items.

2.3.2 Data items to obtain the written information

Various kinds of information are written on the mounting board for each test piece. Of such information, the recipe (chemical composition or raw material mixture) of the glaze and firing temperature are written for almost all test pieces. However, organization was necessary since the descriptions were not uniform even for such basic information.

The Seger formula is used for the chemical composition of the main ingredient of the glaze. Seger formula is a compositional equation that uses molar ratio, and the physical properties such as the melting point or coefficient of thermal expansion can be approximated from the coefficients. This makes possible the search, for example, of "content of sodium oxide 20 mol% or less." We thought such advantages were necessary for the future glaze research and development.

The additive elements such as the colorant and opacifier can be selected from the period table of elements. We also set the item to list all the elements contained in the glaze. The chemical equation data will be absent for the test pieces where the glaze recipe was described by raw material mixture, but in such cases, the elements are entered by the decision of the entry personnel. This enables search based on the presence or absence of an element.

Although the material mix, or the so-called "glaze recipe," is an important data, we employed the method of entering the text data as comments without digitization, because there are so many materials and because the chemical and mineral compositions differ by period even for materials with the same names. While this method allows entry of various material types, it is inferior to the search function organized by material and recipe percentage, and this is our future issue.

For firing condition, the figure for maximum firing temperature is entered, and selection can be made for oxidation or reduction of firing atmosphere. Depending on the glaze test piece, the firing conditions such as the maximum temperature retention time, temperature increase, and cooling schedule may be written. For some glazes, the results may be determined by the maximum temperature

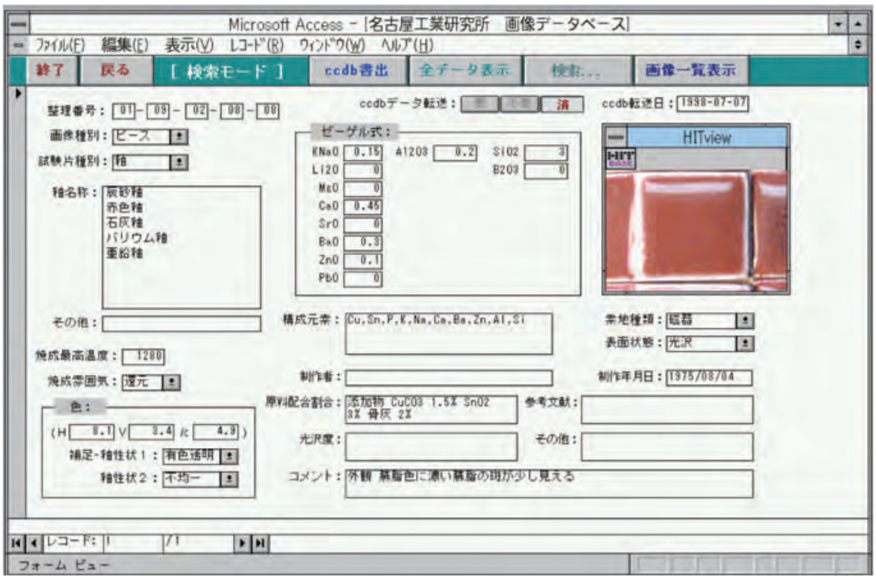

Fig. 3 Example of database screen

only, while for others, the cooling conditions such as the crystal precipitation are important. However, in many cases such conditions were missed and were not written. To fill in the gap, we set the data item for the kiln. This is because the approximate temperature increase and cooling rate can be estimated from the type and capacity of the kiln. There are many test pieces where the firing temperature was expressed as heatwork in terms of Seger cone. While the heatwork value evaluates the overall thermal history, not just the maximum temperature, there is no record of details such as the measurement status. Therefore, we considered the accuracy and use the simple temperature-converted value as data.

2.3.3 Data items from instrumental measurement and information obtained by specialists from the test pieces

The name of the glaze is the most basic information. Traditional names such as *kizeto* and *oribe*, names based on ingredients such as lime glaze, and names according to external appearance such as orange peel, cracking, and milky white were categorized and listed. For traditional names, special names were excluded and candidates were selected so most of the glazes can be categorized. Since there were cases where one glaze had several names, up to six glaze names can be selected from the list of candidates. There is no clear rule about the categorization and identification of the glaze names, and several specialists discussed the matter as necessary to choose the generally recognized use. Also, the ranking of the six selected glaze names were determined by the person in charge of data entry and registered to the database.

For the glaze name, there is the problem of failed test pieces. For example, a test piece for testing the *kizeto* glaze may not be called *kizeto* due to failure. When searching for a typical *kizeto* glaze, it may be an inconvenience if such failure data shows up on search, but it may be useful as reference for R&D. In the database, the item for the experimental objective of the test piece was newly set up, to describe that a certain piece was an experimental result of the *kizeto* glaze. The glaze name is the item most frequently used in search. This is clear from the search log of the open database on the Internet. While the glaze name is basic, simple, and important, it is very complex and represents one characteristic of this database.

The color of the external appearance of the glaze is an important data. The color is expressed as the number according to the Munsell Color System, by measuring the hemispherical integrated spectral reflectance of 5~10 mm diameter circular area on the glaze test piece using an optical device (Hitachi C2000S and Minolta CM2002), and then by calculating the color under illuminant C from the spectral reflectance.[2] The reason Munsell system is used is because the enumeration of the three color values, hue, brightness, and saturation, is optimal for intuitive search by the user. One of the issues in the external color of the glaze was the unevenness of glaze color. In case of two-colored mottling, the spectral reflectance does not reflect the original color correctly since it is the average value of the measured surface area. However, the average value of the surface area may be meaningful in the cases of clear dot pattern, asymptotic color changes, or changes in very small surface areas. In the database, the data for the spectral measurement and color calculation for all test pieces are provided, and at the same time, a separate item is set for the evenness of external appearance. Another issue for color was transparency. In the case where the glaze is highly transparent, the external color is affected by the body beneath the glaze. For transparent glaze, the external color is meaningless. In case of translucent glaze, external color is meaningful but is affected by the body. Separate item is set for the transparency of the glaze. By combining these items, the information on color can be provided and searched. By using the three values expressed by the Munsell system, the search can be done by indicating the range of color. Also, search such as “glaze with high saturation regardless of hue” is possible. This is one advantage of the database.

In the comment section of the data item, the ceramics specialists enter the characteristics and observations of the test piece. When describing the characteristic of the glaze, observation by optical microscope is always done. In the database, although the image of external appearance is provided, the actual test piece cannot be seen. Similar impressions are made when the specialists such as the glaze researcher look at a certain test piece. We believe that the comments made by the specialist in charge of data entry provide an alternative to looking at the actual piece. Therefore, we consider the comments made when creating the data as something very important.

The external photograph of the test piece is shot by adjusting the lighting, focus, and brightness so the characteristic of the glaze will be maximized. Initially we considered obtaining the color information from the photographs. We thought the colors from various areas could be measured and the color distribution can be analyzed even for mottled patterns. However, when we obtained an image that correctly reproduced the color properties, the image was dark, the details of the pattern could not be discerned, and the characteristic of the glaze could not be discerned from the image. To show the impression of the glaze that we normally perceive when seen by the naked eye, multiple images with different exposures are needed. For the external images shown on the database, photographs are shot under conditions that maximize the perceived characteristics of the colors and patterns of the test pieces when seen by the ceramics specialist, and they are often different from the strict brightness and hue.

2.3.4 Data entry work

The data entry is done with consideration that there will be various types of glazes in the database. The test pieces are selected by giving priority to the ones that are generally considered good glazes to be used on ceramic products. However, when using the database for R&D, failed test pieces may be important, and considerations are made accordingly.

The series of task include reading the information of the data items, entry to computer, color measurement, and photography. If errors in entry or placement of wrong photographs occur, large amount of work is necessary to find and correct such errors as the amount of data increases. Therefore, we established the work procedure through much trial-and-error, and multiple personnel check and recheck the data during each work phase.

Technical terms, acronyms, and proper nouns are included in the written information, and advanced expert knowledge may be necessary to read them. Also, decisions and corrections must be made when there are errors in the original written information. From this perspective, double checks by multiple people are done.

In conducting data entry, there are many cases where review and assessment are necessary. For example, the “reduction firing” in porcelain manufacture generally requires that the reduction state is maintained from the point the firing temperature reaches 800-900 °C to cooling. Some test pieces were treated in special atmosphere for experiment. For the data entry for firing atmosphere in such special cases, “oxidation” or “reduction” can be selected, considering the use by ceramics researcher. To make decisions about such minor but specific problems that arise as we proceed, we weighed the significance and value of the database.

The goal of entries of the original database is 50,000 entries, and the open database on the Internet aims for 10,000 entries (Table 1). The data entry for the original database was started in 1997, and the recent number of entries is about 2,000 per year. The completed number of entries is about 33,000 as of November 2012, although there are some data that are in the process of entry. The number of entries in the open database is 3,826 as of November 2012.

3 Usage and product of the database

3.1 Usage on the Internet

The test piece search became easy by this database construction. Since it is available on the Internet, it is used by the general public. One of the methods for knowing the usage status is the number of accesses and the search log installed in the database. The number of access is average 6,000 per month, and may reach 10,000 per month. However, specific status of use cannot be fully understood through the Internet. The opportunity to know the usage is when we directly or by mail receive response, comments, and inquiries from the users.

We received comments from the researchers of the research institutes and corporations that the database has been used frequently and is highly useful when starting a glaze R&D. This is the case when a specific glaze must be realized. In the development by the glaze manufacturing company, the glaze test piece is made and the recipes are improved. At least one day or normally several days are needed for firing and cooling. Much time and labor are necessary since the recipe improvement is repeated upon observing the firing effect. If the large amount of existing glaze test pieces can be used, the time needed for experiment can be shortened. Several months may be necessary to seek a recipe particularly in products that demand both the physical property and strict color matching, and the usefulness of the database is high.

Another assumed usage is the search of a glaze without specific search conditions. Loose conditions such as “bright and brilliant color” or “baked at 1250 °C” may be set, and such search is made possible by this database. In such usage, many users have actually visited the institute to directly view the test pieces.

The usage and the responses of users are fed back to the database for improvement. There was a demand for simplifying the color search. Since color is important information in glaze search, we responded to the demand by adding simplified color search based on color names in the item of glaze names for users who are not used to the search by numerical classification of color.

3.2 Usage in technical consultations

The technical consultation is an opportunity to learn about the usage of the database. There are a number of consultations indicating the color and property of a desired glaze and wanting to know the recipe and the manufacture method. As a specific example, there was a consultation by a company that wished to create a glaze that was exactly the same as the sample. The company researcher said that they repeated tests over several months but could not make the same glaze. Using the database, about half a day was spent to search for a similar test piece, a test piece with completely the same property was found, and the information for its recipe and firing condition were obtained. In another consultation, there was a request for a glass material with a composition that devitrified without containing a certain element. The target manufacturing condition was found from the database. In this case also, the issue that could not be solved by other methods was solved by the database.

3.3 Usage in joint research and R&Ds

The usefulness of the database was clearly recognized in new R&D. In the research for reducing the use of boron and other hazardous elements in the mid-fire glaze used in roof tiles and semiporcelain, the issue was the development of a glaze that melted at 1150 °C or less with reduced content of such elements. The database search was conducted along with the work of finding the optimal glaze by testing various glaze compositions. The search conditions were the firing temperature of 1150 °C or less and a glossy glaze, instead of the melting status. The search result of the database and the result of the experiment showed almost the same range of composition.

In the development for a glaze suitable for recycled porcelain, the glaze candidates were searched from the firing temperature, the glaze name, and the chemical composition. Various types of glazes with optimal thermal expansion coefficient were developed including the crystalline glaze that could be used at low firing temperature for recycled porcelain. This contributed to the practical use of recycled porcelain.

The database was used in fields other than ceramics. Use was considered in the fields of printing and armoring, and this led to joint research where the database was used in the basic research for color and external appearance. In research related to the solar reflectance of building material, the data for color and spectral reflectance were used. Applications that were not considered before became possible through the database construction and its publication.

3.4 Collaboration with other institutes

The possibility of collaboration with other databases was considered from the beginning of database construction. In the ceramics field, the physical property prediction system was studied to obtain the relationship among the chemical composition, thermal expansion rate, firing temperature, and others. In the field of ceramics design, the prototype fabrication system using CAD and 3D modeling is studied through the design development support on the computer. The joint use of the data with other institutes was considered by linking with the other systems. It was technically simple and partial test implementations were done, but there has been no further development due to the problems in publicizing the data.

On the other hand, progress was seen in the collaboration with overseas public institutes, and the other countries have built the glaze database with common data items and formats in accordance with our database. In the future, we expect the mutual utilizations of data and system collaborations.

4 Future issues and prospects

The number of users and usage frequency of the glaze test piece information increased dramatically through the publication on the Internet. Its usefulness increased with the added search function that used to be impossible. The possibilities for new developments and the issues are becoming clear. Three of them will be considered.

First, the effectiveness of the database in nonconventional ways or fields other than ceramics was recognized. In the future, developments are expected for use in various ceramics and glass materials as well as color research. From this perspective, the future issue is to further enhance the data items.

The candidates for new data items include the data for glossiness and spectral reflectivity. The measurement of glossiness of the test pieces in compliance with the JIS measurement method can be done relatively easily.[3] Also, visible spectral reflectivity is already measured in the color measurement, and this can be provided as numerical data. Other than this, information that can be obtained from the test pieces include surface roughness, crystallization, infrared reflectance, optical properties (such as refraction index), water repellency, cracking, phase state (mottling pattern), and others. Just as in the case where glossiness was used as the guideline of the molten state in the R&D, the matte state of the surface reflects the type and size of the precipitated crystals, and the cracking indicates the thermal expansion and hardness. The data can be utilized from those perspectives. Also, the selection of test pieces entered in the database and the creation of comments and data are being done based on the basic design concept. If the use other than for ceramics is considered, expansion and redesign of the standard will be an issue.

Second, the following development can be considered in using the test piece information. Although the database was designed focusing on the importance of the information that can be obtained from the test piece group, the basic design is based on the individual test pieces. The glaze test pieces were made for some kind of experimental purpose. For example, the experiments might have been done to study the molten state of the glaze by gradually and systematically changing the chemical composition, or to review the color by changing the type and percentage of the colored elements added to the basic glaze, or to observe the state of the glaze by changing the firing condition. The primary information of the test pieces is the results of such experimental objectives. While some accommodations were made to the data items so the experimental objective can be entered, the organization and utilization of the information that can be obtained from the test pieces are major, unachieved issues. We conducted partial survey correlating the test pieces and the research reports. This is useful in strengthening the information for individual test pieces. Only a few test pieces showed complete correspondence to the details of the experiments as shown in the research reports. However, if a specialist studies the information on the mounting boards, the outline of the experiments can be determined. The categorization and organization can be done based on the conditional factors that were emphasized in the experiment, such as the chemical composition, firing temperature, and additives. Then, the method for providing the information should be considered. Since these cannot be handled in the current database structure, it is necessary to construct a new sub-database. It is necessary to study the construction of a small-scale test database.

Third, the development utilizing the vast amount of data can be considered. The advanced search of the test pieces became possible through the database construction, but the voluminous data have the potential for a new kind of development. For example, the database mainly assumes looking up a single test piece that best matches the search condition. However, even if there are no data that completely matches, the information can be epidemiologically extracted from the large amount of data. In the R&D for a glaze that melts at low temperature while reducing the content of hazardous elements or in the development of a low-fire crystalline glaze for recycled porcelain, various glazes related to the conditions were searched and extracted, and the information of such glazes were used as reference of R&D. In the search of numerical data, wide range of search can be done by setting the upper and lower limits, but further fuzzy search conditions may be employed. Also, the function to extract common information and trends from the various data group obtained as search results can be considered. The ceramic industry is a world of craftsman, and glaze is a field that is characterized by craftsmanship. In the development of a new glaze, along with the external appearance such as color and gloss, various conflicting conditions such as thermal expansion and molten states must be satisfied simultaneously, and this depends largely on the experience and insight of a skilled craftsman. Recently, the decrease in the number of skilled people and the transfer of technology are the issues of the industry. This database was constructed in the hopes of replacing the “experience” of the craftsman through large amount of data, and we believe the objective has been achieved. We are not sure whether we can step into the “insight” of the craftsman by improving the database, but that is one of our future topics.

5 Summary

The Ceramic Color Database was constructed by organizing the data of glaze test pieces. The 300 thousand glaze test pieces were created in the course of more than 80 years of ceramics research. The usefulness of the database is affected by the research level of the original test pieces and the quality of the task of creating the database. The database construction has being continued for more than a decade. This database was created in a very good environment, and its usefulness was proven through the various usages by the industry and in new R&D. The use expanded as the open database was publicized on the Internet. It was also useful in the material development and basic research of fields other than ceramic glaze. The improvement of the database is based on such usage status, but we must return to the basic concept of the database for future development.

Acknowledgement

Although this paper was written by a single author, the construction of the Ceramic Color Database was done as an organization. The database construction was started under the cooperation of the Applied Technology with Ceramics Group and the Planning Office of the Government Industrial Research Institute of Nagoya. For the creation of the open database, we received support from the personnel of the International Standards Promotion Division and the Tsukuba Advanced Computing Center, AIST. The improvement of the database was done through the discussions with the part-time personnel who are in charge of data entry for more than a decade and are experts of the ceramics field.

The database construction became possible because over 300 thousand glaze test pieces were created, organized, and stored. I pay my respect to the seniors of our Institute who engaged in glaze research.

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[3] JIS Z8741 (in Japanese)

Author

Toyohiko SUGIYAMA

Completed the master's course at the Department of Earth Sciences, Graduate School of Science, Nagoya University in 1984. Joined the Government Industrial Research Institute of Nagoya (currently, AIST) in 1984. Engaged in the researches of far-infrared radiation ceramics, ceramics, and glaze. Currently, leader of the Applied Technology with Traditional Ceramics Research Group, Materials Research Institute for Sustainable Development, AIST. In this research, was in charge of the overall construction of the Ceramic Color Database, including its design and data entry. Executed the joint researches and technical consultations using this database.

Discussions with Reviewers

1 Overall structure of the paper

Question (Hiroshi Tateishi, AIST Tsukuba)

This paper describes the structure and usage of the Ceramic Color Database that was constructed based on the glaze test pieces left at the AIST Chubu, but I don't feel much impact. One of the greatest reasons is because the start up of the database is mentioned only lightly. When shifting from the physical entity called test pieces to the virtual resource called database, the initial design of what the content should be is extremely important. There must have been lots of arguments, but there is hardly any description of this process, and this shortage makes the paper just an ordinary technical report. To clearly state the "creation of social value" that is the hallmark of *Synthesiology*, I think you should consider the following structure of the paper.

Between subchapters 2.1 and 2.2, you should set a subchapter on "database design," and explain the scenario of Fig. 1. The points are as follows:

- How did the talk about creating a database start?
- What is the specific objective?
- To achieve the objective, what kind of structure should the database have?
- In what form should it be opened to the general public?

Question (Kazuo Igarashi, Institute of National Colleges of Technology)

Although each chapter is interesting, overall, it is difficult to see what this paper is trying to convey. I think the problem is the overall structure of the paper. In the issue of database construction explained in this paper, on what design philosophy the construction was done is important. However, the descriptions pertaining to this are dispersed throughout the chapters, and the most important part is placed at the middle and the end of chapter 4 "Future issues and prospects." For example, why not separate the background/objective and the conclusion, and bring the design philosophy to the top using the following chapter configuration? Please consider revising.

(1) Design philosophy of the database
(2) Scenario to realize the database
(3) Items and considerations needed for construction
(4) Utilization of the database
(5) Extracted issues and future development

Answer (Toyohiko Sugiyama)

I was wondering how to structure this paper as I wrote. Based on your comments, I created subchapter 2.2 on the database design, and described the scenario. Also, the explanation of the glaze test piece of subchapter 2.1 was allotted to the previous and the following subchapters.

2 Relationship between the detailed DB and open DB

Question (Hiroshi Tateishi)

In subchapter 2.2, you explain the content of the original database, but you go on to the explanation of the open DB after 2.3 without clearly giving the reason why you have the dual structure of the original DB and the open DB, so it is confusing. I think it will be easier to understand if you correlate to the items in Fig. 3 that you give as examples, and provide explanation in the main text.

Answer (Toyohiko Sugiyama)

Since the two databases were unclear, I added a description in the new subchapter 2.2. Fig. 3 and 2.3 are mainly about the original DB. Since the open DB has almost the same structure, the content refers to both the two databases. I added a description in 2.3.1. I organized the description by making sections in 2.3. Although it has a different order compared to the data items in Fig. 3 and the correspondence is insufficient, the items follow the categorization of the data items shown in the scenario diagram.

3 Explanation of the database usages

Question (Hiroshi Tateishi)

The description of database usage in chapter 3 is a cluttered list. I think you should set up some categories and organize them. You should also include the specific comments from the users and their feedback. Also, what specifically are "various non-technical concerns"? Can you describe them clearly as much as you can? You write, "the usage and effectiveness of this column is untested, but it is positioned highly in data creation." Please indicate the reason why you consider it important even when untested.

Question (Kazuo Igarashi)

In "Database usage" in chapter 3, not only are there several cases that are listed given the same weight of importance, but there are some conclusive sentences and I am not sure what you are trying to say. Please organize the text by either setting up sections or giving priorities to the cases.

Answer (Toyohiko Sugiyama)

I created subchapters. Also, part of the text was moved to another chapter. Along with the revision of the overall chapter structure, I transferred part of the text to "Design philosophy." I also created sections. The specific example of "various non-technical concerns" was that the local industrial association commented against the corporate research institute, and limited the disclosure to public (limited disclosure to people of the same industry in other regions) for the software and data created by the research institute.

For the description of "untested," I added the reasons in the appropriate places in 2.3.2. The reason I wrote "untested" is because there is no user log left in the comment column. I deleted this expression in the revised text.

4 Collaboration with the overseas database

Question (Kazuo Igarashi)

In the last paragraph of chapter 3, you write, "Collaboration with other databases is technologically simple but has not been realized due to various reasons. On the other hand, in overseas public institutes, similar databases with uniform data items and data formats are being constructed, and there are progresses in mutual use of data and system linkages." Does this mean that a database system that surpasses this database has been built abroad? If so, I think you should explain the "various reasons" that prevented the author from doing so. I think you should also reference the overseas system.

Answer (Naoto Kobayashi)

The overseas research institute (specifically, National Metal and Materials Technology Center, Thailand) created the glaze database with matching data items and format with the AIST database. The researchers visited each other's institutes and engaged in research cooperation. The reason I wrote "progress in collaboration" is to mean the collaboration with this database. I revised the text.

5 Adequacy of the research level of the test pieces

Question (Kazuo Igarashi)

In the summary, you write, "The high or low of the usefulness of the database depends on the research level of the original test pieces and the quality of the work to create the database." I think this is certainly true. How was the research level of the test pieces that continued over 80 years guaranteed, and what made you decide the research level was adequate to create the database?

Answer (Toyohiko Sugiyama)

Before starting the database, the corporate researchers used the test pieces, and their usefulness was recognized. The researchers at AIST (Government Industrial Research Institute of Nagoya) were also aware of the benefit of the test pieces as they used them in research. Particularly, when considering the direction of the experiments at the initial stage of research, the reference to the past experimental data was useful, and vast data provided on-target information in many cases.

Also, there were test pieces related to world renowned R&D such as the ones for iron-based glaze, and this drew attention in Japan and overseas.

On the other hand, there is the problem that not all test pieces have guaranteed research levels. I think the remaining test pieces are only those considered to meet a certain level as judged by the person who was in charge of the research when they were created. We also select the pieces in the data entry work.

6 Number of data entered and future prospect

Question (Hiroshi Tateishi)

In the beginning of subchapter 2.2, you write, "The database design was started assuming the data capacity of 50,000 cases." Then, on the third page, you write, "By selecting more typical test pieces from the original database (for open database on the Internet), the search results could be obtained in a short time." However, in the paper, it is not written how many data are entered in the original and the open database. Why don't you add the figures in Table 1?

Also, if you have a goal for the final entered number, please explain that, and mention the prospect of when this work will be completed.

Answer (Toyohiko Sugiyama)

I added the number of current data entries and the goal to Table 1. At the end of section 2.3.4, I added the description of the number of data entries. About 15 years have passed since the start of data entry. The number of registered data for the original database is about 33,000 entries including the data that are currently under construction, and there are over 20,000 entries with which the work is completely finished. We set our goal as 50,000 entries. When we started the database, we could hardly enter 1,000 entries per year. With improvements in the entry system and work procedure, the efficiency of the entry work increased dramatically. Meanwhile, we strengthened the recheck of data correctness so that the workload doubled. Currently, the rate of entry is about 2,000 entries per year. If the work continues at this pace, about ten years will be required to reach the goal of 50,000 entries. The glaze databases are being constructed in many public research institutes, but there is no other case where the project is continuing for so long. This is one great advantage or our database.

I did not write the prospective achievement date of the goal in the paper, because that can change according to the external factors such as future work situation or number of personnel allotted.

A brief history of arcade video game display technologies

— From CRT displays to real time graphics —

Yukiharu SAMBE

[Translation from *Synthesiology*, Vol.6, No.2, p.93-102 (2013)]

Since the rise of the market in the 1970s, arcade video games have evolved via the adoption of various display technologies. Initially transistor-to-transistor logic (TTL) was used, then bitmapped display—as seen in the smash hit Space Invaders—was adopted. Later display technologies include sprite display technology, an arcade industry innovation that played an important role in expanding the market, and real time polygon displays incorporating very fast numerical operations such as DSP. The arcade business has been an early adopter, introducing, developing, and utilizing new display technologies years before they appear in other industries. These arcade game technologies led to the development of many other new entertainment systems, such as home console games, mobile phone contents, and even network (downloadable) karaoke. This paper describes the evolution of arcade game display hardware technologies and its background.

Keywords **:** Video game hardware, arcade game, sprite display, real-time polygon display

1 Introduction

The world video game market is about 5 trillion yen in size.[1][2] Japan's share is 20 % of this figure, with the Japanese domestic market divided into home console games and arcade games (also called "game center" games or commercial games). Japan has the largest arcade game market in the world, and the industry is driven by the introduction of new technology. While arcade games provide players with extraordinary experiences, the industry is strictly business. Even if a game features excellent hardware and programming, its development will be terminated if it fails to generate sufficient profit during the prototype's standard two-week period of arcade location test. Only about 20 % of game prototypes survive this income test, and only a few percent of completed games go on to become hit products. Those game concepts and the hardware that survive such harsh competition are invariably excellent in terms of business and technology. This author has been involved in the R&D and marketing of entertainment devices including arcade games for over 30 years, since the 1970s. This paper describes the history and background of the arcade video game display technology and its unique, little-discussed evolutionary path. (While concepts are an important factor in an arcade game's success, they will not be discussed in this paper, and shall be a subject of another paper.)

2 The development of video game displays

2.1 The earliest video games

It is said that the first video game was created in 1958 by William A. Higinbotham at the Brookhaven National Laboratory, USA,[3] but commercial success did not come until the early 1970s release of the arcade PONG by Nolan Bushnell's Atari, Inc. Gaining inspiration from this game, Japanese arcade game engineers engaged in their own original research and development. Worldwide hit Space Invaders (1978, Taito Corporation, developed by Tomohiro Nishikado) was one success story from this period. In the fierce competition with the United States, the display technology of arcade video games progressed along a unique path in a seven to eight year cycle, in step with the advances in the electronics technology. The progress will be described in sequence.

2.2 Early video games: electromechanical games from the 1960s

In the 1960s, before the arrival of the video games, game machines like the one shown in Fig. 1 were already available, and the play field was approximately equivalent to the

Fig. 1 Electromechanical game machine

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current video games. During this age there were no central processing units (CPU) or high-speed logic parts; instead mechanical parts, motors, light bulbs, and sequencers using magnetic relays were used. In the example of Sky Fighter II (1971, Taito Corporation, developed by Tomohiro Nishikado), the game machine was composed mainly of five electromechanical units that handled: 1) the display of clouds drifting in the background, 2) the display of enemy aircraft, 3) the display of enemy explosions, 4) the display of bullet trails, and 5) hit detection. Although this and other electromechanical game machines dominated the market for a while, engineers shifted their focus to the development of interactive games using cathode ray tubes (CRT). Unlike electromechanical games that were prone to mechanical deterioration and magnetic relay contact failures, game machines using CRTs required less maintenance and were also able to display fast-moving graphics.

2.3 Video game display fundamentals

While video games debuted in the 1970s, the fundamental display technology remains the same today. A raster is drawn by passing the electron beam right-left and up-down on the CRT, and the image is displayed by placing graphical elements on top of the raster (Fig. 2.1). Figure 2.2 shows the generation of the basic signal for display, and Fig. 2.3 is a diagram that shows the concept of the display time and the blanking time in video game display. In this example, one horizontal scanline is drawn in 63 μsec (blanking time in that time is 10 μsec) and one vertical scanline is drawn in 16.6 msec (blanking time of 1.3 msec). These frequencies are close to the National Television System Committee (NTSC) television display. Figure 2.4 shows the sprite display blanking period (to be discussed later), where weak memory performance was compensated for by increasing the horizontal blanking time. (Although these ratios will shorten the width of the display in the horizontal direction, an ordinary TV receiver absorbs the difference, and there is no interference with the screen display or the synchronizing behavior of the TV.)

2.4 The TTL method: early 1970s

PONG, made by America’s Atari, Inc., was released in 1972 and became an instant hit when it was introduced to Japan. Lacking almost any reference materials, Japanese arcade game engineers gained technical inspiration from their analysis of PONG’s logic circuit. Within six months they began releasing totally new and different video games using original technology. The core of the electronic circuit used transistor-transistor logic (TTL), which delivered high speed at a low cost, further spurring the development of arcade video games. Figure 3 shows the functional block of the racing game Speed Race (1974, Taito), and how graphics are drawn on the desired display position on the CRT using the digital counter’s preset function. The all-important hit detection—in this case, collisions between competing cars and the curb—was handled by the hardware, which checked for overlapping pixels among the on-screen graphics. This process was primarily controlled by TTL, as CPUs had not yet been adopted.

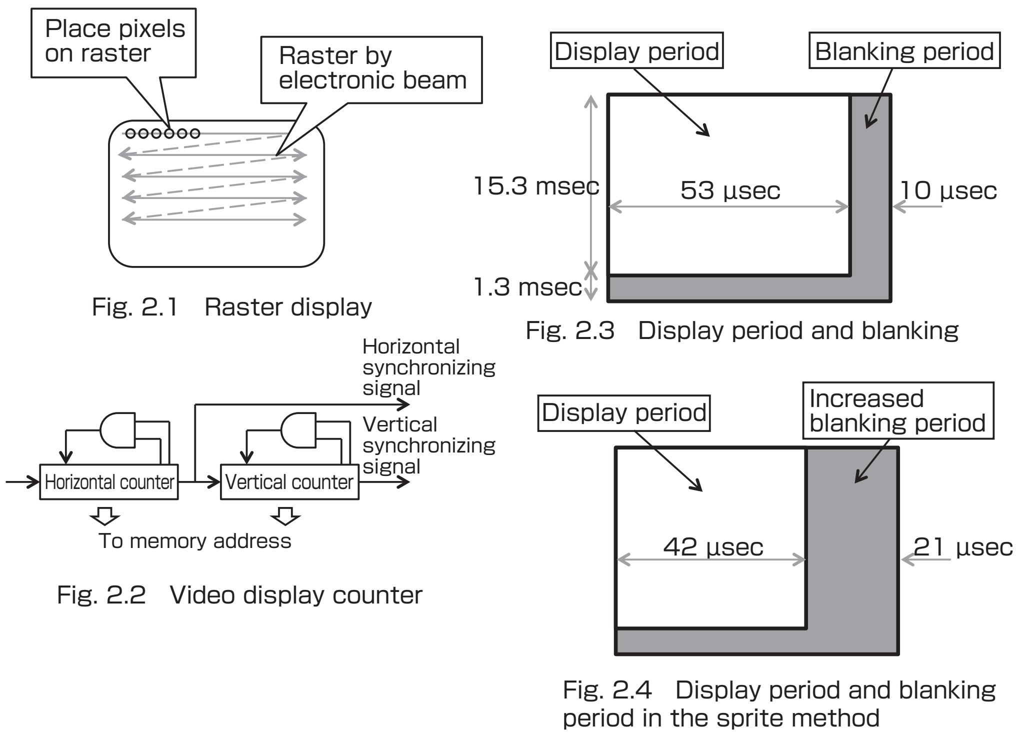

Fig. 2 Video signal fundamentals

[TTL video game limitations]

During this period, the hardware (TTL circuit) itself was responsible for realizing the game concept. However, hardware engineers with an understanding of game concepts were few in number, and human resources were limited. Initially, around 200 TTL circuits were sufficient for commercial video games, but the number of TTL circuits required increased as demand grew for more complex games with more on-screen objects, and hardware costs soon became prohibitive.

2.5 The age of CPU bitmapped graphics: late 1970s

In the mid 1970s, an American company introduced a CPU-based game called Gunfight (1975, Midway Manufacturing Co.). While it was not a commercial success in Japan, it inspired the use of CPUs in Japanese arcade games. CPUs added flexibility to game development, and for the first time it was possible to separate game concepts from the physical hardware used in the game. Japanese engineers studied foreign CPU-based games, and soon began to produce their own, designed with their own scratchbuilt development tools. The highly successful Space Invaders is one example of a game designed entirely with handmade development tools.

At the time, character display, commonly used as the console for mini computers, was the dominant image display method. The advantages of this method were that it used only a small amount of memory, the circuit configuration was simple, and the cost was low. However, there were many display limitations, since only a small number of characters and graphics could be displayed, and in limited positions at that (Several commercial products used this method, including card and mahjong games.) However, arcade engineers aimed to create games where objects could move freely around the screen, so they shifted to bitmapped graphics despite their expensive memory requirements. Figure 4 shows the functional block used in Space Invaders, which used a bitmapped graphic method where the image display memory was time-shared between the CPU and the display. Bitmapped game display technology delivered much more flexibility compared to the TTL logic game machines.

[The introduction of game development tools]

The Japanese game developers of this period were multi-talented engineers that engaged in the fabrication of hardware, software, and graphics, and they even developed their own unique tools in an effort to work more efficiently. Graphic work was digitized by hand, using paper and pencil in the early days, but specialized graphic rendering tools were created and used to correct graphics, change colors, and check the animation. Also, in game software, several subroutine programs ran concurrently and cooperatively, and engineers created and implemented the original real-time OS to integrate and run them. Finally, scratchbuilt debuggers were used as a program development tool. In addition to their basic debugging function, these debuggers worked with the hardware and allowed the real-time measurement and display of the CPU occupation time for each program, an innovative feature at the time.

[CPU bitmapped graphics limitations]

Using the bitmapped graphic method as seen in games like the aforementioned Space Invaders, to move a displayed object, a new object was drawn in the new display position, and the old one drawn in the former position was deleted. These processes were handled entirely by the CPU program. As a result, the processing limit was readily reached in games with fast-paced action. For example, in the Space Invaders hardware, the area of the screen that could be filled in at real time was only about one-fourth the whole screen, and that was insufficient for games with vigorous action. As a solution, faster CPUs were used to increase the rendering speed of bitmapped graphics, as seen in QIX (1981, Taito Corporation) and Halley's Comet (1986, Taito Corporation), but it was not long before this solution reached its limits.

2.6 Age of the sprite: 1980s

In 1978, Atari, Inc.[4] launched the sprite display method, in which the desired graphic is displayed by the hardware as the CPU entered the location coordinates and graphical code of the object to be displayed. Figure 5 shows the functional block of a video game system using this method. In sprite display, the line buffer memory was configured

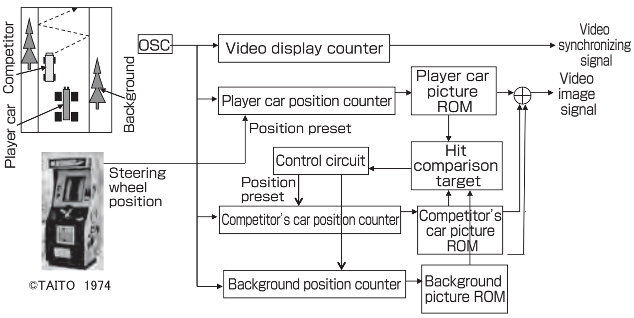

Fig. 3 Video game circuit block by TTL

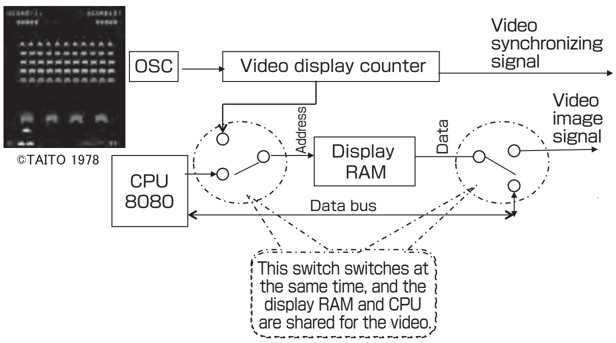

Fig. 4 Video game circuit by bitmapped graphics

using expensive high speed memory, and the hardware and software processes were separated in a good balance. Galaxian (1979, Namco Limited) was the first game to use sprite graphics. The speed of the memory elements (accessed at about 70 nsec) and the processing speed of the surrounding TTL circuits was just barely enough to produce the line buffer circuit, and the craftsmanship of the circuit designer really shined through (however, leaving such little room for error occasionally contributed to problems after the game was released to the market[5]). Many ways were devised to write as many graphical elements in the line buffer within the TV's horizontal blanking time such as leaving room in the design by widening the blanking time to twice the standard TV signal (NTSC). While the bitmapped method struggled to slowly move 55 Space Invaders around the screen, as a result of these design efforts sprite technology allowed more than ten times as many objects to be moved around freely at high speed. During the 1980s, many video game concepts were based on this basic method. Most of the video game categories seen today were established during this period, and this display method was carried over to the early home console games.

[Division of labor]

During this period, development roles including the programmer, hardware engineer, game concept creator, graphic designer, and the producer who organizes the group (in many cases, a middle level manager) became specialized and defined. Particularly, the producer assumed the important roles of realizing the game concept for the next age while directly being exposed to external competition, integrating the programmers, hardware engineers, and game concept creators, and then opening the way for future technological developments.

[Market expansion and sprite display limitations]

The market expanded rapidly with the huge hit of the Space Invaders, and while many games were being developed using the sprite method, there was a great deal of demand for newer expressions and more complex video games. On the other hand, with the sprite method it was necessary to prepare many graphics for the enlargement, reduction, and rotation of each displayed object. Therefore, the graphic work and the memory to store the pictures increased exponentially, yet while costs increased display quality remained insufficient.

2.7 Age of the DSP polygon: early 1990s

When Taito Corporation released an electromechanical flight simulation game in 1986, the prototype was well-received during the market test. While electromechanical games were easy to understand, there were durability and cost-related problems. In response, the commercialization of a similar videogame with dramatically expanded sprite display technology was attempted, but there were many technological difficulties in the enlargement, reduction, and rotation of the displays of daytime landscape and landing strip during take-off and landing. Therefore, the flight simulator game that showed only the nighttime guiding lights was developed by expanding the sprite technology. If only the guiding lights were involved, then the rotation, enlargement, and reduction of the linear arrangement of lights were no longer needed, and this could be accomplished by the sprite technology and by relatively small amount of numerical operations. This game received high marks in the market introduction test. Meanwhile, display technology that allowed the simulation of daytime take-off and landings was developed concurrently, and this led to the concept of polygon display hardware.

Figure 6 shows the polygon display block diagram at the time. Here, a digital signal processor (DSP) is used to calculate the vertex coordinates of the polygon. Although I

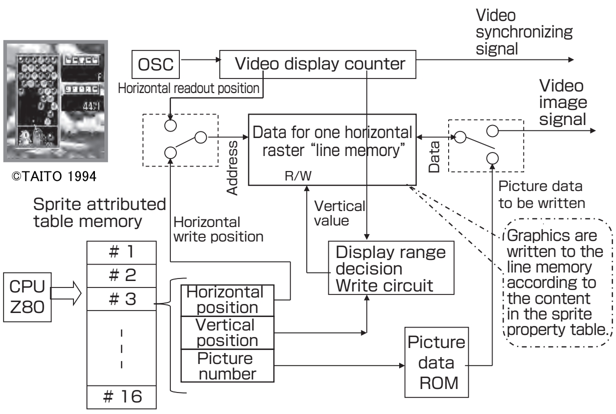

Fig. 5 Video game circuit by sprite display circuit

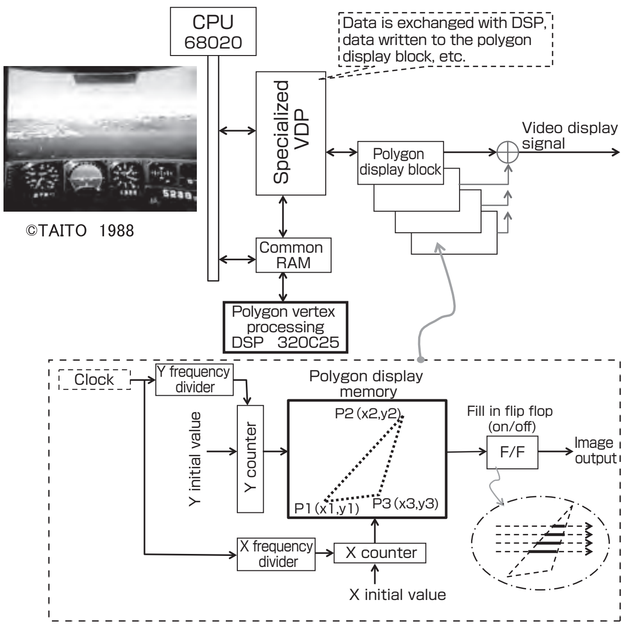

Fig. 6 Video game circuit for DSP and polygon displays

shall omit a detailed explanation, the “polygon display block” in the figure is a block where the inclined line set by the X and Y frequency dividers is rendered according to the count up of X and Y counters on the polygon display memory, and the triangular polygon formed by these three lines are rendered.[6] The polygon display memory used here has ten times the width of the memory needed for TV display, and the circuit configuration allows the polygon to be rendered completely even if the position of the polygon runs off the edge of the screen. For displaying on TV screens, only the display area is cut out and the triangular polygon pixels are displayed sequentially on the raster of the TV screen. To fill in the polygon during the raster rendering, the area from the first intersection of the raster and the triangular polygon line to the intersection with the next line in the horizontal direction is filled in. The screen image of Fig. 6 is from the flight simulator game Top Landing (1988, Taito Corporation), which implemented the polygon display for the first time in Japan.

[DSP polygon display limitations]

In the above flight simulator game, the relatively monotonous ground surface seen from the sky and a few high-rise buildings were displayed by polygons. In the train driving game, Densha De GO! (1997, Taito Corporation), many more polygons were needed compared to the flight simulator. In the early polygon games, multiple DSPs were used to handle the high number of polygons and hardware in which the polygon processing capacity was enhanced were used, but technical limits were reached in no time. Also, the effect of single colored images was unnatural, like a coloring book. Therefore, the next development goal became the creation of a hardware device that could display irradiating and reflected light as well as subtle differences in color.

2.8 Age of GPU rendering: 2000s

A three-dimensional image is created in three steps, as shown in Fig. 7. First, all the objects (people, building, background, etc.) composed of multiple polygons are arranged in the desired location using enlargement, reduction, or rotation in the “world coordinate,” a miniature landscape space. After “clipping” and other processes by which the objects are cut out in a two-dimensional plane from the direction of the point-of-view, colors are added with the direction of light in mind by the “rendering process.” Immense amount of real time numerical operations are necessary for all these processes. In the early period, multiple DSPs were used, and specialized graphic large-scale integration circuits (LSI) were designed and developed originally by arcade game companies such as Taito Corporation, Sega Corporation, and Namco Limited. However, the design work gradually became overwhelming, and after 2000, partnerships were signed with the specialized graphics processing unit (GPU) manufacturers that expanded their business to personal computers. Currently, NVIDIA Corporation of the United States and ATI Technologies, Inc. (later incorporated into Advanced Micro Devices, Inc.) of Canada are the two major GPU manufacturers. Figure 8 shows an example of the internal configuration of the current polygon display LSI (GPU).[7] Stream processors that excel in product-sum operation are arranged (SP in this diagram), and a micro-program (called the thread) is carried out. These engage in various tasks including vertex computation, clipping, or texturing, as needed. The main CPU provides the GPU with a certain data sequence (the data format is standardized in either Microsoft Corporation’s DirectX or Silicon Graphics International Corporation’s OpenGL), and the GPU conducts the desired process as it switches the thread and then writes the result to the video memory. In a sense, this part is a black

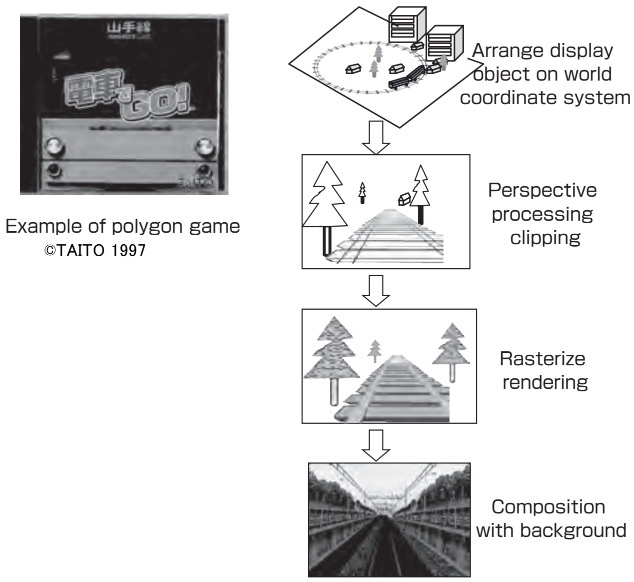

Fig. 7 Processing steps for three-dimensional display

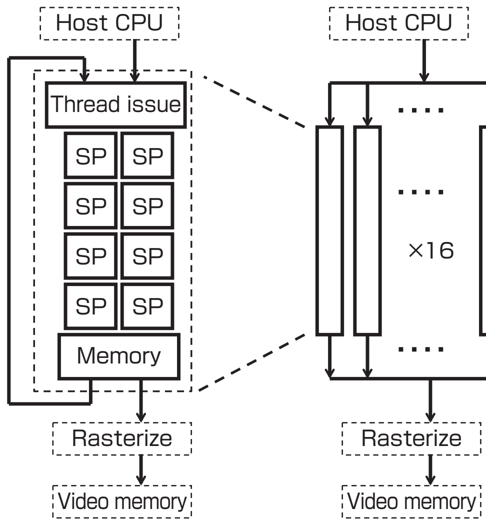

Fig. 8 Internal configuration of GPU
(created by author from *NVIDIA GeForce 8800 GPU Architecture Overview*)

box process. In the latest model, over 1,000 SP processors are installed, and the same GPUs are utilized in some supercomputers.

3 Introducing new technologies

In the arcade game industry, new technologies are often commercialized several years before other industries. The author feels there are three primary reasons for this: 1) the process of planning, prototyping, and market testing for arcade games runs in a short time cycle, 2) relatively expensive new technologies can be used, and 3) multi-talented human resources are available.

3.1 Short-term testing

In the arcade game industry, consumer feedback can be readily obtained by experimentally installing the prototype in the video game arcades, even with incomplete experimental products. In addition to the examples described above, various other original video display technologies were tested. Some of these technologies include the vector scan display method[8][9] that enabled the enlargement, reduction, and rotation of multiple displayed objects by directly rendering with electron beam of the CRT, the method that enabled the enlargement and reduction of the sprite displayed pictures on the hardware,[10] and the method that combined the game display and the laser disc (LD) that stored the moving image.[11] The consumer, regardless of the game manufacturer or the brand, puts in a coin (typically 100 yen), plays the game, and does not return if he/she does not like the game. The result is definitive, and various new technologies can be tested using the market as the testing ground. On the other hand, with home console game software, commercial success is determined by the number of games sold. This process is slow, since real consumer demand can only be measured after the game software has been finalized and the game discs pressed and distributed to the market.

In any industry, there are mechanisms for market tests such as provision of samples, but the process in the arcade game industry is particularly quick and accurate.

3.2 The costs of introducing new technology

The wholesale price of a standard arcade video game machine in the 1970s was about 500 thousand to a million yen, and about half of the cost was dominated by electronic parts. The CPU and memory were still expensive then (about 50 thousand yen), but the reason they could be actively deployed in the arcade games was because of the relatively high trading price of the game machines. Figure 9 shows the cost of introducing new technology to various markets. The left side shows the technologies that are innovative but still have issues in reliability and implementation costs; these technologies are generally reserved for research laboratory use. The right side shows consumer-oriented technology, and many are technologies that may take time before going over to the general consumer but the reliability and implementation cost have been thoroughly considered. The center portion is where the relatively high-cost new technologies and ideas are utilized, and this is where the arcade game market resides. For example, several years before microcomputer CPUs were widely adopted for general use, their appearance in the arcade game market stimulated use in related industries. Also, for polygon arithmetic processing, arcade games incorporated and popularized DSP in the early days of the technology, while it was still expensive and difficult to use. As known widely, the DSP has since come down dramatically pricewise, and multiple units are installed as the main part of the cell phones.

3.3 Multi-talented human resources

As mentioned earlier, the early arcade game industry was led by multi-talented people who engaged in the design of hardware, development of software, creation of graphic and sound effects, as well as hand-making their own development tools. This trend is still in place, and even in recent arcade game development,where the roles are specialized and divided, the producer tends to be well-versed in multiple technologies. (Specializations mainly include: 1) creating game concepts, 2) designing electronic circuit hardware, 3) programming, 4) graphics, 5) creating sounds, 6) networking, 7) mechanical configuration, and 8) production.)

Despite a different business model, this same background is found in the development of network karaoke, which grew from arcade game companies such as Taito Corporation and Sega Corporation,[12] and then led to the cell phone ringtone business.

Video game players enjoy novelty, and producers seek out new game concepts and technology that enables new forms of expression in an effort to respond to this demand, thereby

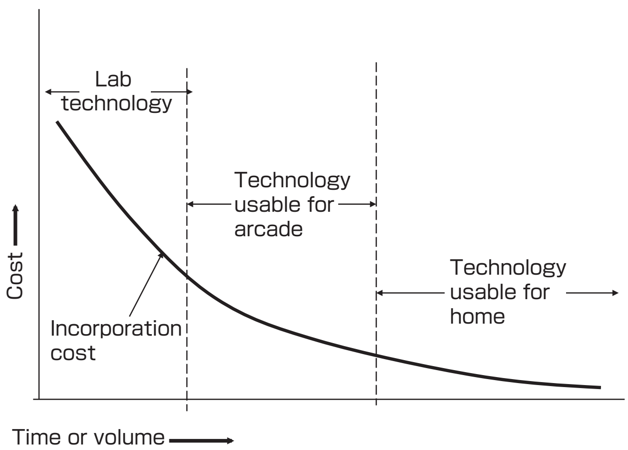

Fig. 9 The cost of introducing new technology

spurring technological innovation. The introduction of sprite and polygon technology are two examples of this. On the other hand, "novelty" is an abstract and intangible concept. Novelty can only be achieved through experimentation and implementation, which is why game machine prototyping and market testing are so important.

4 Display technology timeline and background

Figure 10 shows a summary and timeline of the evolution of arcade video game display technology.

The fundamental goal of video game display technology is to achieve a wide variety of hardware-based visual effects without overloading the CPU. To achieve this, circuit designs that enable the efficient and effective read-write of the video memory are important. The circuit design technology is utilized as follows: in the design where CPUs compete for the access to the video memory during the gaps in CRT display in the CPU bitmap method, in the logic where the pixels are directly written to the high-speed memory without mediating the CPU in the sprite method, and in the logic in which the polygons that reflect the result of the DSP computation is directly written to the memory in the DSP polygon method. Most of the electronic elements such as TTL and memory that were available at the time required design that enabled action at approximately their speed limit, and many design engineers found out from experience that even a slight oversight would lead to later problems.[5]

The background factors that promoted such technological evolution are summarized as follows.

[TTL → CPU bitmap] 1) There was a shortage of people who have both the ability to design hardware and to develop games, and it became necessary to separate the hardware and software. 2) In game development, fine-tuning and revisions were mandatory to increase the quality of the game, and the introduction of CPU was important to simplify these processes. 3) Independent display circuits (mainly logic circuit combined with a counter) were necessary for the display of moving objects, and when the number of objects increased the circuit size increased accordingly, and the measures against increased cost became necessary.

[CPU bitmap → sprite] To achieve exciting graphics, the sprite method was devised where the hardware logic was responsible for displaying 1) in high-speed, 2) multiple moving display objects, 3) without overloading the CPU.

[Sprite → DSP polygon] This was devised to display three-dimensional objects. While polygon technology was used in large-scale or specialized computers, their costs were way beyond what could be used for arcade game machines. Therefore, the following measures were taken for use in game machines: 1) thorough simplification, 2) employment of DSP as numerical operation element, and 3) design of specialized LSI for high-speed rendering. On the other hand, as a method to replace the polygon method, the vector scan display mentioned earlier, was available and used in many games in

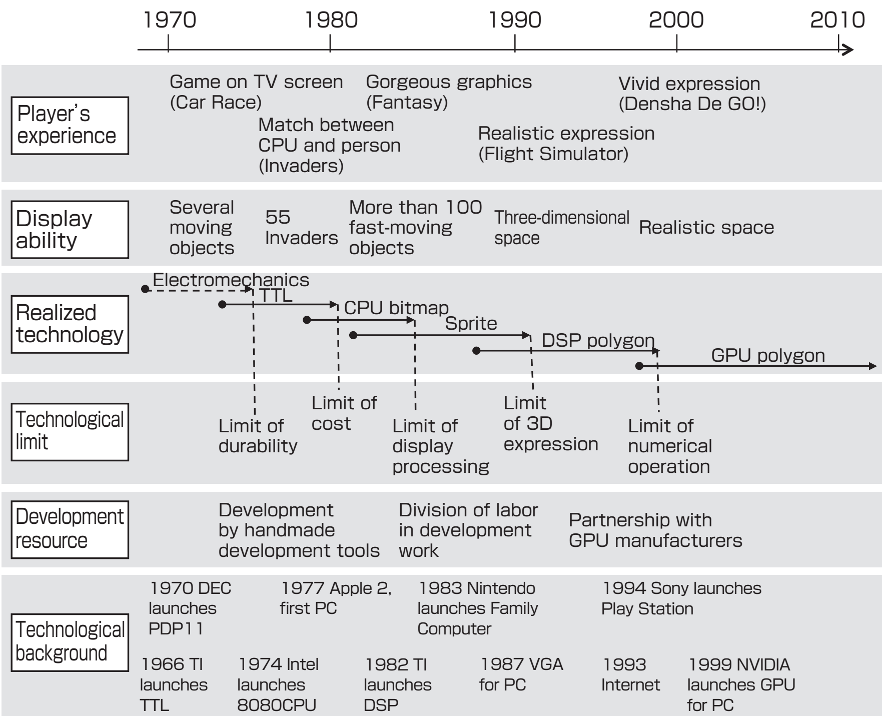

Fig. 10 Display technology timeline and background

the United States.[8][9] However, this method dropped out of favor because it was mainly line drawings so the objects were geometrical and could not be colored.

[DSP polygon → GPU rendering] In the polygon display, the vertex data are arithmetically processed, but the processing capability became insufficient when several DSPs were simply arranged in line, because 1) the polygon display of nearly hundred times more than in the DSP polygon was needed, and 2) the natural rendering and coloring with attention to lighting were demanded. The method of arranging dozen or more DSPs was considered at the time, but the data transfer speed between the memories was slow, and it became apparent that the cost and development time would be too great if they were done within the company, so partnership with specialized GPU manufacturers began.

On the other hand, because of the partnerships, the arcade game manufacturers now have less opportunity to utilize their original display technology. As a result, many games end up having similar visual expressions. Fresh technological innovation is awaited in the future.

5 Conclusion

Taito Corporation has been providing the Type X arcade video game hardware equipped with the graphic hardware of the aforementioned GPU manufacturer companies since 2004 (Fig. 11). It has a similar configuration to a high-performance personal computer, and an ordinary PC can be used directly as its development environment. Over 20 game companies including Taito create game software for this platform, and over 70 game titles have been marketed. The conventional arcade video game companies including Taito are now focusing on the development of the software library to maximize the performance of this hardware.

As mentioned earlier, arcade game technology is closely linked with business, and there are many games that were buried without ever seeing the light. On the other hand, technologies with little known history are actively incorporated, and may appear several years before their adoption by other industries, making arcade game developers technological pioneers.

There were times when video game arcades were considered delinquent hangouts, and something to be kept on the fringes of society. However, through the efforts of many engineers, creators, and the game arcade center operators, social recognition and legitimacy has been achieved. Currently, half of all game arcade visitors are women. I believe that the game industry—which is often discussed with Japan's other specialty, anime—will continue to advance, and new entertainments will be born.

Fig. 11 Video game hardware
TYPE-X (Taito Corporation)

Acknowledgement

I have learned much from Mr. Tomohiro Nishikado, who almost single-handedly built the foundation of the electromechanical games, TTL video games, and Space Invaders, during the earliest days of Japanese video games. He has my gratitude. Also, in writing this paper, I received a great deal of advice from the reviewers, Dr. Motoyuki Akamatsu and Dr. Masaaki Mochimaru of AIST, about how to meet the objectives of *Synthesiology*. I am thankful.

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Discussions with Reviewers

1 Overall structure

Comment (Masaaki Mochimaru, Digital Human Research Center, AIST)

This paper is an overview of the evolution of video games, the changes in software development system, and the ripple effect to peripheral technologies, with focus on the changes of arcade game image display technology. Finally, it offers prospects for the future arcade game technology. I think the overview and prospect of how the technologies are synthesized with focus on image display technology is beneficial content for *Synthesiology*.

Comment (Motoyuki Akamatsu, Human Technology Research Institute, AIST)

This paper describes the changes of the arcade type video game technology, addressing the technologies introduced over time, and it is a good example of the social introduction of technology. To avoid it from becoming a history paper of technology, please describe why the new technologies changed in the course of technological progression (goal setting), the basis of the selection of technologies to achieve the objective, and the technological issues that were solved to achieve the goal (development scenario and process).

Answer (Yukiharu Sambe)

Thank you very much for pointing out the places where clarifications are needed. I have revised the manuscript. Here are some additional perspectives:

Goal setting: Video game players enjoy novelty, and producers seek out new game concepts and technology that enable new forms of expression in an effort to respond to this demand, thereby spurring technological innovation. The introduction of sprite and polygon technology are two examples of this. On the other hand, "novelty" is an abstract and intangible concept. Novelty can only be achieved through experimentation and implementation, which is why game machine prototyping and market testing are so important.

Development scenario and process: The fundamental goal of video game display technology is to achieve a wide variety of hardware-based visual effects without overloading the CPU. To achieve this, circuit designs that enable the efficient and effective read-write of the video memory are important. The circuit design technology is utilized as follows: in the design where CPUs compete for the access to the video memory during the gaps in CRT display in the CPU bitmap method, in the logic where the pixels are directly written to the high-speed memory without mediating the CPU in the sprite method, and in the logic in which the polygons that reflect the result of the DSP computation is directly written to the memory in the DSP polygon method.

2 Progression of the developed technology to other products

Question (Motoyuki Akamatsu)

Since the technology and cost shown in the figure are very important points, I think it will benefit the readers if you discuss using specific examples. Specifically, can you describe, for individual technologies that were introduced as arcade game technology, how much was completed in the laboratory stage, how these technologies were improved so they could be used as game technology, and how they could be used as home-use technology through the progression of arcade game technology?

Answer (Yukiharu Sambe)

I added simple descriptions about CPU and DSP in the revised paper. Additional perspectives are as follows.

・In the 1970s when the CPU was still expensive and was not widely used industrially, it was used actively in arcade games. The TK80 (1976) that was sold by NEC Corporation as a CPU learning kit for engineers was priced at about 100 thousand yen. During this period, CPUs were already installed in some arcade video games. However, it took more than ten years before CPUs were installed in home-use machines.

・As you may know, DSP was introduced in the early 1980s by NEC Corporation and others for digital signal processing of audio compression, and was offered to various research institutes and some specialists. Later, Texas Instruments, Inc. of USA started shipment of DSPs, and the latest TI DSP (MS320C25) was installed in the arcade game Flight Simulator (1988). The trading price at the time was over 10,000 yen, and it was one of the most expensive semiconductors, but it is still used in various devices today.

・In creating the flight simulator game, we considered the flight simulator technology that was used for actual pilot training. However, the cost was so high just for the image display (several tens to hundreds of millions of yen), and it became obvious that direct transfer was not possible. As a result, original consideration and design of the simplified polygon display function (1988) was created. Polygons were used in home game machines seven years later, in 1995.

・Copy-protect method. This was not described in this paper, but after the Invader game, many game copiers proliferated throughout the world (early 1980s). As a copy countermeasure, we employed a method inspired by the "knapsack cryptosystem (1978)" that was being researched at the time. Specifically, a stored-program single-chip microcomputer that cannot be read externally was developed jointly with an American company, and copy prevention was achieved by conducting encrypted communication between the microcomputer and the main CPU. This was used in games including Front Line (1983, Taito Corporation). It had the same mechanism as the USB dongles that are currently used to prevent unauthorized copies.

3 Social objective of the technology

Question and comment (Masaaki Mochimaru)

One of the objectives of *Synthesiology* is to accumulate papers on how technologies were selected and synthesized when an objective was set to make some change in society, and what the results were. What are the social objectives of arcade games? For example, can you define them as “new user experiences” or “efficient development and management of devices”? This paper describes the changes of technology from electromechanics, video, TTL, CPU, polygon numerical operation, and GPU rendering. I think there were “new user experiences” or “efficient development and management of devices” that you wished to realize through the introduction of the technologies in each period.

When describing the changes of the image display technology, if you set the “new user experiences” or “efficient development and management of devices” that were demanded at the time as the objectives of that age, to achieve this goal, what kind of core image display technologies were selected (what were the reasons for their selection), and how were the peripheral technologies such as the CPU and memory, display device, and software development methods changed and combined? I think the paper will become significant to *Synthesiology* if you give an overview of the history of technology in terms of “selection and integration of the technologies for an objective.”

Answer (Yukiharu Sambe)

・The social objective of the arcade games is to have the players experience the extraordinary and to provide richness to life. The player will continually seek the next “extraordinary experience,” and the game company must create new game concepts to respond to such demands and develop new technologies, such as for display. As a result, expressions that could not be conceived in 1970 are now possible, and it has grown into a major industry.

・I revised and added the descriptions on the selection and integration of the technologies toward a goal. Particularly, I described the process of the shift from sprite to polygon.

4 Technological development in one’s discipline and the introduction of technology from outside disciplines

Comment (Masaaki Mochimaru)

Considering that the new image display technologies are selected and integrated according to the social demand for “new user experiences” or “efficient development and management of devices,” aren’t there two courses: 1) the developed technology is transferred from the technological progress in other fields (TTL?), and 2) the technological development is led by the arcade games (sprite? GPU?)? You present a framework where even if the sprout of the synthesized elemental technology belonged to one’s discipline, if the technology progresses elsewhere, one can incorporate the technology that progressed in another discipline without being trapped by the technologies of one’s own realm. I think the paper will be significant as a *Synthesiology* paper if you also include the description of how the synthesis of such technologies were effective in achieving the objective of “new user experiences” or “efficient development and management of devices.”

Answer (Yukiharu Sambe)

I added descriptions to part of the revised paper. Additional perspectives are as follows:

・As you know, TTL was developed for use in general-use computers, and it was recognized from the beginning that its ability to provide easy digital processing was essential in video games.

・The DSP that was used in the early polygon display was introduced for digital signal processing for audio compression in the late 1970s, and the game industry that realized the excellent numerical calculation capacity used it for the numerical calculation of polygons.

・For GPU, there was a plan for using a dozen or more DSPs to display complicated polygons, but the cost was too much for the development and product, and we started partnerships with external GPU companies. As a result, the game development environment could be purchased from the GPU companies (i.e., it was no longer necessary to prepare them within the game company), this reduced the development cost, and realistic three-dimensional expressions became possible by using the GPUs that evolved along with the advancement of PCs. On the other hand, since many arcade game companies deployed similar products, the expressions became similar, and this is one of the most important points of consideration when thinking of the future direction that must be taken by the arcade game industry.

5 Prospect of the arcade technology

Comment (Masaaki Mochimaru)

In looking at the prospects for the “next arcade technology,” I think the point of the whole paper would become clear and easy to understand if you take the viewpoint of what objectives are set as “new user experiences” or “efficient development and management of devices.”

For the category, “new user experience,” hasn’t it reached the saturation point? Because the “new user experience” has been taken to the limit for certain users, I feel many users have quit following games. Seen by the reviewer, the three-dimensional display and hemispherical screen display are directions for heightening the “new user experiences” in terms of the advancement of image display, and the “return to electromechanics” is suggesting a “new user experience” through interface with different physical capacity other than high-speed motion or high-quality display. In terms of home-use machines, the former may be positioned as the Sony Computer Entertainment product and the latter may be Wii. I think it will be interesting if you discuss this area deeper and provide prospects for future technology.

Answer (Yukiharu Sambe)

・As you indicated, the category, “new user experience,” has somewhat become saturated. There are probably more than a hundred different shooting games like Space Invaders on the market, and this genre has become saturated except in certain areas. It is also a genre where some enthusiastic fans sought increasingly difficult games and the general users dropped away.

・In the initial draft of the paper, I wrote about the hemispheric screen and return to electromechanics as part of the “new user experiences” category. As you indicated, these are new experiences through the advancement of image display and interface. However, because they depart from the “evolution of video games” that is the core of the paper, and also because of the rather unclear descriptions, I omitted this section in the revised version.

6 Change in the number of people involved in the development

Question (Motoyuki Akamatsu)

It is interesting that the numbers of people involved in the development changes in each generation. Can you describe for which technology how many people became necessary?

Answer (Yukiharu Sambe)

The specific number of people involved in development cannot be counted easily, and I didn’t include them in the paper, but the number of people that increased the most was those in charge of graphics. Initially, simple graphics were used, but recently, the number of developers increased for 3D modeling and motion creation. While the number of programmers increased, due to the evolution of development tools (OS environment and development language), it has not increased as much as for the graphics. For the people of electronic circuit hardware, the number was highest during the age of the polygon when we designed the LSI on our own, but hardware specialists decreased since we changed the policy to using the GPU of NVIDIA, etc., during the rendering age.

7 Background for entering the video game industry

Question (Motoyuki Akamatsu)

Taito Corporation was a jukebox company in the beginning, but what was the motivation for going into video games? Also, I think placing the Space Invaders game machines in the cafés was a new business model. Can you describe why you decided to do so?

Answer (Yukiharu Sambe)

On jukeboxes: As you indicated, Taito was engaging in the business of importing and renting jukeboxes in the 1960s. At that time, imported pinball machines were placed next to the jukeboxes. We decided to place our original electromechanical games there, and this led to the development of video games.

On why the games were placed in cafés.: On the tables in the cafés in the 1970s, there were Peanut Vendors, which were small vending machines that sold small amounts of peanuts in exchange for coins. As peanut sales dropped, games were considered as a possible replacement service to keep customers spending coins while sitting at the café tables. In fact, table-form TV games for cafés were already on the market before the arrival of Space Invaders, but I think because Space Invaders became so popular, it became strongly associated with cafés.

I am made aware once again that technology and business continue to grow as they gradually change their forms.

A scientific challenge to the delineation of Japan's continental shelf

— Contribution to validating the Japan's rights over marine areas based on earth science —

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The national project of the Delineation of the Extended Continental Shelf was conducted by ministries of the government of Japan as one. The intention of the project was to summarize the information containing scientific basis on the outer limits of the extended continental shelf and to submit the application to the United Nations. The researchers of AIST in the field of marine geology carried out the marine survey, analyzed the collected rock samples and interpreted the results, and participated in the Task Force for the preparation of Japan's Submission. In this way, AIST contributed to the delineation of Japan's continental shelf by utilizing all the required resources as a professional marine geologist group. The information on Japan's extended continental shelf made up through the cooperation of concerned government ministries and agencies became the basis of the application which was finalized and submitted to the "Commission on the Limits of the Continental Shelf" of the United Nations by the government of Japan on November 12, 2008. And the government of Japan has received "the recommendations" as a result of the review by the commission on April 26, 2012. In this manuscript, the authors first explain the "continental shelf" and the "continental shelf of Japan." Then, they describe the background and the results of the participation of AIST researchers in the Task Force, which was really a rare opportunity in the sense that the utilization of scientific information contributed to the expansion of the legal rights over marine areas of Japan. Finally, they discuss the issues encountered in the operation of such a project.

Keywords : Continental shelf, United Nations Convention of the Law of the Sea, marine geology, submarine topography, Japan's Program for Delineation of the Outer Limits of Continental Shelf

1 Introduction

The mission of "the national project of the Delineation of the Extended Continental Shelf" (hereinafter, will be called the Continental Shelf Surveys) involved a series of projects in which the Japanese government and its ministries and agencies joined as one to conduct ocean surveys and to organize the results as application documents to be submitted to the United Nations (hereinafter will be called the UN). The aim of the mission is to delimit the extended continental shelf over which "the coastal state exercises sovereign rights for the purpose of exploring it and exploiting its natural resources on/beneath the seabed" past the 200 nautical mile limit, as determined by the UN Convention of the Law of the Sea[1] (hereinafter, will be called the Convention). The deadline of the submission of the application was determined by the date when the applicant coastal countries ratified the Convention, and the deadline for Japan was May 12, 2009 along with many other countries. Although the primary aim was that the application would go through the examination process smoothly, and the maximum range of the Japanese continental shelf would be maintained, within the limits set by the law, the second important hurdle was to meet the deadline of the submission as early as possible, because any submission of the coastal states would be put in the examination process on a first-come-first-served basis. As a result of years of collaborative efforts, the Japanese government submitted the application for the extended continental shelf for Japan on November 12, 2008, and after the examination process, the recommendations were received on April 26, 2012. This paper will first describe: "what a continental shelf is," "what kind of tasks were required in the Continental Shelf Surveys," and "what the results were." Next we describe what were the roles played by the researchers of the National Institute of Advanced Industrial Science and Technology (AIST) in this process, how the Continental Shelf Surveys were conducted, and how the researchers attempted to meet the objective of contributing to the application submitted to the UN based on scientific evidences. Moreover, we describe the issues in the application of the extended continental shelf, the difficulties encountered in the course of the project, and how these issues were overcome.

2 What is a continental shelf and what is the survey for the delineation of the outer limits of the continental shelf ?

The delineation of the continental shelf is the preservation of the maritime rights for Japan to develop the marine resources, or plainly speaking, it is the same as the expansion of the Japanese territory. On the other hand, the ocean must be managed, used, and protected as the common asset of humankind, and it must not be used selfishly as something

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that belongs to the coastal state exclusively. The delineation of the continental shelf is to create a system by which the rights to ocean development is executed and managed in an orderly manner, by determining the range of a country's jurisdiction as legally allowed by the Convention. This was a rare occasion where people involved in science could make a major contribution, since this delineation could be done based on scientific evidence, rather than disputing among the countries involved using military force.

To obtain and provide the scientific evidences to support the Japanese policy of maintaining the maximum extended continental shelf in accordance with the Convention is a good way of showing that science can be useful in supporting a policy that was formed in an international framework. Also, by submitting the application, it is an opportunity to present Japan's high capacity in science and technology. The surveys and researches conducted for the delineation of the continental shelf dramatically increase the geoscientific data in the candidate area of the Japanese continental shelf and the neighboring areas, and will also contribute to scientific understanding. The range of the extended continental shelf should be beneficial to the future society and to the people of Japan because, as written in the original definition of the continental shelf, it allows the natural resources to be explored and exploited wisely.

In the following subchapter, the "continental shelf" and the "delineation of the continental shelf" will be described.

2.1 Definition of the continental shelf according to the Convention

The continental shelf is a term defined in the Convention as representing the areal extent of the ocean in which a coastal state holds the rights and interests, and is a term that is often heard along with the generally well-known terms such as "territorial waters (closed sea)" or "exclusive economic zone (EEZ)." It is a term for "the area of interest in the ocean floor for the development of the resources in the ocean," and is probably easy to understand if it is called "the exclusive seabed and subsoil zone of marine resource development." On the other hand, the continental shelf is a term that is used widely in society and in geoscience (geomorphology and geology) as "the geomorphological region that is flat or that has a gentle slope and is, in general, 200 m or shallower in depth surrounding the continent or island states." Because this concept is held by many people, the "continental shelf" in the Convention has become somewhat confusing.

The concept of the continental shelf in the Convention has been built through historical discussion. In September 1945, immediately after the end of the World War II, President Harry S. Truman of the United States claimed its rights to the natural resources of its continental shelf regarding "the natural resources of the subsoil and sea bed of the continental shelf beneath the high seas but contiguous to the coasts of the United States as appertaining to the United States, subject to jurisdiction and control." Following this, other coastal states started to claim rights to the development of marine resources. In the first Conference on the Law of the Sea in 1958, the "Convention on the Continental Shelf" was adopted, and the continental shelf was set as "up to the depth of 200 m or to depth where the natural resources can be explored," and that the coastal states have "the sovereign rights for the purpose of exploring it and exploiting its natural resources in the seabed and subsoil."[2] The resource of interest at the time was offshore oil, and the depth at which it could be mined was limited to the geomorphological continental shelf as in a scientific term. Due to the advances in technology, the "depth that can be explored" became deeper than the geomorphological continental shelf, and the seabed natural resources expanded to the manganese nodules in the deep sea. In 1982, the term "continental shelf" continued to be used as the range over which the coastal states have "the sovereign rights for the purpose of exploring it and exploiting its natural resources in the seabed and subsoil" according to the Convention that set the laws for all issues regarding the ocean territory. This definition continues to the present.

As mentioned earlier, the "continental shelf" used in the delineation is defined in Article 76 of the Convention as a concept different from the geomorphological continental shelf. The definition is: "The continental shelf of a coastal State comprises the seabed and subsoil of the submarine areas that extend beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin, or to a distance of 200 nautical miles from the baselines from which the breadth of the territorial sea is measured where the outer edge of the continental margin does not extend up to that distance (paragraph 1, Article 76, the Convention)." The continental shelf that extends beyond the 200 nautical mile limit is determined by the method described in sections 4 to 6 of Article 76 (section 2), and the outer limits of the continental shelf is determined by "where that shelf extends beyond 200 nautical miles from the baselines from which the breadth of the territorial sea is measured, by straight lines not exceeding 60 nautical miles in length, connecting fixed points, defined by coordinates of latitude and longitude (section 7)."

The outer limits of the continental shelf is set by either of the two methods quoted below that allow the extension of the limit[3] (Fig. 1).

- Fixed points at each of which the thickness of sedimentary rocks is at least 1 % of the shortest distance from such point to the foot of the continental slope.
- Fixed points not more than 60 nautical miles from the foot of the continental slope (the foot of continental slope is the point of maximum change of gradient at the base of the

continental slope).

Since the extension of the continental shelf may spread infinitely using the limit according to the above rules, it is set that either of the following limits may not be exceeded.

- It shall not exceed 350 nautical miles from the baselines from which the breadth of the territorial sea is measured.
- It shall not exceed 100 nautical miles from the 2,500 meter isobath (this does not apply to submarine ridges that are not the natural components of the continental margin, and the outer limit of the continental shelf shall not exceed 350 nautical miles in such a case).

These rules determine the outer limits of the continental shelf.

The geoscientific data such as geomorophology and geology serve as the basis for determining the "outer edge of the continental margin following the natural prolongation of the territorial land" and whether it is a "natural component" that determines the outer limits of the continental shelf.

The territorial sea is defined as 12 nautical miles from the territorial sea baseline and the EEZ as 200 nautical miles. These are determined solely by the spatial relationship (distance) from the territorial sea baseline that is set based on the standard in relation to the territorial land. However, the extended continental shelf, which is the continental shelf set beyond the 200 nautical mile limit, is characterized as follows: it is determined by the geomorphological and geological conditions; application must be submitted by the coastal state describing the basis and the range; and the determination is made according to the recommendations given upon examination of the application. If it is determined as the continental shelf, the coastal state may exercise "over the continental shelf sovereign rights for the purpose of exploring it and exploiting its natural resources (Article 77)" outside the 200 nautical mile EEZ where "the coastal state has sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, ... of the waters superjacent to the seabed and of the seabed and its subsoil (Article 56)."

2.2 Process of delineating the extended continental shelf

For the determination of the continental shelf, the coastal state must submit an application by preparing the information on the outer limits of the continental shelf including the evidences. On May 13, 1999, the "Commission on the Limits of Continental Shelf (CLCS)" created the "Scientific and Technical Guidelines of the Commission on the Limits of the Continental Shelf (hereinafter, will be called the Guidelines)"[4] as a preparatory guideline for application. The Guidelines were created for the purpose of clarifying the scientific and technological evidences that were accepted in the application process for the CLCS to issue recommendations for the application. They were guidelines for the applicant coastal states on how to write the application. Also, they had the "objective of clarifying the interpretation of the scientific, technological, and legal terminologies in the Convention," and give several examples to explain some important concepts and terminologies. However, for several important issues, discussions and interpretations were carried on even after the Guidelines were published without establishing interpretations according to the Convention.[5] Moreover, due to the advances in science and technology, discussions became necessary for the data and evidence that were not conceived at the time when the Guidelines were drafted. The Guidelines clearly state that they do not offer descriptions for everything, and some issues must be considered on case-by-case basis, and in making the application, it was important for the applicant state to clearly

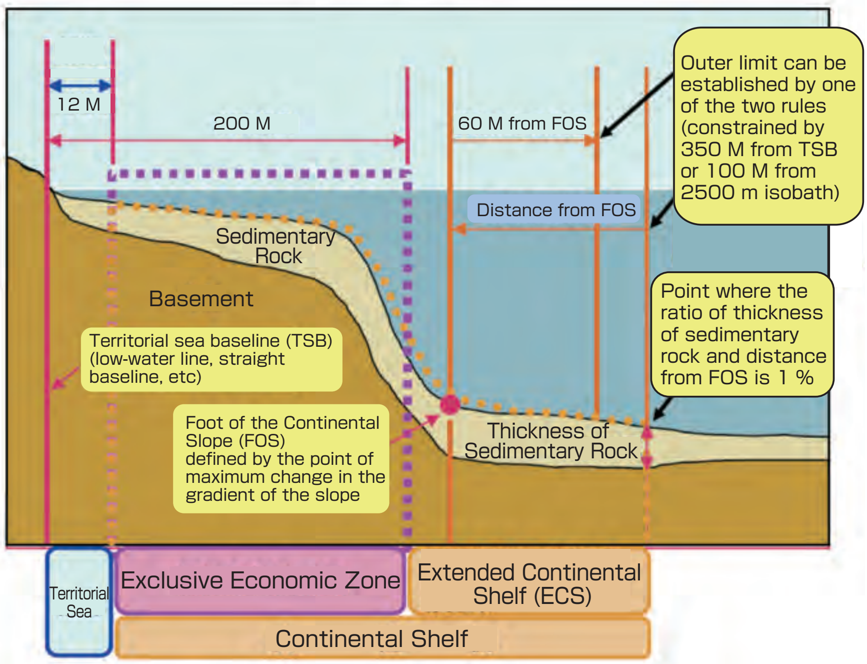

Fig. 1 Definition of the continental shelf pursuant to UNCLOS
The legal definition of the continental shelf is different from that of the geoscientific term "continental shelf."
M: nautical mile
Source: Press release from JCG (Oct. 31, 2008)[3]

analyze and describe the subject.

The time limit for submission was set within ten years after the ratification of the Convention, but for the states that ratified the Convention before the Guidelines, the deadline for application was set as ten years from the point the Guidelines were released. Since Japan ratified the Convention in 1996, before the Guidelines were publicized, the deadline for application was postponed to May 12, 2009 along with many other states.

3 Framework of the Continental Shelf Surveys

Soon after the Convention was adopted in 1982, the Hydrographic Department (currently, Hydrographic and Oceanographic Department), Japan Coast Guard started the survey of the continental shelf in1983 in a timely manner.[6] Russia submitted the first application to CLCS for the extension of the continental shelf in 2001, but the recommendations issued in June 2002 by the CLCS were harsh in terms of required contents and scientific evidences. Therefore, the Japanese government took the enhanced tactics for the Continental Shelf Surveys by offering solid scientific evidences in the application documents of the continental shelf. In 2003, the Advisory Committee consisting of the specialists of geoscience and law was established, and the Coordination Office for the Continental Shelf Surveys was set under the Cabinet Secretariat, to coordinate the overall process. The strategy for the Continental Shelf Surveys was discussed and drafted and the ministries and agencies of Japan joined together to embark on the survey.

As an institute that conducts comprehensive survey and research in geosciences, AIST joined the Continental Shelf Surveys and became involved in the project. The participation of AIST was due to the high research capacity of its researchers who had the experience and expertise in the target ocean regions, the survey technology that has been fostered over the years, and the high-level dating and chemical analysis technologies for the rocks in the region. There was also high expectation for the integrated efforts by the researchers in the delineation of the continental shelf.

The Continental Shelf Surveys involved a series of projects from survey to the drafting and the submission of the application, and Japan's Continental Shelf Surveys were designed and pursued just in the same way. Following is the description of 1) the overall coordination, 2) the survey, and 3) the preparation of the application documents (Fig. 2).

(1) Overall coordination

At the top of the organization of the Continental Shelf Surveys was the Headquarters for Ocean Policy of which the head was the prime minister of Japan. Under this headquarters are the interministerial working groups for communication, coordination, and discussion among the ministries and agencies that were responsible for the survey and the final draft

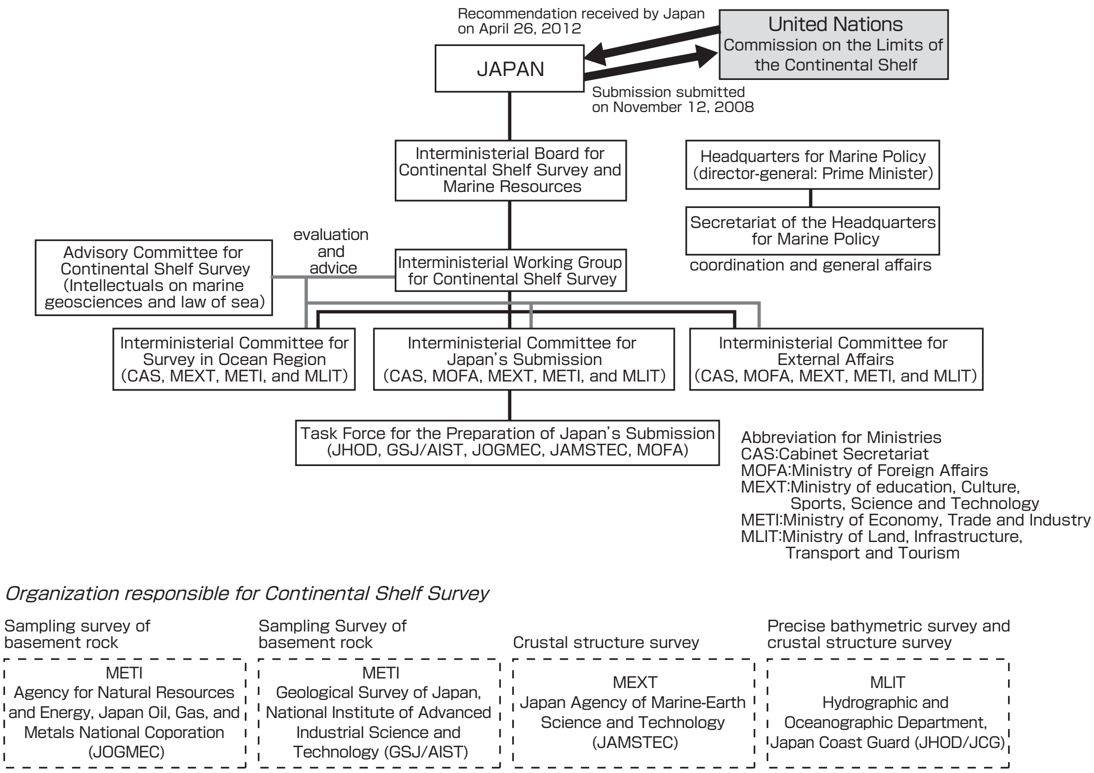

Fig. 2 Organizational structure for the Continental Shelf Surveys in Japan
In this figure and text, we used informal names for some of the committees and task force, which have formal names only in Japanese.

of the application, as well as the three committees including the "Interministerial Committee for Japan's Submission." The coordination among these committees was conducted by the Secretariat of the Headquarters for Ocean Policy (until 2007, this was done by the Coordination Office for the Continental Shelf Surveys). The Advisory Committee composed of the specialists provided recommendations to these committees from the academic aspects.

Although the Continental Shelf Surveys were organized as a joint effort of the government, the Coordination Office for the Continental Shelf Surveys (currently, Secretariat of the Headquarters for Ocean Policy) was the only administrative organization established as the coordinating secretariat.

(2) Survey

To establish scientifically firm evidence for the delineation of the Japanese continental shelf, three surveys (precise bathymetric survey, crustal structure survey, and basement rock sampling) were planned, with consideration on understanding the complex geomorphology and geology of the ocean area around Japan. The survey target had already been roughly narrowed down by the Hydrographic and Oceanographic Department, JCG (JHOD). The specific survey lines and the candidate points for rock sampling were discussed in the closed ad hoc team consisting of the researchers of the institutes conducting the survey and the researchers who were preparing the documents, and the results of the discussion were spelled out as the survey guideline after receiving comments from the Advisory Committee.

Precise bathymetric survey (institution in charge: JCG). To compile and analyze the bathymetric data to determine the continuity of the landmass to the outer edge of the continental shelf. All target areas were completely covered by multi-narrow beam sounding or swath bathymetry.

Crustal structure survey (institution in charge: JCG, JAMSTEC). The geological continuity was investigated and inferred from the crustal structure. To determine the crustal structure from shallow to deep parts, multi-channel seismic reflection profiling and seismic refraction profiling using ocean bottom seismographs were done along the same survey lines.

Basement rock sampling (institution in charge; JOGMEC, AIST). The geological continuity was examined and discussed from the constituent rocks of the geologic bodies. To sample the geologic bodies on site, drilling using the benthic multi-core system (BMS) set on the seafloor was employed as much as possible. Depending on conditions of the seafloor morphology and depth, rock samples were also collected by dredging. AIST was in charge of the dating, identification of trace elements and isotopes, and the analysis and interpretation of samples of all the regions. Since the crustal structure survey and basement rock sampling were handled by multiple institutions, each institute was allotted its target regions in the surveys.

(3) Preparation of the application documents

As the working group that will draft the application documents, the "Task Force for the preparation of Japan's Submission (hereinafter, will be called the Task Force)" was established under the Interministerial Committee for Japan's Submission that was composed of the administrators of the ministries and agencies involved. The Task Force was composed of the members from: Ministry of Foreign Affairs (MOFA); Japan Coast Guard (JCG); Japan Agency for Marine-Earth Science and Technology (JAMSTEC); Japan Oil, Gas and Metals National Corporation (JOGMEC); and AIST. While the final goal of the Task Force was to prepare and draft the application, it was also in charge of coordinating the regional surveys as well as the analysis of the results of the surveys. The Task Force included the members from the institutes conducting the survey, and had a good understanding of the progress of the surveys.

The Task Force met as appropriate to discuss the integrating policy, to understand the current progress, to solve the mutual issues, and to keep the schedule. Smaller working group meetings consisting of a small number of people were also held to discuss specialties or individual regions and to tackle specific issues. The groups were composed of the members of various institutions, and since the work was done at the institutes to which the members belonged, the meetings where people could actually meet face to face, discuss, and make adjustment were important. There were more than 50 general meetings of the Task Force, and there were even more meetings of the smaller working groups.

From AIST, nine specialists of marine geology and geophysics (structural geology, petrology, stratigraphy, submarine resources, gravimetry, and magnetics) participated. The drafting of the application documents started with the study of what a continental shelf was. Then, the members of AIST set out to investigate the whole region based on the respective fields of science and technology, and worked on the scenario for individual regions to determine the outer limits of the continental shelf through analysis and integration of data. AIST was in charge of documenting the technologies used for obtaining the survey data and their analysis, and drafting the regional documents describing the evidences for the extended continental shelf.

4 Implementation and results of the Continental Shelf Surveys by AIST

The geoscience research sector of AIST that conducted the integrated geological survey and research forms the largest geoscientific research institute in Japan. In participating in the Continental Shelf Surveys, a continental shelf project team was established at AIST to handle the "regional survey," "analysis and interpretation of the rocks," and "preparation of the application documents." AIST has been conducting marine geology surveys for all areas of the seas around Japan till today, and has accumulated a large amount of geoscientific data and know-how for the geological survey in the regions. So, AIST has a well-grounded geoscientific foundation that enables it to look at and interpret any regions around Japan from the geological and geophysical point of views to integrate the data as a geological map. Because there are many specialized researchers and personnel who have the geoscientific knowledge of the regions relevant to the extended continental shelf, it was expected to make major contributions. Moreover, AIST has high standards in the techniques and researches of dating the rocks[7] and analysis and interpretation of the trace elements. Particularly in the dating the rocks in the region, it had the highest-level technology in the world for accurately calculating the formation ages by evaluating the degree of the weathering and alteration in marine environments.

Of the Continental Shelf Surveys conducted by AIST, "regional survey" and "analysis and interpretation of the rocks" are described in subchapters 4.2 and 4.3. For "preparation," AIST's contribution to the Task Force is described in chapter 5 in relation to the drafting of the application documents. These three tasks including the "preparation" were not individual activities but were closely related. It should be particularly noted that these tasks were carried out thoroughly and in a well-coordinated manner in every respect because AIST and many of its researchers were in charge of more than one task at the same time.

4.1 Activities of marine geology survey by AIST

The Geological Survey of Japan that was the predecessor to the geoscience sector of AIST is a research institution with 130 years of history since its establishment in 1882. Since its inception, the survey and research for the geology of Japanese land area has been done steadily, mainly for resources exploration. The geology of Japan has been clarified and published in various geological maps. In 1974, the Marine Geology Department was established staffed with a substantial number of experts in environmental coastal stratigraphy and limnology and a full spectrum of survey and research on marine geology began in Japan. It was also the time of a rising expectation in society for the development of marine resources such as manganese nodules. The R/V Hakurei-maru for geological survey that was launched also in 1974 has been used to study the offshore geology of Japan and its first achievement resulted in the series of publications of 1:1,000,000 marine geology maps of the waters around Japan, followed by the detailed scaling of the geologic structures, and the sedimentological maps of the waters surrounding the four main Japanese islands. As for the regions relevant to the Continental Shelf Surveys, the survey for the 1:1,000,000 marine geological map for the "Ogasawara Arc to Northern Mariana Arc," the survey for resources such as manganese nodules and geologic structures in the "Northeastern Philippine Sea," and the trial survey of the hydrothermal deposits in the "Izu-Ogasawara region" have long been conducted. In addition to the above mentioned basic data of the region, the research was enhanced through the participation in the Ocean Drilling Program (ODP), the survey by American universities of the related regions, the joint surveys with the Ocean Research Institute (current AORI), the University of Tokyo, and the open application researches and cruises of Japan Marine Science and Technology Center (current JAMSTEC). Through such surveys and programs, the capability of the AIST researchers was highly recognized particularly for the Izu-Ogasawara Arc and the surrounding regions relevant to the Continental Shelf Surveys.

4.2 Regional survey and sampling of basement rocks

For "basement rock sampling," the rocks were sampled from the seabed by boring as many samples as possible in regions where the geological background was supposed to be critical in clarifying the formation and ages of the rocks of each point, the formation process of the geomorphology and geologic structures, and the geological continuity. Of the government ministries and agencies involved, these surveys were under the authority of the Ministry of Economy, Trade and Industry (METI), and the institutes executing the survey were JOGMEC and AIST. Using the R/V Hakurei-maru No.2 that was equipped with a powerful tool BMS, basement rocks were sampled at over two hundred candidate sampling points successfully.

AIST was assigned to survey in the offshore of East Japan region, and about two 30-day survey cruises were conducted in 2005 and 2007. Compared to other areas with possibilities of continental shelf extensions, there were very few detailed bathymetric data in this area, so the survey included two missions at the same time, i.e. the selection of the candidate sampling points for BMS and the ordinary geological survey.

In the actual survey, basement rock samplings were done by BMS or by a dredge. In some occasions, sampling by BMS could not be done due to strong currents and water depth beyond its capacity, and dredging was used in such cases instead. Since this survey was concurrently conducted as the discussions at the Task Force progressed on land, the sampling points were chosen so that it would be directly helpful to the geological reasoning that was necessary as an evidence for continental shelf extension. Also, the surveys were done taking heed of the high survey skills of AIST formed through its experience in dredge sampling, e.g. determining the position of the ship for sampling in narrow points correlated well with the bathymetric and seismic data, and skills to evaluate whether the sampled rocks were constituents of the basement or not.

There is a seamount called Mogi Seamount formed in the cretaceous period in the Izu-Ogasawara Trench off the coast of Hachijo Shima Island. The axis of the deepest part of the trench was disrupted at the Mogi Seamount, and the western slope of this seamount was morphologically joined to the continental slope of the Izu-Ogasawara Arc. The body of this seamount was deformed by the large displacement structure due to the normal fault accompanying the subduction of the seabed on the Pacific side. In the Continental Shelf Surveys, we succeeded in determining the range of the body of this seamount by sampling (Fig. 3).

As a byproduct of the Continental Shelf Survey, recommendations were made to name the seamounts that were not previously named in this survey region, based on the newly obtained bathymetric data in 2005. In the GEBCO-Subcommittee on Geographical Names and Nomenclature of Ocean Bottom Features, three new seamounts were named Hotta Seamount, Kazuaki Seamount, and Takahiro Seamount.[8]

4.3 Analysis and interpretation of the basement rock samples

The greatest significance of basement rock sampling was to prove the close correlation among the individual geologic bodies (basement rock samples) through the geological development, including the geological continuity. This is the geological principle of argument that supports the assertion for geomorphological continuity. For the submarine landmass consisting of continuous elevations, this argument plays the role of a key evidence for discerning whether they are "submarine ridges" which are not natural components of the continental shelf, or "submarine elevations" which are natural components of the continental shelf. Since this identification is connected to the application of one of the two limiting lines, it has a direct impact on the breadth of the extended continental shelf.

AIST has been carrying out various ranges of geological surveys started well before the Continental Shelf Surveys, particularly in the Izu-Ogasawara and Mariana regions. There have been ample discussions and arguments on the geological development and the tectonic history of these regions.[9] On top of these accumulated knowledge and arguments, newly compiled "basement rock data set" that covered the whole area in an extremely systematic manner was prepared, utilizing the advanced technology for dating and trace element detection for the basement rock samples. The precise dating and the geochemical properties provided multitudes of new findings on the geological development and the mechanism of geologic body formation of this area. These were published as academic papers, and were also excerpted in the application documents submitted to the UN, and further analyses are in progress for more publications.

One good example was the proof of the geological continuity of the Kyushu-Palau Ridge through analyzing the rock samples from the ridge. This ridge was a series of topographic elevations that run, as the name implies, from Kyushu to the Palau Islands. As a whole, it could be identified as a narrow band of elevations, and small and large seamounts have grown along this band. Before the Continental Shelf Surveys, there were hardly any data set for chemical compositions that showed the ages and types of the volcanic rocks that formed the foundation of this ocean ridge. The spider diagram pattern of trace elements and the determination method of the origin and component of the magma by isotope composition were applied in the chemical analysis of the major and trace elements of the basement rocks sampled from the seamounts that form the ridge, and the geological equivalency was shown that all basement rocks were composed of the island arc volcanic rocks. It was also found that the radiometric age of the volcanic rocks was concentrated around 25~29 million years ago, immediately before the onset of the spreading of the Shikoku and Parece Vela Basins[10] (Fig. 4). The concurrency of the formation age and the property of the volcanic rocks of the island arc clearly showed that the Kyushu-Palau Ridge was part of the volcanic arc that composed part of the Paleo Izu-Ogasawara-Mariana Arc before the formation of the Shikoku-

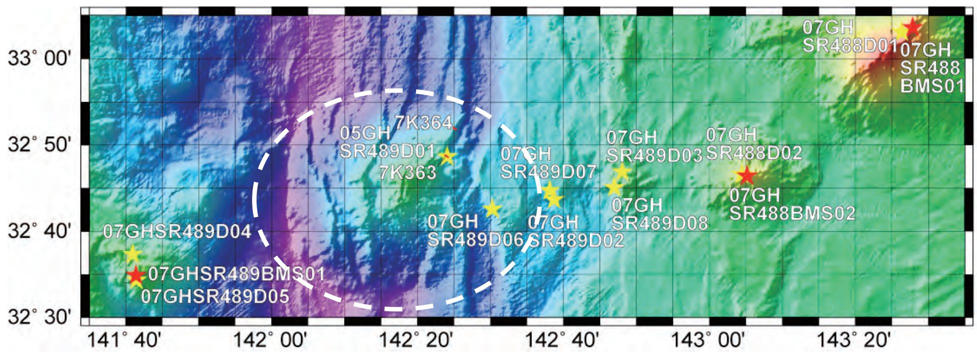

Fig. 3 Sampling of basement rock in the offshore region of East Japan (original map from Ishizuka)
Sampling points (red star – boring, yellow star – dredging) in the area around Mogi Seamount (surrounded by white dashed line) off the coast of Hachijo Shima Island

Parece Vela Basin, and that it was both geomorphologically and geologically part of the continuous submarine elevations.

Not only the basement rock data mainly of the igneous rocks of the area, but also other marine geological and geophysical data collected in the same survey by JOGMEC were analyzed by AIST and were published in papers.[examples are Refs. 11, 12]

5 Drafting highly reliable application and the submission of application

The Task Force that created the draft of the application documents started by considering what a continental shelf is, which contents should be included in the documents to be submitted for the continental shelf application, what is necessary, and how this should be tackled. Ultimately, the draft of the application was created by considering the geological and geomorphological properties of the ocean regions relevant to the Japanese continental shelf. Here, the issues in increasing the reliability and persuasiveness of the application and how they were overcome will be described, including the process of how the draft was written.

5.1 Understanding of the legal description

In drafting the application for the continental shelf, the bases were "the Convention," "Guidelines," "various documents of the CLCS," and others. Japanese is not one of the official languages of the UN. The Japanese translation of the Convention had already been published.[13] However in practice, in drawing the draft of the application documents in accordance with Article 76 of the Convention, it was necessary to consider the original writing rather than the Japanese translated text. On the other hand, there was no official Japanese version of the Guidelines. For the discussion and drafting of the application documents, and for organizing and explaining the research results in Japan, it was necessary to share a common understanding of the terminology and text of the Guidelines. The Task Force engaged in the discussions and creation of the translation for the Convention, Guidelines, and procedures. Except for the scientific terms, English to Japanese translation was done with the guidance from MOFA and the personnel who worked in the related sections, to study the strict legal terms and the conventional terms. This was an important process as a foundation that brought together people with different knowledge and experiences to jointly engage in the discussions and preparations.

5.2 Problem of terms in the Convention and Guidelines

Many "scientific terms" are used both in the Convention and the Guidelines. The term "continental shelf," for example, is a term that has a distinct legal meaning defined in the Convention, but it is also a "scientific term" defined

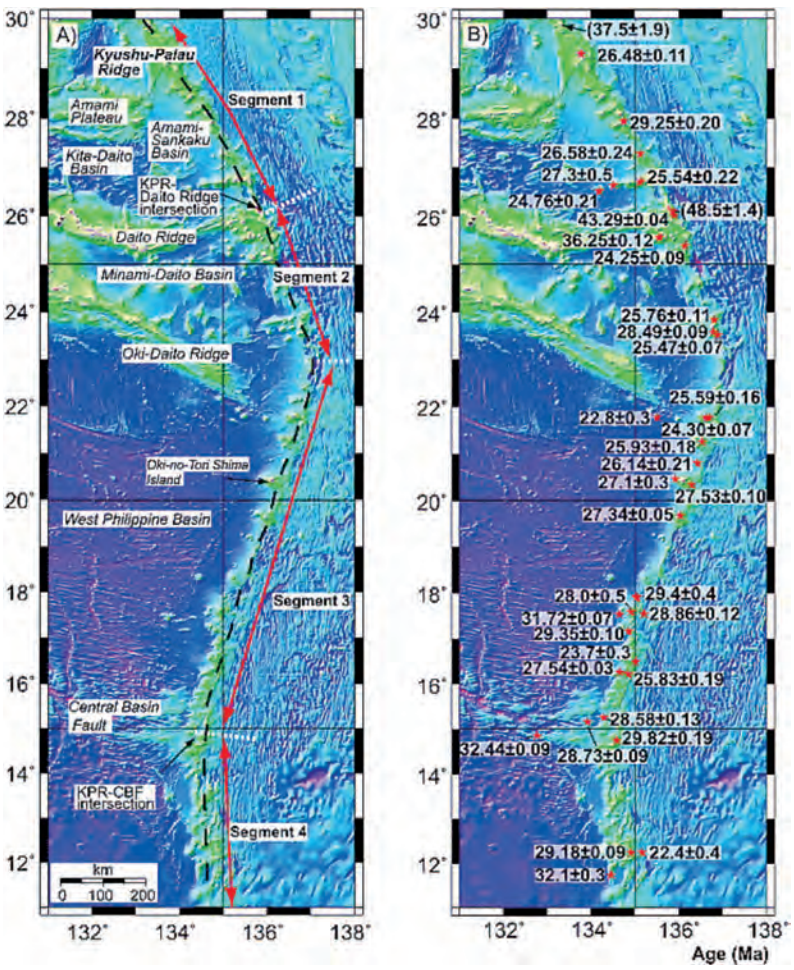

Fig. 4 Radiometric ages of volcanic activities of the Kyushu-Palau Ridge
A) Bathymetric features and their names, B) Distribution of $^{40}Ar/^{39}Ar$ age (in Ma; million years ago) of the volcanic rocks
Source: *Geochem. Geophys. Geosyst.*, 12, Q05005, Fig. 2[10]

differently in geomorphology and geology used commonly in society. When such "scientific terms" are used in the submission documentation or in determining the outer limits of the continental shelf, it is imperative to use them in the context of the legal meaning. In the early stage of the preparation work, the Task Force surveyed and discussed the historical arguments by CLCS and others, and the meaning and usage of those "terms" in the Convention and the Guidelines. The terms pointed and listed to be important by the Task Force are shown below.

・continental margin
・land mass
・continental shelf
・continental slope
・continental rise
・deep ocean floor
・oceanic ridge
・submarine ridge
・submarine elevation
・plateau
・rise
・cap
・bank
・spur

The following phrases comprise the heart of key legal concepts of the Convention with which our scientific discussion and evidences should comply.

・natural prolongation of the land territory
・natural components of the continental margin

Ultimately, for the use of the terms, importance was placed on the general reasoning that was described in the Guidelines. The terms were carefully chosen upon considering the characteristics of each extended continental shelf in the region of Japan, and their use was unified to avoid discrepancies when applying them as terms and concepts for the application documents by Japan.

5.3 Measures for the content and format of the application documents

Although we wished to engage in the drafting of the application documents by referencing the applications and recommendations of other countries, the detailed contents of the applications and recommendations of others were not disclosed when the Task Force started its work. Efforts were spent to collect information of the countries that applied earlier, and although we were able to know the outline, the details were unknown. From the autumn of 2008, the contents of the discussions and recommendations of the CLCS were disclosed, and the specifics of the discussions and recommendations between the CLCS and the applicant states during the examination processes are now disclosed.[14] However, when Japan was drafting the application, they were undisclosed and whatever was discussed at the CLCS was unknown.

In preparing the information for the continental shelf extension for the application to the UN, the structure of the documents and the content that must be described were presented in the Guidelines. The format of the documents and the number of copies that must be submitted were shown in the procedures. It consisted of three parts: the executive summary, the main body, and the supporting scientific and technical data. Only the executive summary was published on the website of the CLCS after the application was submitted. By interpreting the content of the abstracts that were submitted earlier, the frame of mind of the continental shelf decision and the basis of application were analyzed and used as references. The information on the outer limits of the continental shelf that must be written in the application included the interpretation of the paragraphs of the Convention by the applicant state, statement of the outline of the geomorphology and geology of the target region, and the most important information was the evidences of continuity from the territorial land to the continental margin based on geomorphology and geology. The documents must specifically include the information of the base of the continental slope, the position of the foot of the continental slope determined according to that information, and the range of the continental shelf considered according to the Convention and the Guidelines.

5.4 Convincing expression

In the work for creating the application for the Japanese continental shelf, focus was placed on presenting the maximum continental shelf by applying the Convention, starting with the interpretation of the paragraphs in Article 76 of the Convention that determined the continental shelf as discussed earlier and from the geomorphological and geological property of the target Japanese region. Therefore, the focus was placed on the final conclusion, or the decision of the foot of the continental slope and the interpretation and description of the continuity from the territorial land. However, in the preparation at the final stage and in the explanation after submission, the focus shifted to the explanation of the proof of geomorphological and geological continuity through the understanding of the temporal change of the geomorphological and geological features of the whole area and the individual target regions. Taking this into account, we decided to provide a simple explanation of the so-called historical formation process of the target regions by describing the present geomorphological and geological features and explaining how the features were formed. Therefore, importance was placed on the description of the background geomorphology and geology of each region, and figures were used to promote simple and comprehensive understanding.

For landform, since it is a "form," showing the diagram before describing by words was the requirement for achieving understanding. There was no definitive standard of how to show the geomorphological continuity, and the expression and the understanding obtained from it were important. The precise bathymetric survey in the Continental Shelf Surveys had been done over a long time, and the sounding data that covered almost 100 % of the target region were accumulated by the state-of-the-art bathymetric survey using the multi-narrow-beam echo sounder (SEA BEAM). Using these data, a characteristic method unseen in the application by other countries was used to determine the foot of the continental slope that was extremely important in determining the outer limit of the continental shelf (the method for this determination is written in the Guidelines). For geomorphology of land, the terrain reading by stereoscopic viewing of aerial photo or the 3D images created by the digital elevation mode (DEM) were used. For the geomorphology under sea, since seawater was in the way, the overall image could not be seen by flying over on an aircraft, looking out from a ship, or travelling on a submarine. However, the 3D image of the landforms could be created from the precise, wide-range digital depth data obtained in the Continental Shelf Survey. The landforms could be expressed by various methods such as the bathymetric map, contour map, or the shaded map. However, the 3D image was best for the understanding of the information of various landforms that included the whole geomorphology, the form and arrangement of the small geomorphological features, and the relationship of those features to the main geomorphology. Based on the experiences accumulated in the visualization technology of the geophysical data, the members at AIST contributed greatly in creating the presentation material using the advanced 3D visualization technologies such as geomorphologic 3D imaging and anaglyph[15] (Fig. 5).

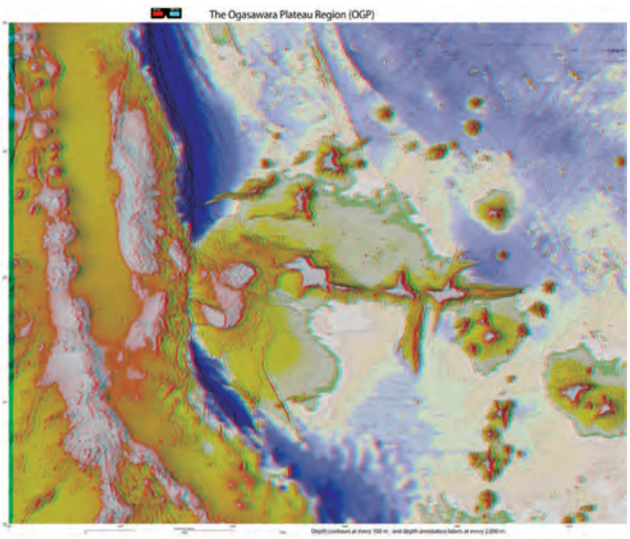

Fig. 5 Anaglyph 3D geomorophological map in the vicinity of "Ogasawara Plateau"
The dynamic form where the Ogasawara Plateau collides and accretes to the Izu-Ogasawara Arc from east to west, past the joint of the Izu-Ogasawara Trench and the Mariana Trench (can be seen in 3D when viewed using red-blue glasses)
Source: *AIST TODAY*, 9 (6), (2009)[16]

5.5 Discussion of the extension of the continental shelf based on the characteristic of Japanese geology

It can be imagined that the continental shelf in the Convention was defined based on the geomorphology and geology observed around the continental margins along both sides of the Atlantic. The description, "the continental margin comprises the submerged prolongation of the land mass of the coastal State, and consists of the seabed and subsoil of the shelf, the slope and the rise (section 3, Article 76, the Convention)" clearly showed that tendency. The continental rise was a landform created by the continental breakup, denudation of the continent after the breakup, and the accumulation of the deposits of erosion at the lower part of the slope. It was a product of a passive margin. The foot of the continental slope was used as the standard point when determining the continental margin in the Convention, and when the continental rise was present on the outer side of the slope, the standard point was the upper limit of the continental rise. On the other hand, the topographic elevations in the target region for the extension of the Japanese continental shelf were those in active margins. They were island arcs and intraplate volcanoes, and these were formed by the accretion and collision in the subduction zone of the plates, island arc magmatism, and intraplate magmatic processes. The sediments accompanying the growth of the marginal zone, that is, the volcanic deposits due to the activities of island arc volcanoes and intraplate volcanoes, as well as the volcanic rocks such as the lava created the slopes with the progressive growth of the volcanic body, but these slopes were not continental rises. Considering the differences of the geomorphological and geological processes, careful explanation was provided in the application of the Japanese continental shelf to describe the consistency between the definition and interpretation of the Convention and the characteristics of geology of Japan.

The western slope (inner-arc slope) of the Izu-Ogasawara Arc forms a series of the geomorphology from the active volcanic chain of this arc to the Shikoku Basin (Fig. 6). How this inclined morphology is judged by the CLCS greatly affects the range of the continental shelf because it is related to the determination of the foot of the continental slope that is important in determining the continental shelf. Looking at the growth process of the Izu-Ogasawara Arc, it started from the volcanic activities that derived from the subduction of the oceanic plate at the trench in the Eocene Epoch. The growing island arc eventually formed an intra-arc rift due to the increased heat source accumulated beneath the island arc, and split into the island arc of the next generation (current Izu-Ogasawara Arc) and the back-arc of the remnant arc (Kyushu-Palau Ridge). The back-arc basin formed between the two features became the Shikoku Basin. At the extremities of the Shikoku Basin, rift walls were formed accompanying the separation between the island arc and the remnant arc, and this showed the characteristic of the passive marginal area.

Therefore, using the geological data and formation history, it was specifically explained that the slopes were formed as part of the series of island arcs in the west side of the Izu-Ogasawara Arc, a passive marginal area.

It is said that magnetic lineations are present in the relatively flat inner-arc slope area on the west of Nishi-Shichito Ridge that was the back-arc ridge of the Izu-Ogasawara Arc (Fig. 6 bottom). If this indicates the presence of an oceanic crust accompanying the spreading of the Shikoku Basin, the inner-arc slope of the Izu-Ogasawara Arc can be considered the ocean floor itself, or can be deemed the same as the continental rise of the deposits formed on the deep ocean floor. Therefore, it is possible that this upper limit will be identified as the base of the continental slope. However, by showing that the geologic body that composes the inner-arc slope is the volcanic complex (deposits and intrusive body) originating from the island arc, and that it is continuous from the volcanic body of the back-arc ridge in terms of geologic structure, it can be shown that this is geologically a series of slopes and that it is part of the continental slope that continues from the shelf of the islands on the Izu-Ogasawara Arc. The basement rocks collected from the region clearly showed the characteristics of the island arc volcanic rock as a result of the chemical analysis for major and trace elements. The results of radiometric dating showed that the volcanism in the region had been active during the period of the formation of the Izu-Ogasawara Arc since the end of the spreading of the Shikoku Basin, and that the period of the volcanism of the inner-arc slope has a tendency to be young

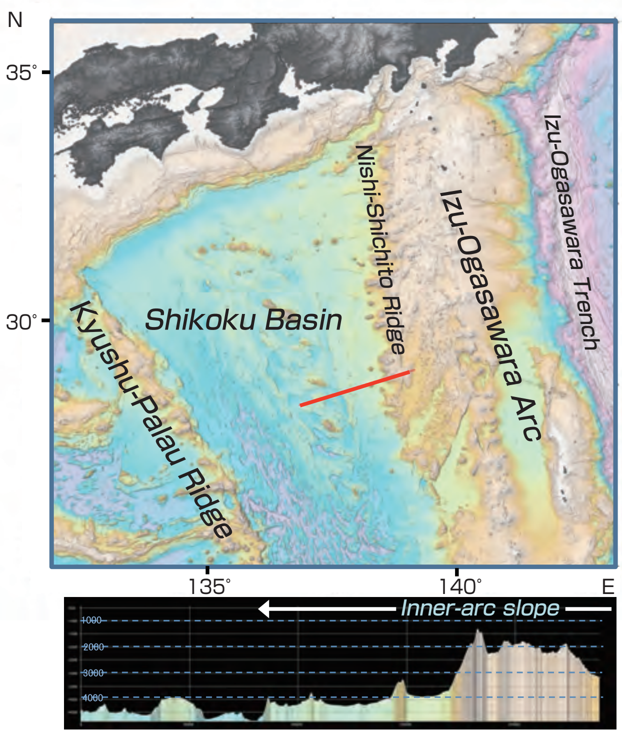

Fig. 6 Geomorphological map from the Izu-Ogasawara Arc to the Kyushu-Palau Ridge
The diagram at the bottom is the bathymetric profile along the red line of the top figure (the vertical exaggeration is 12 times).

easterly to the current volcanic front, that is, a series of island arc volcanic activities from the back-arc to the volcanic front during the development of the arc has been widely observed in the inner-arc slope.[17] One half of the split or the current Izu-Ogasawara Arc maintained active volcanic activity, and formed the volcanic body widely in the slope area of the back-arc and the sedimentary strata by the massive amount of volcaniclastic materials. The back-arc side of the island arc has two characteristics of active and passive margins, but it was concluded that the inner-arc slope was formed with the growth of the island arc by the island arc volcanic activity. This is an example of the characteristic of the geology of Japan and the discussion of the continental shelf extension.

6 Future prospects

6.1 Geoscientific issues after the Continental Shelf Surveys

Extremely detailed, varied, and massive amount of scientific data were accumulated for the southern submarine region of Japan in the Continental Shelf Surveys. These were described in the application documents as the information on the outer limits of the continental shelf and were used in the deliberation process. Some results were published in scientific journals, and further analyses and write-ups are being done for publication. Also, through these surveys, great results were born due to the synergetic effect of the data set of geomorphology, geology and crustal structure. Brief explanation of the future research topics in geosciences that should be pursued by the AIST researchers are as follows.

1. Geological development of the Izu-Ogasawara-Mariana Arc and the Philippine Sea: The work of constructing the structural geological development of the southern submarine region of Japan in the framework of global plate tectonics using the new data and interpretation of the Continental Shelf Surveys has not been completed. To propose a new detailed model from the diverse and massive data and their analyses is a major topic that must be done as the scientific fusion in the Continental Shelf Surveys.

2. Genesis and development of submarine volcanoes integrating the precise geomorphological and geological data: Because of the precise bathymetric survey that was done as a part of the Continental Shelf Surveys, the southern region of Japan has become an area with extremely detailed geomorphological information. In this region, there are topographic elevations formed by the intraplate igneous activity and island arc igneous activity, and basin floor formed by the spreading of the seafloor in the back-arc. The geomorphological features formed by the igneous activities are the main components. We hope for advancement of the research to clarify the details of the history of the wide-range igneous activities and the formation process of the individual volcanic bodies, by combining the geological ages and the

characteristics of the rocks from the basement rock sampling.

3. Geologic structure and igneous activity as constraints for genesis and process of the submarine mineral resources and evaluation of resources potential: With the move of the foreign companies to develop the hydrothermal deposits in the regions around Japan in the past few years, as well as increased price of rare metals in the world market, a move toward the development of the mineral resources is becoming active in Japan. There are known submarine hydrothermal deposits in the regions where the development and process of the geologic structure have become clear in the continental shelf survey, such as for the Japanese EEZ. For the future exploration of the submarine hydrothermal deposits, it is necessary to provide the geological and structural constraints of the mineral deposit location and the guideline for the exploration of new deposits that may be exploited in the future.

Moreover, there were improvements of the technologies for surveying and sample analysis, confirmation of the efficacy of the methods, and accumulation of technical know-how. These should be utilized when working on the above topics.

6.2 Application by Japan

The Japanese government submitted the application to the CLCS on November 12, 2008, and it was received. The "executive summary" that was the abstract of this application was shown on the website of the CLCS.[18] This showed the map of the ocean region for which the application for the extended continental shelf was submitted and the tables of the coordinates of longitudes and latitudes that set the outer limits of the continental shelf, and the applied provisions. The main body of the application documents that presented the evidences for the continental shelf extension was not disclosed. Since the main bodies of the application documents of other countries were not disclosed, comparison could not be made; however, it was certain that the quality of the scientific data including the full covered bathymetric information based on the multibeam sounding data, analysis of a number of rock samples, geological interpretation of the analysis data, and crustal structure exploration data using seabed seismograph were highest amongst the applicants.

The application for the Japan's extended continental shelf involved the total surface area of 740,000 km^2 over seven regions[19] (Fig. 7). These included the regions where adjustments with the neighboring countries were necessary, even if the CLCS recognizes it as the Japanese continental shelf. The extended continental shelf application by the Republic of Palau after the submission by Japan included the overlapping area within the Japan's extended continental shelf in the Southern Kyushu-Palau Ridge region. Also, the regions of Minami-Io To Island, Minami-Tori Shima Island, and Ogasawara Plateau regions might overlap with the American

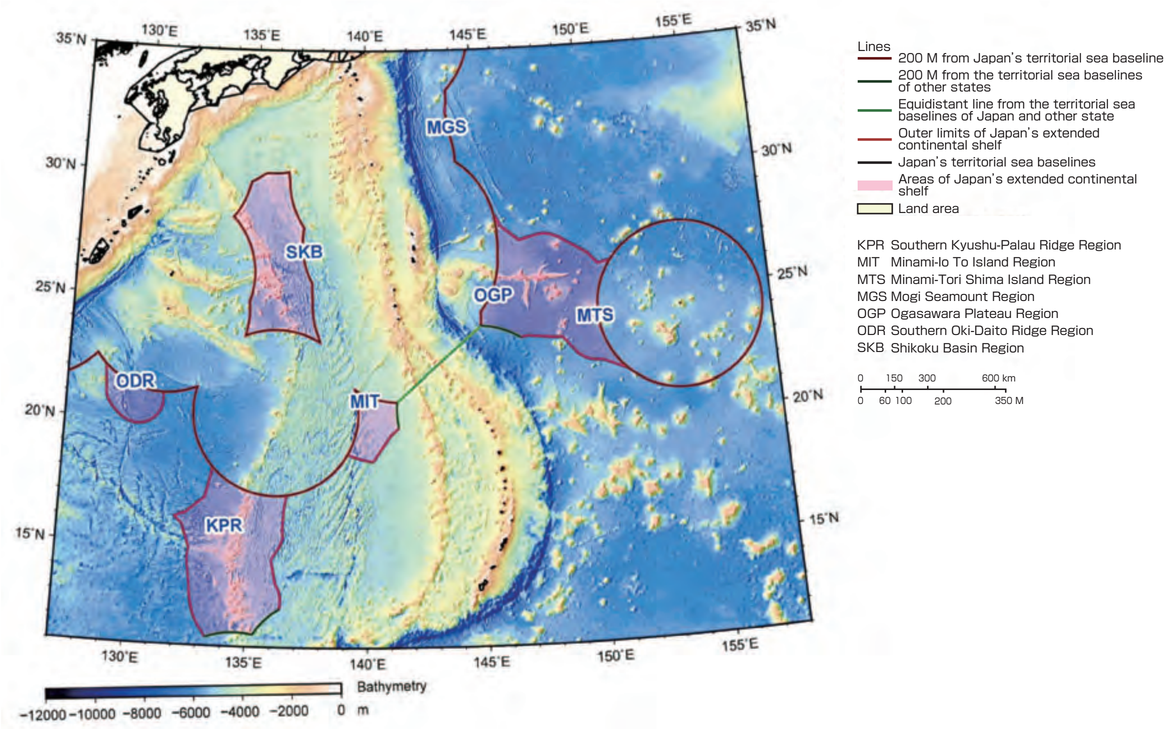

Fig. 7 Japan's extended continental shelf submitted to CLCS

Japan submitted the application for the extended continental shelf in seven regions (Southern Kyushu-Palau Ridge, Minami-Io To Island, Miami-Tori Shima Island, Mogi Seamount, Ogasawara Plateau, Southern Oki-Daito Ridge, and Shikoku Basin regions). The total surface area was about 740,000 km^2.[19]

Source: Commission on the Limits of the Continental Shelf (CLCS): Japan's submission to the Commission on the Limits of the Continental Shelf (executive summary) [18] extended continental shelf. The two countries have recognized the possibility of the overlap, acknowledged the fact that Japan would be applying for the extended continental shelf, and have informed Japan of this prior to Japan's application.[18]

The application by Japan was submitted as the 13th application. After submission by Japan, 37 applications were submitted by May 12, 2009 that was the deadline for many countries including Japan. The examination would be done, in principle, in the order of submission, and due to the number of members of the CLCS and its subcommittees, only three applications would be processed concurrently. If the submission by Japan was immediately before the deadline of May 2009, the start of examination would have been delayed, and we could not have predicted when the examination would start.

6.3 Examination and recommendations

The applications for the extended continental shelf are examined by the CLCS of the UN. There are 21 members of this commission, with regional balance of specialists from geology, geophysics, and hydrography. They are elected by vote at the Meeting of the States Parties to the Convention. For each application submitted by coastal state(s), a subcommittee consisting of seven members of CLCS is formed to conduct careful examination. The result of the examination is organized as recommendations, adopted and decided by the CLCS, and then publicized.

The examination of the Japan's Submission as the Japanese application documents started from the release of the application outline from Japan in the 23rd Session Plenary Meeting of the CLCS in March 2009. The subcommittee in charge of the Japan's Submission was established on September 2, 2009 at the 24th Session, and the full examination started there. The subcommittee examined for two and a half years from the 24th to the 28th Session, adopted the draft of recommendations in the 28th Session in August 2011, and reported it to the Plenary Meeting of the same session. At the Plenary Meeting, the examination of the draft of recommendations started in the 28th Session and the recommendations were adopted in the 29th Session on April 19, 2012. The Japanese government received the Recommendations on April 26, 2012.

The recommendations were given for the six regions out of the seven regions for which the application was submitted. The recommendations were postponed for the Southern Kyushu-Palau Ridge region. The extended continental shelf with a total surface area of about 310,000 km^2 was recognized, including the areas that required adjustment with the neighboring countries[20] (Fig. 8). This included the area that might possibly overlap with the American continental shelf as mentioned previously. The summary of the recommendations is disclosed on the website of the CLCS.[21]

After the submission of the application in 2008, the Task Force for responding to CLCS's examination on Japan's Submission (hereinafter, will be called the Task Force for responding

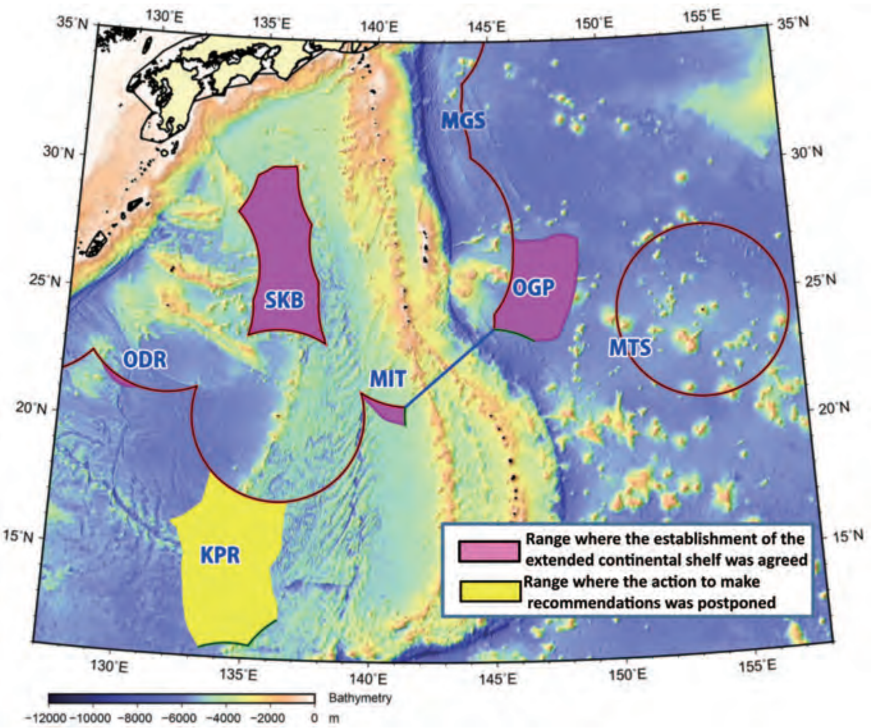

Fig. 8 Recommendation for Japan's extended continental shelf
Abbreviations for regions are the same as those in Fig. 7.
Source: Cabinet Secretariat: On the recommendations of the CLCS pertaining to Japan's extended continental shelf[20]

to CLCS's examination) started in January 2009. The main members of this new Task Force shifted from the Task Force for the preparation of Japan's Submission, including AIST members, and they prepared to answer questions and provide additional explanations in response to the examination of the Japanese application by the CLCS and its subcommittee. The activities included the creation of the answers to questions during the examination process, the presentation of the answers, and the participation as the Japanese representatives to the CLCS meetings held in New York.

7 Conclusion

Japan is surrounded by the sea and possesses the sixth largest EEZ in the world. If the Japanese government determines the outer limits of the continental shelf according to the "recommendations," the extended continental shelf will be obtained and the area in which the submarine resources can be explored will also increase. The "Basic Act on Ocean Policy" was enacted in 2007, and the Basic Plan for Ocean Policy was determined to reflect the law in the policy in 2008. Moreover, the "Plan for the Development of Energy and Marine Mineral Resources" was established in March 2009, and the surveys were promoted for the development of the resources in the ocean region. At the present point, the basic information on the Japanese EEZ and the continental shelf has not been organized sufficiently. Therefore, it is necessary to organize the information such as the geomorphology, geology, and the availability of resources, and to draw a long-term vision of the utilization and development of the resources and regions of the sea.

The members of the geoscience sector of AIST who participated in the Continental Shelf Project were diverse in terms of generation and role, and the sense of achievement in the Continental Shelf Surveys when the "recommendations" were issued and the meaning of the research activities in which they were involved differed. However, we believe that for the people who have engaged in the geoscience research to be involved in the scientific outcomes that helped maintain the international interest of Japan will become the starting point of future research activities.

Acknowledgement

In conducting this project, various support was provided by the Mineral and Natural Resources Division, Agency for Natural Resources and Energy and the Secretariat of the Headquarters for Ocean Policy, Cabinet Secretariat. The activities and work in the Task Force and the Task Force for responding to CLCS's examination were done jointly with their members, including Dr. Kazuchika Hamuro of MOFA and Dr. Yukihiro Kato of JCG. They provided various discussions and advice to the members of AIST.

In AIST, we received various supports from many people including: Dr. Eikichi Tsukuda, President and Research Managing Director of Geoscience Research (former Research Coordinator); Dr. Shigeko Togashi and Dr. Chikao Kurimoto (former Director of the Institute of Geology and Geoinformation;), and Dr. Masahiko Makino (Director of the Institute of Geology and Geoinformation); and Dr. Yusaku Yano, Deputy Research Managing Director of Geoscience Research (former Director of the Institute for Geo-Resources and Environment).

Dr. Kensaku Tamaki, who was Professor of the Graduate School of Engineering, The University of Tokyo and a member of CLCS, became ill during the CLCS meeting that was held in New York in April 2011, and passed away in New York. Dr. Tamaki worked at the Geological Survey of Japan. He was a friend to all of the authors of this paper, and we enjoyed his companionship during the survey cruise and research. He contributed greatly to the delineation of the Japanese continental shelf as a member of the Advisory Committee and as a member of CLCS, and has supported our efforts in many occasions. We present this paper with gratitude to the late Dr. Tamaki, as our activities for the survey for the Continental Shelf Surveys resulted in the "recommendations."

Finally, we shall list the names of the members other than the authors who participated in the Continental Shelf Project at AIST: Manabu Tanahashi, Osamu Ishizuka, Takemi Ishihara, Masato Joshima, Hajime Shimoda, Rie Morijiri, Eiji Saito, Tetsuo Yamazaki (Osaka Prefecture University from April 2008), and Yumi Tanaka. Dr. Osamu Ishizuka has granted us permission to use the original map of the offshore area of Hachijo Shima Island.

We express our thanks to the aforementioned people, and all those who offered us support in various forms.

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Discussions with Reviewers

1 Contribution of the AIST's geoscience sector to the Continental Shelf Surveys

Comment (Shigeko Togashi, AIST)

This paper presents the "process of making contributions to the submission for the extended continental shelf submitted by the government based on scientific evidence" conducted by the AIST Continental Shelf Project, which was the continental shelf delineation survey conducted by the government as a whole. It is appropriate as a *Synthesiology* paper because it is an example where the scientists were directly involved in returning the results of research to society, all the way to the presentation at the United Nations.

Specifically, the paper describes the position of AIST research in the overall scenario, as well as the activities conducted by the AIST researchers in the Task Force of the government, concerning the "regional survey," "analysis and interpretation of the rocks," and "preparation" for which AIST was in charge as a general research institute of marine geology.

Comment (Masahiro Seto, AIST)

This paper is a summary of the results obtained by the full-force effort of AIST geoscience field, in the "continental shelf delineation survey" that was an important project of the government. It mainly describes how AIST was able to make contribution based on its technological and scientific potentials, and how new scientific findings were made. I certainly think it is appropriate as a paper to be published in *Synthesiology*.

2 Restructuring of the paper from the synthesiological perspective

Comment (Shigeko Togashi)

While the first draft was like a "commentary," the paper has been dramatically improved by restructuring with attention paid to how the research was carried out and the methodology taken toward social contribution.

Comment (Masahiro Seto)

The first draft was like an activity report. The structure of the paper was changed after revision, the technological points in question were clarified, and I think it has improved much.

The comments on the first draft were as follows.

Comment (Shigeko Togashi)

Since the structure of the paper is like a "commentary," please restructure the chapters and the descriptions, provide a scenario, and add descriptions of the research potentials and research results so it will be appropriate as a *Synthesiology* paper. Also, please consider the research methodology, and describe the positioning of AIST research in the scenario.

Comment (Masahiro Seto)

I think this paper is like a report of the activities of the AIST team. Please describe specifically what the technological and scientific potentials were that were the basis of why AIST joined this project for the delineation survey. You mention that the age determination and analysis/interpretation of the trace elements of rocks were evaluated highly, but it is hard to see what the technologies were and how these technologies were related to this survey.

Answer (Akira Nishimura)

I am grateful that you provided advice on the basic problem and on restructuring the paper in the first review, and that you carefully read and checked the details in the second review. I revised most of the points that you have indicated.

3 Roles expected for AIST and the challenging issues

Comment (Masahiro Seto)

I think it will be easier to understand if you organize the roles expected of AIST and the challenging issues in "1 Introduction."

Please discuss specifically how AIST was able to determine the range of the extension with high reliability by integrating its potentials including the accumulated knowledge from basic research, and how it solved the new issues. I think the meaning of "challenge" will become clear if you describe what the technological issues were that posed new challenges in determining the extension range in the Continental Shelf Surveys, and what specific efforts were spent to overcome them.

Also, you write about the organizational changes such as the establishment of the Marine Geology Department in the "Role of AIST." Here, I think you should describe what the potentials of AIST's marine geology survey were, and in which scientific discipline AIST excelled as the best in Japan or as of world standard, to clarify the significance of why AIST participated in this survey.

Answer (Kiyoyuki Kisimoto and Akira Nishimura)

We simplified the "Introduction" and then wrote the roles in terms of "how we worked on the objective of conducting the survey for the delineation of the Japanese continental shelf, and thereby contributing to the making of the documents for the UN based on scientific evidences, and how we attempted to achieve the goal." Moreover, the meaning and role of AIST's participation to the Continental Shelf Surveys was described in the beginning of chapter 4, and the changes in the organization and the experiences in the past oceanic surveys were described as the pathways that built AIST's potentials. In subchapters 4.3 and 5.5, we described the case of "determining the extension range with high reliability" through the efforts by AIST.

Regarding the wording of "challenge" used in the English title and its Japanese equivalent "*chosen*," we'd like to elaborate a bit more about our rare experience of the Continental Shelf Mission, instead of giving a direct reference to an explanation, "technical issues as challenges," as follows .

The Japanese word *chosen* used here has closer connotation to the English word "challenge." meaning "a demanding or stimulating situation". In English, it probably can be rephrased: "the task was a scientific challenge for all geoscientists." In Japanese, it can be roughly translated to: "it was a rare occasion where the scientists took on the role of direct contribution based on the scientific and technological findings, for the extension and delineation (expansion of territorial land) that were goals that had not been handled before." It has a different nuance from (the challenge of assuming) the role of "making a discovery of a certain advanced technology or function" that is expected in ordinary scientific and technological efforts. When we explain our work on the continental shelf to a layperson, we do not say, "It's a challenge," but instead we say, "It's a rare opportunity for science." We came across the expression, "it is a scientific challenge," when we were working on various tasks and meeting people of the geological research institutes around the world in relation to the continental shelf. We were impressed that the word "challenge" could be used in such a situation.

It is not that any specific potential or capacity of geoscience research at AIST was challenged (of course, there was this factor), but the challenge was posed to AIST along with JHOD, JAMSTEC, and JOGMEC, which are institutes that hold national authority in the matter of geoscience necessary for the continental shelf delineation, and we were obliged to respond. There are more than 60 countries that submitted the continental shelf applications, and the examination for Japan was done as the 13th submission. The Japanese application was based on the overwhelming quantity and quality of bathymetric and geoscience information compared to other applications that had already been reviewed. Although USA, a major power in science and technology, has not yet submitted its application, the Japanese application stands out among other countries in terms of quantity and quality. However, it was not that the Japanese application was overwhelmingly advantageous. The geomorphological and geological background of Japan in the world was extremely "challenging" to prove and to convince others of the "extension of the continental shelf" in terms of the Convention. In that sense, "challenge" is used here with double meaning.

4 What the new findings and discoveries were

Comment (Masahiro Seto)

In the Continental Shelf Surveys, were there any new findings, discoveries, or inventions in geology or geophysics? The efforts you spent on the committees and documents are described in detail, but I think you should describe more of the technological aspects. For example, when you organized the basement rock data set, you found numerous facts about the mechanism of the formation of the geologic bodies and their temporal changes. Can you explain them a bit more specifically to the extent you can reveal to this journal?

Answer (Akira Nishimura)

I described them in subchapters 4.3 and 5.5.

5 Meanings of the "extended continental shelf" and "information on the outer limits"

Comment (Masahiro Seto)

You use the term "extended continental shelf," but that requires a definition. I think the "continental shelf to be extended" is better. Also if you can summarize what were the "information on the outer limits" necessary for applying for the extension of the range of the continental shelf, I think it would be easier to understand the issues and what you actually did.

Answer (Akira Nishimura)

When we first used the term "extended continental shelf" (subchapter 2.1), we stated the definition of the extended continental shelf as "the continental shelf beyond 200 nautical miles." Also at the end of subchapter 5.3, a simple explanation was provided for the "information on the outer limits of the continental shelf that must be written in the application."

6 Specific descriptions of technological issues

Comment (Masahiro Seto)

In the chapters "Regional survey" and "Analysis and interpretation of the basement rock samples," please discuss specifically what kinds of work and research were done in terms of the technological issues. In the "Regional survey," I think the selection of the points from which the samples were taken was important. Please describe specifically how AIST's knowledge and experience were utilized in selecting these points.

Answer (Akira Nishimura)

For the former, I added in subchapter 4.3: "The spider diagram pattern of trace elements and the determination method of the origin and component of the magma by isotope composition were applied."

For your latter indication, I added in subchapter 4.2: "Also, the surveys were done taking heed of the high survey skills of AIST formed through its experience in dredge sampling, e.g. determining the position of the ship for sampling in the narrow points correlated well with the bathymetric and seismic data, and skills to evaluate whether the sampled rocks were constituents of the basement or not."

An introduction to the Research Excellence Framework: A new research evaluation framework for universities in the UK

— A comparison with the status of research evaluation in Japan —

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This article introduces the Research Excellence Framework (REF): a new research evaluation framework developed by the Higher Education Funding Council for England (HEFCE) to evaluate the research activities of higher education institutions in the UK. To promote excellent research so that its potential effect can be maximized, the REF has three criteria for evaluating institutions: output quality, impact, and research environment. Remarkably, although the purpose of the REF is university evaluation, social impact is explicitly included within the evaluation framework. It is proposed that output quality be evaluated by conventional review with the aid of quantitative bibliometric indicators, such as the number of paper citations. In this article, we introduce the REF, from output to impact, and make recommendations for the evaluation of research for universities in Japan.

Keywords : REF, research and technology development evaluation, excellence, bibliometrics, impact, research environment, outcome

1 Introduction

The National Institute of Advanced Industrial Science and Technology (AIST) continuously conducts *Type 1 Basic Research*[1], *Type 2 Basic Research*[1], and *Product Realization Research*[1] on industrial technology to realize the philosophy of "*Full Research* in Society, for Society[1]." Its aim is to contribute to the realization of sustainable development by disseminating research results to society. To promote the broad-ranging research activities from basic research to applied research coherently and continuously is a significant new challenge, where a new research evaluation system is urgently needed.

The Higher Education Funding Council for England (HEFCE) provides basic funds to higher education institutions (HEIs) such as universities in the UK to support research infrastructure including full-time staff and their salaries, facilities, libraries, information systems, and so forth. In effective fund apportion, the HEFCE is currently developing the Research Excellence Framework (REF), which is a new, uniform research evaluation framework.[2] The REF is expected to be introduced for the evaluation starting in 2014, which will replace the Research Assessment Exercise (RAE), a research evaluation that has been conducted approximately every five years until now. (For the RAE, see Ref. [3].)

One of the major features of the REF is that it has explicit "impact" indicators as an evaluation criterion in addition to that for "output quality" such as the significance of a research paper. The HEFCE has proposed a weighting scheme that allocates 20 % to impact relative to 65 % to output quality, indicating that the impact is considered important. Because the budget is allocated selectively based on the evaluation, the introduction of this new framework will significantly influence the research activities at UK universities where the ratio of basic research is relatively high. The fact that an impact criterion was explicitly introduced this time suggests that universities in the UK are expected to generate continuous and strategic ripple effects for society through research.

This article intends to provide an overview of the REF based on the second REF draft[4] released in 2009. We believe this new evaluation framework in the UK will be beneficial for universities in Japan, which are currently struggling to establish a new evaluation system. In addition, because the REF's underlying vision to systematically promote research is quite similar to the strategic research and technology development from basic research to applied research undertaken at AIST (referred to as "*Full Research*[1]"), we might also expect to gain substantial insights for the evaluation of research activities at AIST. In this article, we have overviewed the concept of the REF and also discussed some implications for research evaluation in Japan.

2 The purpose of evaluation

The crucial point to understand before delving into the details of the REF evaluation framework is its rationale for conducting the evaluation. This is because the evaluation procedures (i.e.,

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methods, area of focus, design of review panel, etc.) are all derived from the rationale. In other words, the question of "what is this evaluation for?" becomes the foundation of the grand design for the entire evaluation.

At the center of REF's vision lies the concept of identifying, rewarding, and promoting research of "excellence." More specifically, the REF takes into account the UK's Government aim and expectations as to the role of research in HEIs: they should produce world-leading research across a wide range of academic fields, which in turn would play an essential role in underpinning social and economic growth; they should not only limit themselves to improving the quality of every form of research but also significantly exploit its full potential impact to the economy and society by effectively sharing research findings, disseminating and applying research results, and promoting productive interactions between HEIs and businesses or other users of research results. All these can be made possible by having excellent research as the foundation.

It is for this policy intention that the REF has been developed. The research evaluation should be designed to identify, reward, and promote excellent research effectively and efficiently to achieve this goal. There is a strategic national objective, rather than merely a "show" to fulfill an ostensible responsibility.

To promote excellent research at HEIs and demonstrate their maximum impact potential in this manner, three distinct research evaluation criteria: output quality, impact, and research environment have been introduced in the REF. These criteria have been accessed in advance through pilot exercises regarding the validity of their evaluation methods.[5] In the following sections, we have reviewed several key points in each criterion.

3 Evaluation of output quality

In the first evaluation criterion, namely output quality, the highest quality research output in a given research unit—the unit of evaluation roughly equivalent to a university's department—is selected and evaluated. The HEI under evaluation is required to identify excellent research conducted by the members of the research unit during the evaluation period. The quality will then be accessed through expert review with additional evidence such as citation information and other quantitative indicators of the output.

One of the new features in the REF is the introduction of these bibliometric data to reduce the burden of expert review and improve the transparent process. The HEFCE had initially considered replacing expert review completely with quantitative bibliometric assessment, at least in the fields of science, engineering, and medicine. However, pilot exercises and broad discussions concluded that the method is not sufficiently mature and robust to replace expert review. As a result, citation data will be provided to inform and supplement expert review of outputs in the science-related fields. For other fields such as arts, humanities, and social sciences, use of quantitative indicators are not recommended.

For an expert review that uses bibliometric data, the information relevant to the submitted outputs will be provided. It will be generated using REF's data collection system with a standardized process. The information is also available upon the HEI's request prior to the evaluation, which helps not only reduce the burden for preparation of output submission, but also eliminate discrepancy of information by using consistent dataset. Organization of the information system is another characteristic of the REF.

The primary focus to evaluate output quality is to identify excellent research. It focuses on research of the highest quality and is not intended to conduct a comprehensive evaluation of all research outputs conducted in the HEI under evaluation. This is to reflect the underlying policy that excellent research is being identified, rewarded and promoted. Therefore, even if it were feasible to evaluate all outputs, the REF does not look at those who are not engaged in important, high-quality research.

The REF also requires that the HEI under evaluation select outputs to be evaluated themselves. This is to encourage the HEI to recognize that only institutions under evaluation can identify their own research projects/individuals playing substantive roles. This also helps the HEI cultivate awareness on research management at these institutions.

Grey literature and any output published in a non-standard format are eligible for submission as well as traditional outputs such as refereed papers. These include documents published by the government and academic institutions without being circulated in the general publishing market, confidential reports to government, software, and other such cases. Similarly, research whose citation information is not likely to be available and applied research are eligible for submission. Such research includes projects conducted directly for/with the research users and studies to provide information for public policies. The intention is to give equal and maximum consideration to all high-quality research regardless of the format of outputs, not just to outputs that are measurable by quantitative indicators such as impact factors and/or citation index. The quality of output is evaluated based on the levels of "rigor", "originality", and "significance".

4 Evaluation of impact

The second criterion, namely impact, evaluates the extent of demonstrable influence built upon excellent research. Here, the term "impact" implies influence on the economy, society, public policy, culture, and quality of life, but does not include intellectual influence on academic communities, which is evaluated as “output quality”.

It is crucial to understand the concept of “impact” for conducting rigorous evaluation. In the REF, it is necessary for the HEI under evaluation to demonstrate that the impact for which they claim credit was built upon excellent research undertaken by a research unit within. In addition to that, it is required that the unit was actually involved in creating the impact (Figure 1, also see the description). In other words, it is not allowed to claim credit for impact that was developed and exploited by others irrelevant to the research unit even if the impact was originally based on research conducted by the unit.

For instance, let us first consider a hypothetical situation where a research unit obtained, compiled, and published a research finding, but did not further attempt to generate a profit by, for example, launching a venture company. Let us now consider that a for-profit company discovered the finding by chance, and consequently generated a vast amount of profit by using it without the unit’s involvement. According to the REF’s definition, this influence of the research finding to the company cannot be regarded as the research unit’s impact. In such a case, only the output quality of the original finding is eligible for evaluation as the achievement of the research unit. Thus, the “impact” defined by the REF is a very specific concept (examples of impact are summarized in Ref. [6]). This is one of the significant differences with Japanese universities’ evaluation where rigorous demonstration and verification for social/economic impacts are not necessarily required.

In general, it takes considerable time for impact to emerge; an impact that becomes evident during an assessment period is often the result of research during the earlier assessment period. The REF regards the impact as eligible for evaluation as long as it emerges during the assessment period.

The REF states that impact is evaluated at the research unit level because evaluating impact by individual research outputs and/or researchers would not be feasible in practice while evaluating impact by the entire institution (e.g., university) would be too crude. During evaluation, HEIs are required to identify the actions that resulted in impact, and also explain how the impact was exploited and developed.

Since it is generally considered difficult to evaluate impact using quantitative data only, descriptive methods are mainly employed. More specifically, the evaluation is conducted using two descriptive methods—case studies and an impact statement, both of which should comprise narrative explanations with appropriate indicators of impact as supporting evidence. The REF is proposing several standard indicators categorized into the types of impact (shown in Table 1) to reduce the burden of unit’s preparation for evaluation. The extent of impact is assessed by how widely the impacts are seen and how transformative the impacts will be.

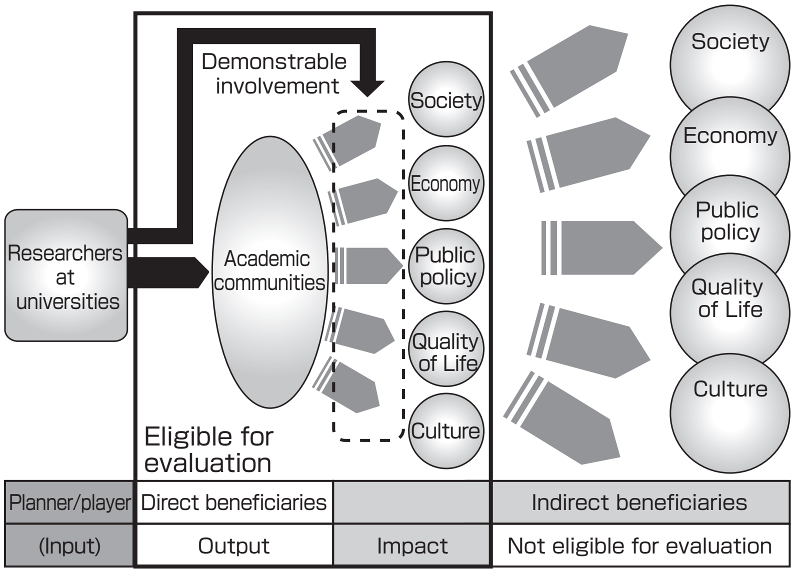

Fig. 1 Definition of output and impact: scope of the REF evaluation
“Academic knowledge” is produced through research activities by researchers in institutions such as universities, and disseminated to various audiences, such as society and the economy, resulting in multiple ripple effects outside academic communities. In this process, university researchers are the “planners and players” of research, academic communities where the academic knowledge is produced and shared are “direct beneficiaries”, and those who benefit from its ripple effects are “indirect beneficiaries”. In the REF, the term “output” corresponds to this academic knowledge and the term “impact” is defined as the ripple effects that were built on excellent research conducted by researchers whose involvement in exploiting and developing the ripple effects are demonstrable (the area within the dashed line). The scope of the REF evaluation is the outputs of the highest quality and the impact defined above (the area enclosed by the thick line). (Created based on Ref. [10].)

Table 1. Main types of impact suggested in the REF [4]

①Delivering highly skilled people
②Creating new businesses, improving the performance of existing business, or commercializing new products or processes
③Attracting R&D investment from global businesses
④Better informed public policy-making or improved public services
⑤Improved patient care or health outcomes
⑥Progress towards sustainable development, including environmental sustainability
⑦Cultural enrichment, including improved public engagement with science and research
⑧Improved social welfare, social cohesion or national security

(Source: An excerpt of the key points of "Research Excellence Framework - Second consultation on the assessment and funding of research", pages 41 and 42[4])

There are several issues that face challenges in evaluating impact: time lags, attribution, and corroboration.

"Time lags" refer to the fact that there can be lengthy time lags between the time at which research is conducted and the time at which its impact emerges. To address this challenge, the REF considers the impact of research over a sufficiently long period and sees broadly the entire impact of the research unit rather than corresponding individual impacts to specific outputs.

The term "attribution" refers to the fact that the process of impact to emerge from research is not linear, and there are numerous factors that affect the formation of impact. Therefore, it is necessary to identify what part of the impact is attributed to the activities of the research unit. To address this issue, the REF focuses on the unit's research-driven contribution to the exploitation of research in realizing impact. In this process, the REF also recognizes the limitation of quantitative metrics to measure the impacts of research. Thus, impacts are "assessed" qualitatively with supporting evidence, which is one of the reasons the REF came to require the narrative explanations for submission.

Finally, the term "corroboration" refers to various challenges associated with the verification of claims made about the impact. In the REF, third party corroboration and expert panels including the user of the research are formed to investigate the credibility of the evidence submitted by the research unit if necessary.

5 Evaluation of research environment and overall score allocation

The third evaluation criterion, namely research environment, assesses the quality of the research unit's environment: sustainability, contribution toward stimulating higher education research bases, and the extent of the contribution beyond the institution and the field. This criterion evaluates the research unit's wide range of support activities and its development of research infrastructure to effectively disseminate and apply excellent research on a continuous basis.

The REF allocates the heaviest weight to "output quality" and a relatively heavier weight to impact than to research environment in accordance with the strategic objective of the REF evaluation explained above. Because impact should be built on excellent research, the allocation influences the overall evaluation outcomes by giving a high score to excellent research that realizes impact.

6 Evaluation design

The REF does not evaluate individual researchers, or whole institutes; rather, it conducts evaluation "at the level of coherent research units that produces substantive bodies of work."[4] The units are to be defined by the range of substantive and coherent academic activities, whose level of details is suitable for funding and informing the REF of the research management. This is considered to be equivalent to a university's department in many cases.

Research units under evaluation should provide submissions that include information on research staff, outputs of high quality, details on qualitatively and quantitatively information on impact and research information, and so forth. The evaluation criteria and process will be set to be consistent across all disciplines and review panels although the REF allows some flexibility in terms of disciplinary differences. This would be useful for maintaining consistency in appraisals for funding purposes, and in eliminating unnecessarily complex procedures in preparation of evaluation for review panels.

7 Relevance to outcome-based evaluation and university evaluation in Japan

AIST began incorporating outcome-based evaluation into the evaluation of research units in fiscal year 2005. This is an evaluation method in which the objective, with regard to the outcome of the research to be produced for the social contribution in the future, is explained along with the scenario and roadmap on how to get there.[7][8] Initially, there was concern about the feasibility of the evaluation method; however, after more than seven years of experience, the method is well-established today, and it seems that it has had a significant effect.[9] What is unique about this evaluation is that an evaluation committee, which comprises of peers and stakeholders (e.g., people from universities, industry, media, government, independent administrative institutions, etc.), assesses whether the target for future outcomes and the path and methods to get there are reasonable. Although outcomes and impacts are closely related and partially overlap, they are not necessarily the same. According to Hirasawa,[10] outcome in the context of research and development refers to the "intrinsic or substantive aspects of the research and development results," and in the context of policies it is the intrinsic substance aligned to the purpose of the policy. For example, if there is a policy for disease prevention, then the intrinsic substance refers to, for example, trends in the number of patients. On the other hand, impact is positioned as "the ripple effect caused by an indirect result of the research after it has left the research and development sector" in the context of research and development, and as "the ripple effect other than intended results" in the context of policies. When outcome is defined as an intended result, while impact is defined as a ripple effect excluding intended results, it becomes clearly understandable that the cases of research and development—such as the ones at AIST—conducted after setting a clear objective, and the cases of research like the ones conducted with basic university funds to pursue "truth," have different aspects for evaluation: outcome and impact, respectively.

Meanwhile, under university evaluation (for national universities) in Japan, the National Institution for Academic Degrees and University Evaluation (NIAD-UE) has been assessing the state of education research in the medium-term target period.[11] The "Analysis of the State of Undergraduate and Graduate Schools" in Japan, which is roughly equivalent to the REF in the UK, corresponds to the output evaluation in the REF. As part of this research achievement analysis results, there is a section for the university to describe the social, economic, and cultural significance of the research in addition to its academic significance. The university is meant to explain the social, economic, and cultural contribution excellence of the research achievement along with objective indicators. Therefore, it is not that they do not consider the impact of research achievement, although we cannot say that it has incorporated a definite impact evaluation. It is interesting to note that lately the NIAD-UE has considered revising the method for evaluating national universities in the second mid-term period (fiscal year 2010 to 2015).[12] In particular, since it is currently at the university's undergraduate and graduate departments' discretion to determine how much of the support documents are to be devoted for evaluating academic significance as opposed to social, economic, and cultural significance, discussions are underway to enable the university to submit support documents for the evaluation of both areas of significance, rather than just one.

We believe that the largest difference between the REF and Japan's university evaluation lies in its utilization. Whereas the results of REF are clearly reflected in changes in the budget to individual universities, Japan's university evaluation has a major defect in that the results of the evaluation are not clearly reflected.

8 Conclusion

Thus far, we have provided an overview of the REF currently being developed. The fact that the UK has specifically introduced the concept of "impact" to evaluate universities where basic research is primarily conducted, and allocated a major significance to evaluating the dissemination of research results to society is quite characteristic.(note) It seems that in the UK,[13] the recognition is widespread that universities focusing on research with abundant entrepreneurial spirit to develop international competitiveness are indispensable to the prosperity and well-being of the state. Furthermore, it can be said that the UK is also focusing on promoting a new intellectual industry based even more on university knowledge to compensate for the weakness in manufacturing industry. From these reasons, it is likely that the UK is putting a great effort into the evaluation and the reform of its methods to produce tangible benefits.

This trend is commonly observed in developed countries that are striving to promote innovation, enhance international competitiveness, and build a sustainable society through research and development. This type of impact evaluation might become a useful tool at public research institutions in Japan such as AIST.

Meanwhile, there are debates on the introduction of an "impact" criterion for university evaluation.[14][15] The weighting scheme in the second draft that allocated a weight of 25 % to impact and 60 % to output, was revised in the final draft in 2011 to a weight of 20 % to impact and 65 % to output, based on the results of pilot exercises and feedback.[16] It will be interesting to see how this will be put into practice in the future.

Acknowledgment

Dr. Osamu Nakamura, Director of AIST Chugoku, and Dr. Chikao Kurimoto, Principal Evaluator, conducted a detailed peer review and provided valuable feedback to us. We also obtained valuable information regarding university evaluation from Associate Professor Takayuki Hayashi at the National Institution for Academic Degrees and University Evaluation. This article was based on the presentation at the 2nd research evaluation seminar held by the AIST Evaluation Department on March 22, 2012. We would like to take this opportunity to indicate our greatest appreciation to the officials of the Evaluation Department who provided us with this invaluable opportunity.

Note: The Research Council UK (RC) also provides separate research funding for UK universities (approximately half of the budget for basic research); however, they provide funds by evaluating each project or program independently. While they also have "impact" indicators as an important evaluation criterion, they look at expected future impact from the research results rather than actual impact.

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Authors

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Ryu Ohtani received Ph.D. in science from the University of Tokyo in 1999. Afterwards he joined the Agency of Industrial Science and Technology (currently the National Institute of Advanced Industrial Science and Technology: AIST) at the Ministry of International Trade and Industry where he conducted research on earthquake science and GPS meteorology using precise geodetic measurement. He was a visiting researcher at Stanford University from 2003 to 2005 and received Program Officer Certificate in research and development evaluation from the Program Officer Academy at the Japan Science and Technology Agency (JST) in 2012. He is currently a senior researcher in the institute of Geology and Geoinformation at AIST. In this paper, he wrote part of section 1, sections 2 through 6, and part of section 8 based on the chapters "Executive summary" through "Assessing the impact of research" in "Research Excellence Framework – Second consultation on the assessment and funding of research," on which this paper is based.

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Completed the master's program at Tohoku University's Graduate School of Science in March, 2009. Joined AIST the following April. After working in the Evaluation Department, joined the Technology Promotion Division of the Industrial Science and Technology Policy and Environment Bureau at the Ministry of Economy, Trade and Industry in April, 2011. She specializes in research evaluation theory. She translated the chapters "The research environment" through "Assessing socio-economic impact" in "Research Excellence Framework – Second consultation on the assessment and funding of research," on which this paper is based.

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Completed the doctoral course at the Graduate School of Engineering, Kyoto University in 1978. (Ph.D.) Joined the Electrotechnical Laboratory (ETL), Agency of Industrial Science and Technology (AIST), Ministry of International Trade and Industry (MITI) in 1978, and worked as director of Planning Division and director of Quantum Radiation Division from 1997. Director of Photonics Research Institute, AIST in 2001; vice president and director of Evaluation Department, AIST in 2003; vice president, director of Safety and Environmental Management, and director of General Affairs Headquarters in 2007. Professor of Center for Research Strategy, Waseda University since April, 2009. Specialties are optical device engineering, semiconductor material engineering, quantum beam engineering, and theories of research strategy and evaluation. For this paper, built the basic concept, considered the overall strategy formation, and discussed the synthetic research evaluation. In this paper, he discussed the current state of program evaluation in Japan based on the translation

of the chapters “Overall assessment outcomes” through “Accountability burden” in “Research Excellence Framework – Second consultation on the assessment and funding of research.” He also wrote part of section 1, section 7, and part of section 8, and supervised the paper.

Discussions with Reviewers

1 Overall

Comment (Osamu Nakamura, AIST Chugoku; Chikao Kurimoto, Evaluation Department, AIST)

With its main focus on providing recommendations for the evaluation system in Japan by introducing a new university evaluation framework in the UK, this is a timely article for considering the evaluation of synthetic approaches that helps to promote research on socio-economic innovations. Therefore, we recommend this article for publication in *Synthesiology* to widely spread the debate.

2 Comparison with the evaluation in Japan

Comment (Osamu Nakamura)

The overall structure is good. You have devoted a large segment towards introducing the REF in a straightforward manner. But, how about further exploring the discussion regarding the comparison with the Japanese evaluation system in practice (especially university evaluation)? More specifically, I would recommend that you describe the reality of university evaluation in Japan in more detail in section 7 to further highlight the differences from the REF case introduced here.

Answer (Naoto Kobayashi)

Based on your comment, we have added the following:

It is interesting to note that lately the NIAD-UE has considered revising the method for evaluating national universities in the second mid-term period (fiscal year 2010 to 2015).[12] In particular, since it is currently at the university’s undergraduate and graduate departments’ discretion to determine how much of the support documents are to be devoted for evaluating academic significance as opposed to social, economic, and cultural significance, discussions are underway to enable the university to submit support documents for the evaluation of both areas of significance, rather than just one.

We believe that the largest difference between the REF and Japan’s university evaluation lies in its utilization. Whereas the results of REF are clearly reflected in changes in the budget to individual universities, Japan’s university evaluation has a major defect in that the results of the evaluation are not clearly reflected.

In addition, you might ask why “impact” is vigorously introduced this way into the REF evaluation in the UK. It is probably because the university is motivated to proactively use the evaluation results for themselves by readily responding to requests from society and the government to contribute to the social value through these research results.

3 Eligible assessment period

Question (Chikao Kurimoto)

The paper does not mention the eligible assessment period (in terms of years) for the REF to be implemented in 2014. I suppose that research outputs are those generated within the eligible period (probably a period of multiple years), but research that has impacted society would probably be those completed prior to the eligible period. I do not think there will be a problem as long as the entity being evaluated (equivalent to a department in this case, assuming that it is in the scale of a research unit at AIST), is maintaining the research elements linking past research to current research. However, there may be difficulties in checking the realities of the research and its impact, and examining the impact after years have passed. What are your thoughts on this?

Answer (Naoto Kobayashi)

As you pointed out, the assessment period for the REF is for multiple years. For output, I believe it is the period between the time of the last evaluation and the deadline for submitting assessment documents for the current evaluation. Meanwhile, in the case of impact, while the period in which the eligible impact is made is the same assessment period as for the output, it seems that the research results that have made this impact are expected to have been generated up to approximately 15 years prior to this period. In fact, the pilot study of impact conducted in 2010 specified the period in which the impact materialized to be between 2005 and 2009, and the original research results that generated the impact to have been created after 1993. This information has been added to the paper.

As a note, our direct and indirect interviews with some officials who were involved in this pilot study indicated that it is extremely difficult to go back to research results obtained quite a long time ago, and the organization and storage of documents will become an important consideration in the future.

Referenced URL:

http://www.ref.ac.uk/background/pilot/

REF impact pilot: revised case study template and guidance, July, 2010

4 Explanation of the figure

Question (Osamu Nakamura)

Regarding figure 1, it would be nice to provide a detailed explanation as to what the figure indicates. Since this diagram is the essence of the REF structure, I would like you to provide an easy-to-understand explanation.

Answer (Ryu Ohtani)

We have added a detailed explanation to the caption of the figure as shown below:

“Academic knowledge” is produced through research activities by researchers in institutions such as universities, and disseminated to various audiences, such as society and the economy, resulting in multiple ripple effects outside academic communities. In this process, university researchers are the “planners and players” of research, academic communities where the academic knowledge is produced and shared are “direct beneficiaries”, and those who benefit from its ripple effects are “indirect beneficiaries”. In the REF, the term “output” corresponds to this academic knowledge and the term “impact” is defined as the ripple effects that were built on excellent research conducted by researchers whose involvement in exploiting and developing the ripple effects are demonstrable (the area within the dashed line). The scope of the REF evaluation is the outputs of the highest quality and the impact defined above (the area enclosed by the thick line). (Created based on Ref. [10].)

5 Utilization of impact evaluation indicators

Comment (Osamu Nakamura)

The types of impact are cited (Table 1). I recommend you to describe that it should be utilized to a great extent, as I think it provides specific and rich information that would be useful in Japan as well.

Answer (Ryu Ohtani)

We included a statement as recommended in the paper.

Lecture at the 27th Conference of the Japan Society for Science Policy and Research Management

Methodology of the introduction of technology to society from the analysis of papers published in *Synthesiology*

[Translation from *Synthesiology*, Vol.6, No.2, p.126-128 (2013)]

This is a report of a lecture and discussion session at the 27th Conference of the Japan Society for Science Policy and Research Management, held at the Hitotsubashi University on October, 2012.

***Synthesiology* Editorial Board**

Participants Naoto KOBAYASHI, Waseda University (Vice Editor-in-Chief, *Synthesiology*)
Motoyuki AKAMATSU, AIST (Editor-in-Chief, *Synthesiology*)

Kobayashi

It is almost five years since *Synthesiology*, a journal that aims "to establish a synthetic methodology that allows the researchers to conduct effective and efficient research that is useful to society," was first published in January, 2008. This journal requires "a description of the social value of the research goal," "a presentation of a scenario and a selection of elements," and "a correlation of elements and their synthesis and integration." We expect that the originality of the papers will be represented by the created scenario, the selected elements, and the method by which the elements are synthesized and integrated.

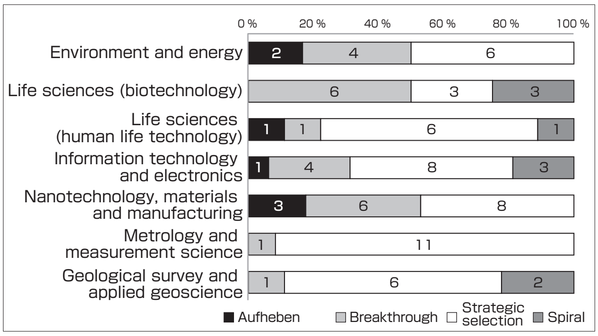
We have analyzed types of synthesis for 70 papers submitted so far in the six fields: environment and energy; life sciences and biotechnology; information technology and electronics; nanotechnology, materials, and manufacturing; metrology and measurement science; and geological survey and applied geosciences. The basic types of synthesis of elemental technologies are "aufheben type," "breakthrough type," "strategic selection type," and "spiral type."

"Aufheben type" is sublation proposed by Hegel, that is, the progressive integration of opposing elements, and we thought that it might also occur in technology. One example is the integration of glass mold and imprint methods. Although the glass mold method was conventionally applied to flat glass, it was not suitable for small structures. On the other hand, the imprint method was used to transfer structures of molds, but it was not suitable for use at high temperature. The two methods were combined to develop a new nano-level processing for glass. In the "breakthrough type," the peripheral elemental technologies are added to the main elemental technology to produce an integrated technology. For example, in "creating non-volatile electronics by spintronics technology," the double breakthroughs of the development of a new material and a new device as well as the development of a mass production technology were achieved. In the "strategic selection type," several elemental technologies are selected and integrated according to a preconceived strategy. The example of the "spiral type" is bioinformatics in the life science field. By creating a pipeline where the knowledge of the genetic characteristic of the G protein coupled receptor (GPCR) was developed and applied using a large-scale computer technology, the issues were extracted as this information was publicized and actually used, and the extracted elements were fed back for product realization. This is a new synthesis method that we did not originally consider.

In the six fields, the strategic selection type was the most prevalent, and 34 papers out of 70 were of this type. There were 12 breakthrough types, 7 aufheben types, 2 spiral types, and the remaining 15 papers were combinations of two or more types. From studying these papers, we were able to see, as the basic types of technological synthesis, aufheben, breakthrough, and strategic selection, and we also saw the importance of the synthesis method called the spiral type, where the interactions with society were repeatedly fed back to the research process. Also, it became clear that the synthesis type of technology was not uniform, but many layers of types could be combined, and that there were characteristic synthesis types for certain fields.

I have so far discussed the introduction of technology to society, so we shall now discuss the use of technology in society.

Result of categorizing into four types by fields
(Combinations are counted with overlap among various fields/types)



Akamatsu

Even if something is a wonderful technology or product (process) that may fulfill a social demand, it may not be easily accepted in society, and it does not necessarily spread easily throughout society once it is introduced.

Using the *Synthesiology* papers, we analyzed how the technologies and products were introduced to society from the perspective of the relationship between technology and demand. The cases can be divided roughly into the case in which "the social demand is clear" and that in which "the social demand is unclear."

Dr. Naoto Kobayashi

First, in a case where "the demand is clear," as it was explained earlier in "the development of a new material and a new device for the development of a mass-production technology" in spintronics, not only the elemental technology for high-performance, high-speed, and low energy consumption memory that society wanted, but also the manufacturing technology that the companies could actually use was developed. Another example where the usage in society is clear is the traceability system of measurement standards. If the technology is expected to lead to a product, stable performance is necessary, and the R&D should be done concurrently with the manufacturing technology to enable mass production of the industrial product. Another important perspective is that it is adaptable with minimum change to the existing manufacturing process. In the example of measurement standards, it employed an easy-to-use design that corresponded to the supply system of the technology.

Next, in the case where "the social demand is unclear," one way of execution is "to make a product and to demonstrate it." The examples are making an impact by creating a prototype of a portable and compact standard of length, or a prototype of a real-time, all-in-focus microscope. There is also the method of "having people try the product." This includes manufacturing organic nanotubes in the amount that could be provided as samples, or to have people use the Cyber Assist (context-dependent information service) at exhibitions or events in conditions that were close to the real situation. These examples impressed people by giving actual forms to technologies and by showing that products could be fabricated using the available technologies. As a product is used in diverse ways, the adaptability of the technology can be investigated and technical issues can be extracted.

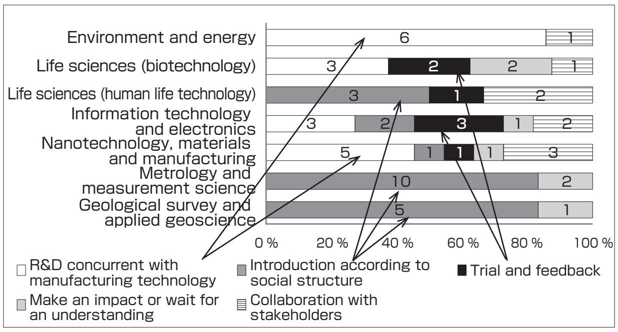
There are cases where "the demand is understood but there is hesitation." I think there are many such cases, and we have "to wait for the people to understand the usefulness" or "to just go ahead and do it." The "evaluation device of UV protection cosmetics" was a case where the basic technology was completed and the demands were understood, but we had to wait patiently since time was required for decision making. In the "dependable information system," not only were the information necessary on site recognized and explained, but also the importance and values were shared by actual demonstrations.

In the next phase, the product is made and set in society. In the "development and diffusion of the IH cookery and cooking system," value was added to the product when a cuisine specialist who was a sensitive lead user proposed new ways of using the product. Also, in Japan where car navigation systems are prevalent, the technology diffused not only through the effort of the car navigation manufacturer, but also through the collaboration of diverse stakeholders including the government, sensor manufacturers, map publishers, and others.

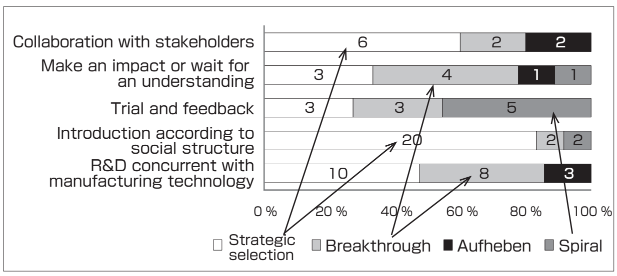
There are special characteristics of social introduction for different research fields. In many cases of the environment and energy field, the manufacturing technologies were developed concurrently. Since many energy problems involved CO_2 emitted by industry, the manufacturing technology development became important because of the need to solve the energy issues as a whole. In nanotechnology, materials and manufacturing, the manufacturing technology itself was the target. On the other hand, in the life sciences (human life technology), metrology and measurement science, and geological survey and applied geoscience fields, the technologies were mostly introduced by adaptation to the social structure. Many developments in the life sciences (biotechnology) and the information technology and electronics fields were spiral types that involved trials.

For the social introduction of the research results to society, it is important to instigate consecutive synthesis toward social introduction. Different approaches are necessary for different cases such as for cases where the social demand is clear or unclear or for cases where the expansion of industry is attempted. Considering “the creation of innovation from social introduction,” it is necessary to accumulate analyses of such synthesis examples, to analyze the dynamism, and to study how the scenarios should be constructed.

Characteristics of social introduction in each research field



Relationship between social introduction and technological synthesis



Audience

Isn’t there a discrepancy between the self-evaluation of the researchers and the external evaluation by the industries that use the results? I feel that such discrepancy is the reason that prevents innovations to occur.

Akamatsu

By writing a paper for *Synthesiology*, one often looks back on how one thought about the feedbacks to society. When you are able to clearly evaluate the degree of systematic thinking that was done, I think it would become easier to talk to society or companies.

Audience

I think basic research can be monitored by the number of citations of the paper. For the application to society, is there any monitoring method that can be automatically tracked?

Akamatsu

As one cannot tell whether the research results written in the conventional journals will actually be used in society, *Synthesiology* exists as a journal that allows the description of the process toward actual use. Although there is a matter of being lucky or unlucky in social introduction, a large factor is how much effort is spent or how much of a mechanism is created to control luck. It is difficult to measure this in a quantitative way, such as by the number of output. However, I think it is possible to evaluate the process. I think we can evaluate it based on whether the necessary process is taken with consideration of the social introduction.

Kobayashi

We believe it is important to accumulate case studies. I think this is where the corporate people excel, and I hope you will produce many papers of this nature.

Dr. Motoyuki Akamatsu

Editorial Policy

Synthesiology Editorial Board

Objective of the journal

The objective of *Synthesiology* is to publish papers that address the integration of scientific knowledge or how to combine individual elemental technologies and scientific findings to enable the utilization in society of research and development efforts. The authors of the papers are researchers and engineers, and the papers are documents that describe, using "scientific words", the process and the product of research which tries to introduce the results of research to society. In conventional academic journals, papers describe scientific findings and technological results as facts (i.e. factual knowledge), but in *Synthesiology*, papers are the description of "the knowledge of what ought to be done" to make use of the findings and results for society. Our aim is to establish methodology for utilizing scientific research result and to seek general principles for this activity by accumulating this knowledge in a journal form. Also, we hope that the readers of *Synthesiology* will obtain ways and directions to transfer their research results to society.

Content of paper

The content of the research paper should be the description of the result and the process of research and development aimed to be delivered to society. The paper should state the goal of research, and what values the goal will create for society (Items 1 and 2, described in the Table). Then, the process (the scenario) of how to select the elemental technologies, necessary to achieve the goal, how to integrate them, should be described. There should also be a description of what new elemental technologies are required to solve a certain social issue, and how these technologies are selected and integrated (Item 3). We expect that the contents will reveal specific knowledge only available to researchers actually involved in the research. That is, rather than describing the combination of elemental technologies as consequences, the description should include the reasons why the elemental technologies are selected, and the reasons why new methods are introduced (Item 4). For example, the reasons may be: because the manufacturing method in the laboratory was insufficient for industrial application; applicability was not broad enough to stimulate sufficient user demand rather than improved accuracy; or because there are limits due to current regulations. The academic details of the individual elemental technology should be provided by citing published papers, and only the important points can be described. There should be description of how these elemental technologies are related to each other, what are the problems that must be resolved in the integration process, and how they are solved (Item 5). Finally, there should be descriptions of how closely the goals are achieved by the products and the results obtained in research and development, and what subjects are left to be accomplished in the future (Item 6).

Subject of research and development

Since the journal aims to seek methodology for utilizing the products of research and development, there are no limitations on the field of research and development. Rather, the aim is to discover general principles regardless of field, by gathering papers on wide-ranging fields of science and technology. Therefore, it is necessary for authors to offer description that can be understood by researchers who are not specialists, but the content should be of sufficient quality that is acceptable to fellow researchers.

Research and development are not limited to those areas for which the products have already been introduced into society, but research and development conducted for the purpose of future delivery to society should also be included.

For innovations that have been introduced to society, commercial success is not a requirement. Notwithstanding there should be descriptions of the process of how the technologies are integrated taking into account the introduction to society, rather than describing merely the practical realization process.

Peer review

There shall be a peer review process for *Synthesiology*, as in other conventional academic journals. However, peer review process of *Synthesiology* is different from other journals. While conventional academic journals emphasize evidential matters such as correctness of proof or the reproducibility of results, this journal emphasizes the rationality of integration of elemental technologies, the clarity of criteria for selecting elemental technologies, and overall efficacy and adequacy (peer review criteria is described in the Table).

In general, the quality of papers published in academic journals is determined by a peer review process. The peer review of this journal evaluates whether the process and rationale necessary for introducing the product of research and development to society are described sufficiently well.

In other words, the role of the peer reviewers is to see whether the facts necessary to be known to understand the process of introducing the research finding to society are written out; peer reviewers will judge the adequacy of the description of what readers want to know as reader representatives.

In ordinary academic journals, peer reviewers are anonymous for reasons of fairness and the process is kept secret. That is because fairness is considered important in maintaining the quality in established academic journals that describe factual knowledge. On the other hand, the format, content, manner of text, and criteria have not been established for papers that describe the knowledge of "what ought to be done." Therefore, the peer review process for this journal will not be kept secret but will be open. Important discussions pertaining to the content of a paper, may arise in the process of exchanges with the peer reviewers and they will also be published. Moreover, the vision or desires of the author that cannot be included in the main text will be presented in the exchanges. The quality of the journal will be guaranteed by making the peer review process transparent and by disclosing the review process that leads to publication.

Disclosure of the peer review process is expected to indicate what points authors should focus upon when they contribute to this journal. The names of peer reviewers will be published since the papers are completed by the joint effort of the authors and reviewers in the establishment of the new paper format for *Synthesiology*.

References

As mentioned before, the description of individual elemental technology should be presented as citation of papers published in other academic journals. Also, for elemental technologies that are comprehensively combined, papers that describe advantages and disadvantages of each elemental technology can be used as references. After many papers are accumulated through this journal, authors are recommended to cite papers published in this journal that present similar procedure about the selection of elemental technologies and the introduction to society. This will contribute in establishing a general principle of methodology.

Types of articles published

Synthesiology should be composed of general overviews such as opening statements, research papers, and editorials. The Editorial Board, in principle, should commission overviews. Research papers are description of content and the process of research and development conducted by the researchers themselves, and will be published after the peer review process is complete. Editorials are expository articles for science and technology that aim to increase utilization by society, and can be any content that will be useful to readers of *Synthesiology*. Overviews and editorials will be examined by the Editorial Board as to whether their content is suitable for the journal. Entries of research papers and editorials are accepted from Japan and overseas. Manuscripts may be written in Japanese or English.

Required items and peer review criteria (January 2008)

	Item	Requirement	Peer Review Criteria
1	Research goal	Describe research goal (“product” or researcher’s vision).	Research goal is described clearly.
2	Relationship of research goal and the society	Describe relationship of research goal and the society, or its value for the society.	Relationship of research goal and the society is rationally described.
3	Scenario	Describe the scenario or hypothesis to achieve research goal with “scientific words”.	Scenario or hypothesis is rationally described.
4	Selection of elemental technology(ies)	Describe the elemental technology(ies) selected to achieve the research goal. Also describe why the particular elemental technology(ies) was/were selected.	Elemental technology(ies) is/are clearly described. Reason for selecting the elemental technology(ies) is rationally described.
5	Relationship and integration of elemental technologies	Describe how the selected elemental technologies are related to each other, and how the research goal was achieved by composing and integrating the elements, with “scientific words”.	Mutual relationship and integration of elemental technologies are rationally described with “scientific words”.
6	Evaluation of result and future development	Provide self-evaluation on the degree of achievement of research goal. Indicate future research development based on the presented research.	Degree of achievement of research goal and future research direction are objectively and rationally described.
7	Originality	Do not describe the same content published previously in other research papers.	There is no description of the same content published in other research papers.

Instructions for Authors

"Synthesiology" Editorial Board
Established December 26, 2007
Revised June 18, 2008
Revised October 24, 2008
Revised March 23, 2009
Revised August 5, 2010
Revised February 16, 2012
Revised April 17, 2013

1 Types of contributions

Research papers or editorials and manuscripts to the "Readers' Forum" should be submitted to the Editorial Board. After receiving the manuscript, if the editorial board judges it necessary, the reviewers may give an interview to the author(s) in person or by phone to clarify points in addition to the exchange of the reviewers'reports.

2 Qualification of contributors

There are no limitations regarding author affiliation or discipline as long as the content of the submitted article meets the editorial policy of *Synthesiology*, except authorship should be clearly stated. (It should be clearly stated that all authors have made essential contributions to the paper.)

3 Manuscripts

3.1 General

3.1.1 Articles may be submitted in Japanese or English.
Accepted articles will be published in *Synthesiology* (ISSN 1882-6229) in the language they were submitted. All articles will also be published in *Synthesiology - English edition* (ISSN 1883-0978). The English edition will be distributed throughout the world approximately four months after the original *Synthesiology* issue is published. Articles written in English will be published in English in both the original *Synthesiology* as well as the English edition. Authors who write articles for *Synthesiology* in Japanese will be asked to provide English translations for the English edition of the journal within 2 months after the original edition is published.
3.1.2 Research papers should comply with the structure and format stated below, and editorials should also comply with the same structure and format except subtitles and abstracts are unnecessary. Manuscripts for "Readers' Forum" shall be comments on or impressions of articles in *Synthesiology*, or beneficial information for the readers, and should be written in a free style of no more than 1,200 words. Editorials and manuscripts for "Readers' Forum" will be reviewed by the Editorial Board prior to being approved for publication.
3.1.3 Research papers should only be original papers (new literary work).
3.1.4 Research papers should comply with various guidelines of research ethics.

3.2 Structure

3.2.1 The manuscript should include a title (including subtitle), abstract, the name(s) of author(s), institution/contact, main text, and keywords (about 5 words).
3.2.2 Title, abstract, name of author(s), keywords, and institution/contact shall be provided in Japanese and English.
3.2.3 The manuscript shall be prepared using word processors or similar devices, and printed on A4-size portrait (vertical) sheets of paper. The length of the manuscript shall be, about 6 printed pages including figures, tables, and photographs.
3.2.4 Research papers and editorials shall have front covers and the category of the articles (research paper or editorial) shall be stated clearly on the cover sheets.
3.2.5 The title should be about 10-20 Japanese characters (5-10 English words), and readily understandable for a diverse readership background. Research papers shall have subtitles of about 15-25 Japanese characters (7-15 English words) to help recognition by specialists.
3.2.6 The abstract should include the thoughts behind the integration of technological elements and the reason for their selection as well as the scenario for utilizing the research results in society.
3.2.7 The abstract should be 300 Japanese characters or less (125 English words). The Japanese abstract may be omitted in the English edition.
3.2.8 The main text should be about 9,000 Japanese characters (3,400 English words).
3.2.9 The article submitted should be accompanied by profiles of all authors, of about 200 Japanese characters (75 English words) for each author. The essential contribution of each author to the paper should also be included. Confirm that all persons who have made essential contributions to the paper are included.

3.2.10 Discussion with reviewers regarding the research paper content shall be done openly with names of reviewers disclosed, and the Editorial Board will edit the highlights of the review process to about 3,000 Japanese characters (1,200 English words) or a maximum of 2 pages. The edited discussion will be attached to the main body of the paper as part of the article.
3.2.11 If there are reprinted figures, graphs or citations from other papers, prior permission for citation must be obtained and should be clearly stated in the paper, and the sources should be listed in the reference list. A copy of the permission should be sent to the Publishing Secretariat. All verbatim quotations should be placed in quotation marks or marked clearly within the paper.

3.3 Format

3.3.1 The headings for chapters should be 1, 2, 3…, for subchapters, 1.1, 1.2, 1.3…, for sections, 1.1.1, 1.1.2, 1.1.3, for subsections, 1.1.1.1, 1.1.1.2, 1.1.1.3.
3.3.2 The chapters, subchapters, and sections should be enumerated. There should be one line space before each paragraph.
3.3.3 Figures, tables, and photographs should be enumerated. They should each have a title and an explanation (about 20-40 Japanese characters or 10-20 English words), and their positions in the text should be clearly indicated.
3.3.4 For figures, image files (resolution 350 dpi or higher) should be submitted. In principle, the final print will be in black and white.
3.3.5 For photographs, image files (resolution 350 dpi or higher) should be submitted. In principle, the final print will be in black and white.
3.3.6 References should be listed in order of citation in the main text.

Journal – [No.] Author(s): Title of article, *Title of journal* (italic), Volume(Issue), Starting page-Ending page (Year of publication).

Book – [No.] Author(s): *Title of book* (italic), Starting page-Ending page, Publisher, Place of Publication (Year of publication).

4 Submission

One printed copy or electronic file of manuscript with a checklist attached should be submitted to the following address:

Synthesiology Editorial Board
c/o Website and Publication Office, Public Relations Department, National Institute of Advanced Industrial Science and Technology(AIST)
Tsukuba Central 2 , 1-1-1 Umezono, Tsukuba 305-8568
E-mail: synthesiology-ml@aist.go.jp

The submitted article will not be returned.

5 Proofreading

Proofreading by author(s) of articles after typesetting is complete will be done once. In principle, only correction of printing errors are allowed in the proofreading stage.

6 Responsibility

The author(s) will be solely responsible for the content of the contributed article.

7 Copyright

The copyright of the articles published in “*Synthesiology*” and “*Synthesiology English edition*” shall belong to the National Institute of Advanced Industrial Science and Technology(AIST).

Inquiries:

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Letter from the editor

We present you *Synthesiology* Volume 6 Issue 2. This issue carries five research papers, one commentary, and one report.

The research papers include: one paper on life science and biotechnology; two on nanotechnology, materials and manufacturing; one on information technology and electronics; and one on geological survey and applied geosciences. The fields are quite diverse. However, all the papers have in common the perspective of technology that seeks new social value. For example, a paper on life sciences discusses a training technology for the visually impaired; the papers on materials describe a large-scale, low-cost separation technology and a database technology for ceramic glazes; an electronics paper outlines video display technologies for arcade games; and a geological paper chronicles a continental shelf delineation survey. These are topics with major social impact. Concrete figures that show the scale of social impact are as follows: the extended continental shelf delineated was 310,000 km^2 which is almost equivalent to the Japanese land territory (geology); over 300,000 glaze test pieces were created in the ceramics research over 80 years (materials); and over 40 years have passed in the development of video games from its earliest stage (electronics). I believe these papers, which are written with a synthetic approach that characterizes this journal, will satisfy the readers.

The realization of social value is a common target for the world in this age of globalization where the main goal is the creation of innovation. It is being used as an index for evaluating the universities that must serve as the fountain of knowledge. The commentary in this issue describes the framework of a new evaluation method for universities in the United Kingdom, and this may affect Japan in the future. I think the article can be considered as a piece of information to which one should pay close attention.

Finally, the paper on the large-scale, low-cost separation technology of a new material introduces the research where a new breakthrough was obtained by the "fusion of different fields." This was a collaboration of the people of the life sciences and those of the nanotechnology, materials, and manufacturing, to apply a method used widely in life sciences to the nanotechnology field. An analysis of the method of synthesis and integration of the selected elements based on the papers of *Synthesiology* had been done, and a report in this issue includes the question-and-answer session when this analysis was presented at an academic society. The submissions of methodologies of synthesis and integration conducted in the R&Ds in diverse sectors are essential for such analysis, and I believe this will support the Japanese manufacturing ability. Therefore, I would like to ask for continued support of the readers and active submissions by the researchers to *Synthesiology.*

Editor-in-Chief
Shingo ICHIMURA

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