

Synthesiology

English edition

Developing an evaluation system of visually induced motion sickness for safe usage of moving images

Spinning process using robot technology

International cooperation for the utilization of earth observational data in an integrated manner

Development of a pressure sensor using a piezoelectric material thin film

Novel functional gels and their commercial distribution as chemical reagents

Evaluating the effects of actions taken to attract visitors to sightseeing areas

Development of basic tools for glycoscience and their application to cancer diagnosis

Synthesiology editorial board

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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Synthesiology Editorial Board

Note 1 : The period was named “nightmare stage” by Hiroyuki Yoshikawa, President of AIST, and historical scientist Joseph Hatvany. The “valley of death” was 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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Developing an evaluation system of visually induced motion sickness for safe usage of moving images

— Fermentation of a social understanding to supply secure and comfortable images through integration of researches on human characteristics, image analysis technique and image production technique —

Hiroyasu UJIKE

[Translation from *Synthesiology*, Vol.3, No.3, p.180-189 (2010)]

We have developed an evaluation system of moving images by estimating temporal variations of discomfort levels of visually induced motion sickness (VIMS) caused by the images. The system is useful for making image producers understand the importance of reducing the possibility of VIMS. This activity will provide an environment that allows people to use moving images at ease in a variety of fields, such as entertainment, education and medical services. The system was developed by the collaborative research of image analysis, image producing and measurements of biomedical effects to apply the basic characteristics of VIMS for evaluating general images.

Keywords : Image safety, visually induced motion sickness, biomedical effects, moving image evaluation, moving image guideline

1 Introduction

Visually-induced motion sickness (VIMS) is a condition where the following symptoms occur when a person views a moving image that contains certain motions relatively frequently.^[1] The symptoms include those of motion sickness (or so called travel sickness) such as dizziness, sweating, drowsiness, increased salivation, facial pallor, stomach awareness, nausea, and vomiting. While the innovative development of recent image media technology has dramatically advanced the possibilities of moving images, it also harbors the increased risk for the viewers who may suffer from VIMS, and quick measures must be taken.

The leading theory for the cause of motion sickness is the sensory rearrangement theory^[2] that proposes that the symptoms occur when the relationships among different kinds of sensory information, such as the visual and vestibular information pertaining to the body motion, differ from the ordinary situation of the body, and this discrepancy can be implicitly sensed as abnormality. A similar idea can be applied to VIMS. For example, the sickness may develop when the viewer is shown moving images as if the body is moving through space, though the actual body is static as one sits in the chair. More specifically, the sickness may be caused by the lack of vestibular perception caused by acceleration and the lack of tactile perception of the change in pressure from the contact with the chair surface, while the visual perception of body motion is presented.

With the development of the recent image media technology, computerized systems have been introduced into the production of moving images. With the wide spread of small, high precision digital video cameras, the expression of moving images with dynamic and vigorous scenes can be created. Also, large, high-precision displays have become available in homes, and people can enjoy viewing dynamic and realistic images. However, motions in such images may be perceived as physical motion information. Therefore, if no measures are taken, viewers may develop VIMS, and rapid measures are necessary.

Recently, occurrences that are thought to be cases of VIMS have been reported in the news. For example, in July 2003 at a junior high school in the Shimane Prefecture, 36 of the 294 first grade students who were watching a video on a large screen at a lecture hall for their class developed sickness and were sent to a hospital for treatment.^[3] The video image was shot by a hand-held camera, and the erratic movements that occurred frequently in the film are thought to have caused VIMS. A very similar case occurred in a school in the Mie Prefecture on November 2006.

VIMS may have greater effect than originally considered. In general, the symptoms may cease in a relatively short time by stopping the viewing in case of relatively mild cases, while for some people and under some conditions, unbearable symptoms may continue for the whole day. Such symptoms may be dangerous depending on the work in which the

Human Technology Research Institute, AIST Tsukuba Central 6, 1-1-1 Higashi, Tsukuba 305-8566, Japan
E-mail: h.ujike@aist.go.jp

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person engages, and people who experience motion sickness in aircraft simulators are banned from flying the aircraft for 24 hours after the simulator training.^[4]

With the advancement of image technology, the moving images are now used widely in various fields such as education, medicine, and welfare. To ensure many people can enjoy the benefits, the provision of the environment that prevents the occurrence of undesirable biomedical effect of moving images such as VIMS is mandatory and urgent. AIST created the term “image safety” as a concept to realize this, and is promoting the creation of a moving image guideline and is engaging in the international standardization activity.^[5] Image safety is not only important for the user of the moving images. For the Japanese image industry to advance steadily, image safety should be like the wheels of an automobile that works alongside the development of the image technology, and is absolutely necessary from the viewpoint of the people of image industry. Therefore, image safety is an issue that must be tackled with the cooperation and mutual understanding of the people of the image industry such as the production companies, image distributors, and image display device developers. Through joint research conducted under close cooperation and collaboration among external research organizations such as the universities and industry people, the author engaged in the R&D for the VIMS evaluation system, the tool to provide the solution. In this paper, I describe the necessity of the VIMS evaluation system and discuss the research scenario that led to the development.

2 Background of the R&D

2.1 Motivation that led to the R&D

To reduce the possibility of VIMS, it is necessary to create a guideline based on objective findings related to the factors that cause VIMS and the degree of effect of VIMS. However, guidelines may not be sufficient. A guideline basically has no binding power even if it becomes the international standard of the International Organization for Standardization (ISO).

For the guideline to be effectively utilized, it is necessary to create and review the guideline under the cooperation of the parties involved in production and distribution such as the image providers that use the guideline. There are a few points that must be considered. First, the image provider needs to understand that some effects of VIMS cannot be neglected. In general, many people may consider VIMS as a minor problem and whatever measures may be taken lightly. However, over 10 % of the students had to receive hospital treatment in the case of Shimane junior high school mentioned earlier,^[3] and it may be dangerous for people to engage in certain works immediately after viewing. Second, sufficient consideration must be given to the freedom of expression and freedom of artistic creativity. Guidelines and international standards are often taken as agents that

limit the art of image production, and the image providers are concerned that they may unjustly threaten the freedom of expression and artistic creativity. It is necessary to make considerations so people would not reject image safety. The following methods may be useful.

- (1) Prior to the creation of the image guideline to reduce VIMS, the importance of image safety including VIMS must be communicated in various ways.
- (2) A method that enables the image provider to specifically check the degree by which VIMS may occur by viewing certain images is developed, and this tool is used to raise the awareness for VIMS.

While issue (1) deviates from the topic of this paper, issue (2) is the origin from which we developed the VIMS evaluation system described in this paper.

2.2 Necessity of R&D

The VIMS evaluation system is a system to evaluate the degree of VIMS that may occur in people who view certain images. By entering the image that one wishes to evaluate, the degree of VIMS that may occur in the viewer is displayed as variation over time. This system is essential from the perspective of having the image providers understand the seriousness of VIMS and to reduce the occurrence of VIMS by utilizing the image guideline that will be created in the future (Fig. 1).

First, the system will be the tool that enables the image providers to specifically understand the degree and

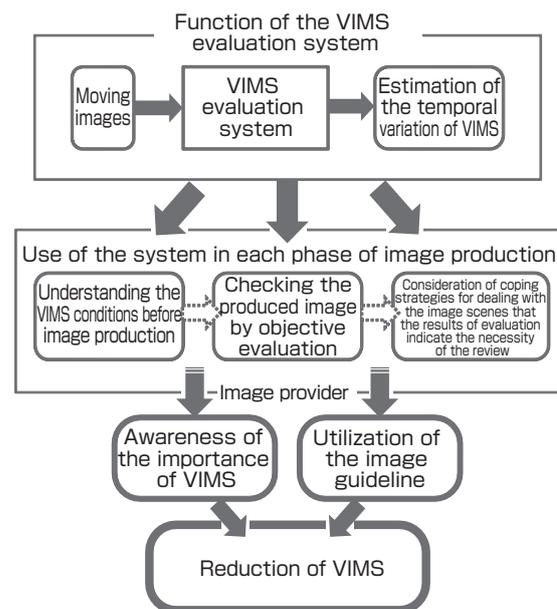


Fig. 1 Effect of use of the VIMS evaluation system on reduction of VIMS

the condition under which VIMS tends to occur. The understanding of VIMS is expected to deepen, if the degree and the temporal variation of VIMS that are generally difficult to understand are made “visible” by repeated investigation of various images using the system.

Second, this will be a method for objectively evaluating the image that will be produced or distributed by the image providers. Since there are individual differences in the susceptibility to VIMS, as discussed later, and people are likely to adapt, it is difficult to evaluate by having certain individuals view images. Therefore, a system that allows objective evaluation of images is necessary.

Third, this enables the specific measures to be taken for the images created by the people involved in the production. If the degree and the time when VIMS is likely to occur are known, the images can be edited based on such information. Therefore, it provides a method for realizing image safety.

In the creation and standardization of the guideline, the VIMS evaluation system can be a powerful tool to verify the effectiveness of the guideline. In the discussions at ISO,^[6] the author has been working on the strategy of international standardization of the guideline based on the basic data obtained using the simple visual motion (see subchapter 4.1). This system is essential to show that the guideline based on the basic experiment data can be applied to general images that contain complex visual motion. Also, in the standardization discussion, an unnecessarily strict standard based on ideals may be suggested, but such standards may not be followable in reality. This system eliminates such useless standards and helps to create a guideline that can be followed practically yet fulfills the minimum requirements, by evaluating the images under various conditions. Moreover, this system provides the method for checking the compliance by the image providers themselves with the image guideline after it is issued. By analyzing and evaluating images using this system based on the guideline and “visualizing” the degree of VIMS for individual images, the policy for production and editing will be easier to establish.

We had opportunities to communicate the information on the VIMS evaluation system to the people of related industries in various occasions, and we received voices from many people that they wanted to try it. For example, the reduction of VIMS is actually a concern of the image producers, and while they think they understand from experience how to limit certain motions, they would like to check objectively. Therefore, VIMS evaluation system is highly in demand by people who understand the importance of reducing VIMS.

3 Scenario of the R&D

The development of the VIMS evaluation system was

done as the “Feasibility Study for the Development (FY 2006; realization in FY 2007) of the Visually-Induced Motion Sickness Guideline Verification System” by the Japan Electronics and Information Technology Industries Association (2006~2007), as a subcontract of The Mechanical Social Systems Foundation.^[7] In the R&D committee, image media companies and filmmakers who were interested in VIMS as well as the university researchers of biomedical effect gathered, and we were able to obtain cooperation from their respective standpoints through specific collaborations and joint research in the actual execution of the R&D. For example, as will be explained later, there were cooperative efforts in speeding up the visual global motion analysis essential for the system, and the production of images that readily causes sickness by the image producers. Through such cooperative efforts, we were able to develop a highly effective VIMS evaluation system that surpassed the initial goal.

The composition of the system is shown in Fig. 2. Of the components, the VIMS evaluation model involves the output based on the results of measured biomedical effects using the simple visual global motion,^{[8]-[10]} and it does not necessarily guarantee an immediately adequate output for general images in which the visual global motion are complexly mixed. Therefore, it was necessary to calibrate the estimated results of VIMS with the actual biomedical effect measurement, and the following procedures were employed for the R&D (Fig. 3).

- (1) The whole system is configured.
- (2) The images that readily cause sickness are prepared. These are entered into the system to obtain the evaluation results, and at the same time, the biomedical effects are measured in a viewing experiment using the same images, and the two results are compared.
- (3) Based on the comparative results, the components of the system are improved to increase the accuracy of the

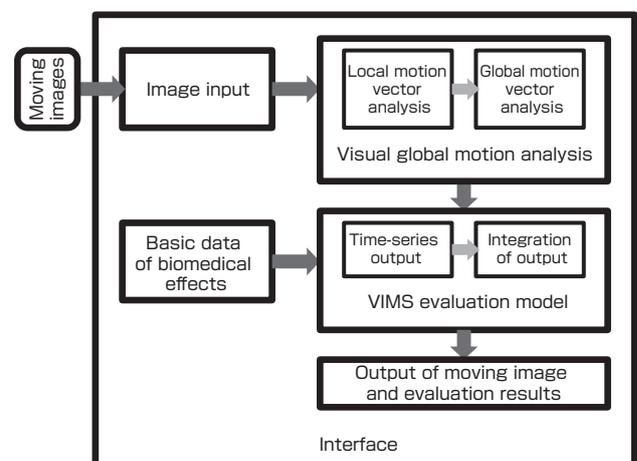


Fig. 2 Configuration of the VIMS evaluation system

Table 1. Factors that affect VIMS

	Primary factor	Details	Secondary factor	Details
Image contents	Global motion	Type of motion, velocity, temporal frequency, amplitude	3D space	Binocular stereopsis, consistency of perspective, presence of depth hints
	Local motion	Spatial distribution of velocity, temporal frequency, amplitude	2D space	Spatial frequency component, luminance, contrast, chromaticity
			Temporal	Presentation period, Prior information
Image presentation condition			Spatial	Viewing distance, environmental illuminance, display size, spatial resolution, ranges of luminance/contrast/chromaticity, binocular stereopsis
			Temporal	Temporal resolution, portability of display (temporal position change)
Viewer attribute			Perception system	Characteristics of vestibulo-ocular reflex and optokinetic nystagmus
			Sensitivity	Sensitivity to motion sickness
			Others	Gender, age, attitude of viewing, posture

evaluation.

- (4) Return to (2) and repeat.
- (5) After going through (4) a certain number of times, the trial of VIMS evaluation system is done by the image industry people. The usability of the user interface is improved based on the questionnaire.

Depending on the progress of the R&D, the method of constructing the system based on sufficient investigation using various images for the characteristics of the sickness caused by general images can be taken. However, since there are several image factors involved in VIMS and there is a time-series effect, numerous images with combinations of multiple conditions will be necessary to clarify the essential factors. Moreover, considering the effect of individual differences, many subjects must participate in the experiment. Therefore, the number of experiments will be considerable, and the execution will become impractical. From such considerations, to construct the system quickly for this R&D, we employed the method of constructing the system based on the basic characteristic of the VIMS found in the basic experiment and then improving the evaluation

accuracy of the system using general images that readily cause sickness.

4 Technological elements and issues

The four technological elements and issues selected to execute the R&D of the VIMS evaluation system are as follows. The relationships of these elemental technologies in the system construction are shown in Fig. 4.

- (1) Findings pertaining to the biomedical effects of visual global motion
- (2) Visual global motion analysis of the images
- (3) VIMS evaluation model
- (4) Production of images that readily cause sickness based on the image production method
- (5) Measurement of biomedical effects to increase the accuracy of the VIMS evaluation model

4.1 Findings on the biomedical effects of visual global motion

While there are several factors that affect VIMS, the first factor that should be the subject in constructing the VIMS evaluation system is the visual global motion. Visual global motion is the whole set of motions that occur in the major portion of the visual field, and basically it is the visual motion within the visual field that occur by the relative motion of the body of the observer and the surrounding environment. Therefore, when the visual global motion is displayed in the large field, the observer perceives it as if he/she is in motion. The relative motions of the observer and the surrounding environment include the translational and rotational motions in the yaw axis (up-down vertical direction), the pitch axis (left-right horizontal direction), and the roll axis (to-and-fro horizontal direction) in the Cartesian coordinate system with the observer at the center. Therefore, the corresponding motions can be considered in the visual global motion.

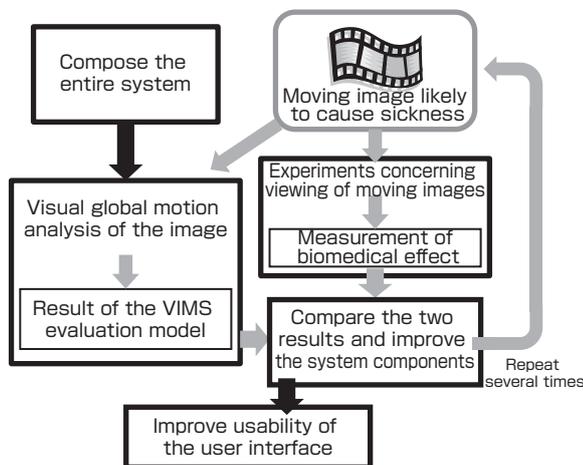


Fig. 3 R&D procedure for the VIMS evaluation system

The factors of VIMS can be categorized into image content,

image display condition, and viewer attribute, as shown in Table 1, as well as the primary factors that trigger VIMS and the secondary factors that strengthen or weaken it. According to this table, the primary factor that triggers VIMS is the visual global motion categorized as the image contents. The basis is the sensory rearrangement theory mentioned earlier, and more specifically the visual global motion that is given when the body is actually static becomes the motion information, and causes discrepancy between the sensory information from the somatic and vestibular sensory systems and thereby causes sickness.^[2] Therefore, in the VIMS evaluation system, the findings from biomedical effects pertaining to the visual global motion were selected as the primary component.

The basic characteristic of the biomedical effect by visual global motion was studied by the author *et al.* in the “Standardization

of the Image Safety Evaluation Method (FY 2003~2005),” a Standardization Certification R&D Project, Ministry of Economy, Trade and Industry. The author *et al.* set up a virtual room by CG where the observer stood in the center of that room. The three axes (pitch, yaw, and roll axes mentioned earlier) were set with the observer’s head in the center, and the observers were shown the CG moving image in which the reciprocating rotational motion (oscillation) around each axis occurred. The size of the image was 82 deg × 67 deg, duration about 1 minute, and the observer was asked for a subjective evaluation pertaining to VIMS on a 11-point scale. Two types of amplitudes (30, 90 deg) and six types of temporal frequencies (0.03, 0.06, 0.12, 0.24, 0.49, and 1.0 Hz) were used as the conditions for the reciprocating rotational motion around each axis. As a result, as shown in Fig. 5, the effect of VIMS was dominated not by the temporal frequency of the visual global motion in the image but mainly by the velocity component.^[10]

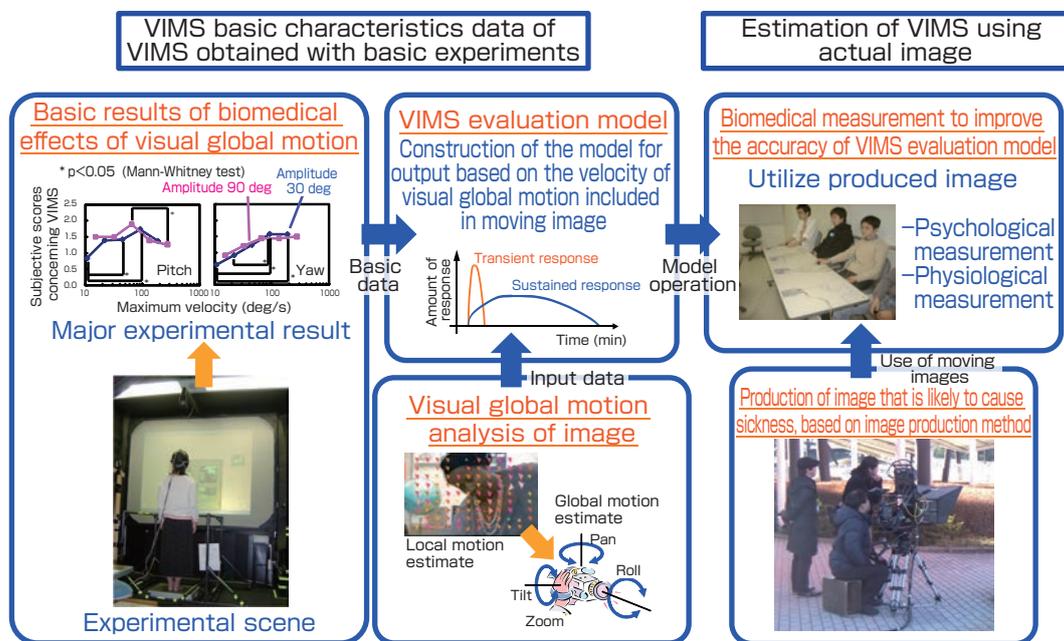


Fig. 4 Relationship of the elemental technology in the VIMS evaluation system

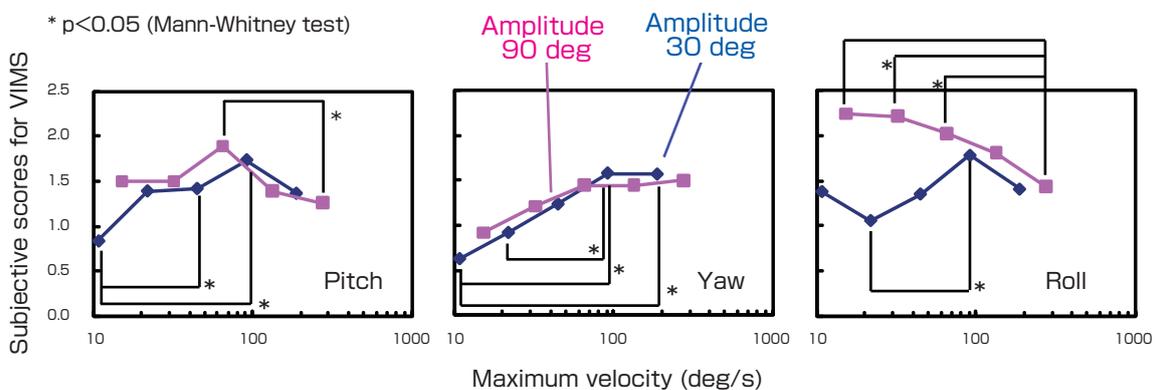


Fig. 5 Effect of the visual global motion on VIMS

Therefore, the biomedical effect occurred when the velocity of the visual global motion in the image was in the range where the biomedical effect level shown in the vertical axis in Fig. 5 reached a certain level.^[11]

The point to notice in the VIMS experiment is the adaptation effect to the VIMS, and to reduce the effect, it was necessary that the participant of the experiment took at least a two-week interval before participating in the next experimental session. The combination condition in Fig. 5 is when the adaptation effect was minimized as much as possible, but with over 40 participants and with the requirement of keeping two-week intervals between sessions, over half a year was necessary to obtain the results.

4.2 Visual global motion analysis of the image

If the types of visual global motion and the temporal variation in the image subject to evaluation are clarified, it will be possible to evaluate the degree of VIMS that may be induced, based on the findings in the previous section. Therefore, in the VIMS evaluation system, it is necessary to analyze the visual global motion of the subject image, extract the components and the speed of motion contained in the image, and to calculate the temporal variation of speed. The researches of the image compression technology can be applied to realize the above.^[12] Therefore, we selected this technology as the compositional element of the VIMS evaluation system, and had people and companies that specialized in the image compression technology participate in the R&D phase.

There are two phases in the process of the visual global motion analysis technology. In the first phase, the image region is divided into, for example, 16 rows × 16 columns, and the place to which each region transferred in the next frame is searched by pattern matching. The amount and direction of transfer are calculated as the motion vector (local motion vector = LMV) of each region. In the second phase, the LMV component of each region is subject to cluster analysis, and the global motion vector corresponding to the basic motion of the camera such as pan, tilt, roll, or zoom is calculated. This corresponds to the visual global motion in this system.

The issue of trade-off between the analysis time and analysis accuracy must be considered for this visual global motion analysis technology. In the initial phase of the system construction, about 15 second analysis time per frame of image was necessary, since we increased the accuracy of the system as a whole by incorporating the method with highly accurate motion analysis to improve each technological element. However, considering practical use, it was desirable that the speed of analysis be about the same as the replay time. Therefore, in the final stages of the development, we improved the method of LMV calculation to reduce the

analysis time, and also checked that there were no practical issues in the analysis accuracy, and realized the practical analysis technology for visual global motion. This analysis technology was realized by Hitachi Consulting Co., Ltd.

4.3 VIMS evaluation model

In the VIMS evaluation system, the core part was the input of the temporal variation of speed and the types of the visual global motion in the image, and the output was the temporal variation of the degree of VIMS that may occur.^[13] Since the assumption based on the basic characteristic of VIMS was necessary between the input and output, we created the VIMS evaluation model to realize this. The VIMS evaluation model was important in the following two perspectives.

- (1) While this system assumes the temporal variation of the degree of VIMS, there is no temporal factor included in the findings of biomedical effects explained in subchapter 4.1. Therefore, it is necessary to consider the effect of the display time of images to construct a model including this factor.
- (2) While this system aims for the estimation of VIMS in general images including the complex visual global motion, the findings of biomedical effects explained in subchapter 4.1 use simple visual global motion only. It is necessary to investigate whether it is possible to estimate the degree of VIMS in general images using this basic finding.

Therefore, from the perspective of (1), we investigated the variation of discomfort due to VIMS when the speed of visual global motion in the image is included in the speed range that may cause VIMS. As a result, it became clear that, due to the existence of the visual global motion that corresponded to that speed range,^[13] there were transient responses in which discomfort increased in a short time, and sustained responses where the discomfort did not decrease for a while even after the disappearance of the visual global motion. Therefore, in the VIMS evaluation model, the transient and the sustained responses are output when each type of visual global motion are included in the corresponding speed range for a certain time.

Next, from the perspective of (2), to increase the accuracy of the VIMS evaluation model, the image introduced in subchapter 4.4 as likely to induce VIMS was prepared to calculate the temporal variation of the degree of VIMS by using the VIMS evaluation model. Then, the biomedical effects were measured by having the participants view the image using the same image in the procedure explained in subchapter 4.5, and the two results were compared. The parameters of the VIMS evaluation model were adjusted based on the results.

4.4 Production of images likely to cause sickness based on the image production method

For the images that contain the potential factors of VIMS to be used in improving the accuracy of the VIMS evaluation model, the production was subcontracted to the image producers who are experts of image production. For the production of such images, it was possible to use the CG images of simple contents containing complex visual motion or live-action images that were shot by the researchers, but these might not be necessarily acceptable to the experts of image production. For example, a non-expert image that contains potential factors of VIMS may not necessarily contain the visual effects and methods that are utilized by the experts, and may not be convincing to the image producers. This is not necessarily easy to explain in terms of logic, and is beyond the bounds of technological discussion, but it may be an important point in gaining understanding and cooperation on the image safety from the image industry people.

As conditions for the image production, in addition to the inclusion of potential factors of VIMS, the condition was the use of live-action images that could be assumed as the actual subject of evaluation. In the former perspective, to investigate the effect of the motion speed of pan, tilt, roll, and zoom that are basic motions of the camera, we attempted to include those potential factors based on the findings pertaining to the basic characteristic of VIMS. However, they had to be live-action images from the latter perspective, and the speed of the motion of the camera was difficult to measure at the shooting session, and the following procedure was used upon discussion with the image producer. First, five-step speed was set for each of the basic camera motion. Specifically, for pan, tilt, and roll, the settings were: very slow 7.5 deg/s, slow 15 deg/s, medium 30 deg/s, fast 60 deg/s, and very fast 80 deg/s. In case of zoom, the magnifications (and reductions) between the frames were: very slow 1.15 (0.86), slow (1.30 0.77), medium 1.50 (0.67), high 1.75 (0.57), and very fast 2.00 (0.50). Next, these speeds were held constant by special effects (SFX) shots, and motion was in one direction for the first 8 seconds, in the opposite direction for the next 8 seconds, and the basic image of 16 seconds in both directions was created. Since there were five-step speeds for the four types of basic movements, there were a total of 20 types of images. The motion of the camera used in shooting each scene was matched with the motion of the camera of the respective basic images, so the final live imagery contained the scenes that corresponded to each speed expressed in 20 types of basic images.

The important point in these images was that the participants of the experiment could view the images without becoming bored during the experiment, and so a minimum plot was added to the image. However, it was necessary to keep the plot to a minimum to prevent the story from

providing emotional effects that may affect the biomedical measurements. Therefore, the cooperation of the image producer was essential.

4.5 Biomedical effect measurement to increase the accuracy of the VIMS evaluation model

In the biomedical effect measurement for VIMS, in general, there are psychological measurements that rely on subjective evaluation and the physiological measurements that investigate the effect on the autonomous nervous system. In the previous researches, the emphasis was mainly on either one of the measurements, and there was hardly any investigation on the relationship of the two measurements for temporal variation of VIMS. However, subjective evaluation requires supportive evidence of objective data as much as possible, since there is an issue of propensity in the individual differences. On the other hand, in physiological measurement, it is necessary to match with the subjective evaluation to investigate what the variations in the measurements indicate. Therefore, the two measurements were mutually essential to increase the reliability of the measurement data of VIMS.

In the development of the VIMS evaluation system, the psychological and physiological measurements were conducted simultaneously, and the investigations were done for the relationship of the temporal variation of the two. For the physiological measurement, we obtained cooperation of the Tohoku University, Niigata University, and Fukushima University that had plentiful experiences in developing the measurement method, and we investigated the relationship of the temporal variation of the subjective evaluation and the physiological indices during the image viewing.^{[14]-[17]} To execute this experiment, common experimental protocols were used and the measurement data were shared among the above universities and AIST, and this enabled efficient collection of data from several experimental participants. Through such biomedical effect measurement, the Tohoku University and Fukushima University showed that the ρ_{\max} , which is the maximum cross correlation function between the blood pressure and heart rate, changed with about 1 minute gap along the temporal variation of subjective evaluation, and that it was possible to estimate the temporal variation of subjective evaluation using the multiple physiological indices obtained by the measurements of electrocardiogram and photoplethysmogram.^{[14][17]}

In the VIMS evaluation model, as discussed in subchapter 4.3, the specification was that it would output the transient and sustained responses each time the visual global motion was included in the corresponding speed range for a certain time. For the output of the model, the accuracy was improved by approximating it to the impulse response function estimated from the time-series data of the biomedical effect measurement conducted using several images explained in

subchapter 4.4. The subjective evaluation measured every 1 minute was used as the time-series data of the biomedical effect measurement, but since it was possible to estimate the temporal variation of subjective evaluation value through multiple physiological indices as mentioned above, this VIMS evaluation model was also supported by the physiological measurement indices.

5 Linkage of the technological elements and the evaluation

5.1 Characteristic of the linkage of technological elements

We constructed the VIMS evaluation system through the combination of technological elements in the previous chapter (Fig. 6). This evaluation system was software built mainly by Fukushima University. By linking the technological elements, this system has the characteristics shown below.

First, the configuration enables the improvement of accuracy only by integrating and linking the individual technological elements. Therefore, it is possible to include the effect of viewing environment condition that cannot be ignored as secondary factor, independent from the effect of visual global motion that is the primary factor of VIMS. The viewing environment condition includes the display size of the image, viewing distance, brightness level, and luminosity of the surrounding. In fact, attempts were made to see the effect of the viewing environment by conducting biomedical effect measurements using the same image while changing these conditions and then modifying the output of the system based on the results.

Second, a list of the time period and types of visual global motion of the images that may trigger VIMS was made, and it became possible to evaluate the degree of VIMS in the case where such motions were not included. In the VIMS evaluation model within this system, certain responses (transient and sustained responses) are output each time the speed range in which the visual global motion is present during a certain time in the image. Therefore, the effect of those visual global motions can be checked by cutting off the corresponding outputs from the model. Using this function, it is possible to check the effect of the reduction of VIMS while the image producer edits the scenes that may have effect.

5.2 Evaluation of the system

For the purpose of increasing the usability of this system, we conducted a trial questionnaire with the cooperation of the parties involved at the R&D committee discussed in chapter 3. The subjects of the questionnaire were 12 people of the image industry. According to the result of the questionnaire, the analysis speed and display received overall good marks. However, there were comments that the displayed terms were too technical and hard to understand, or that the contents of the display were difficult. Therefore, we made improvements such as using simple terms, adding glossary in the manual as needed, and improving the display content.

6 Future development

The VIMS evaluation system is a prototype at this point, and we plan to increase the accuracy and usability through accumulation of trial questionnaire surveys. Also, the evaluation for the degree of VIMS is matched to the average value of the biomedical effect measurement. The large data

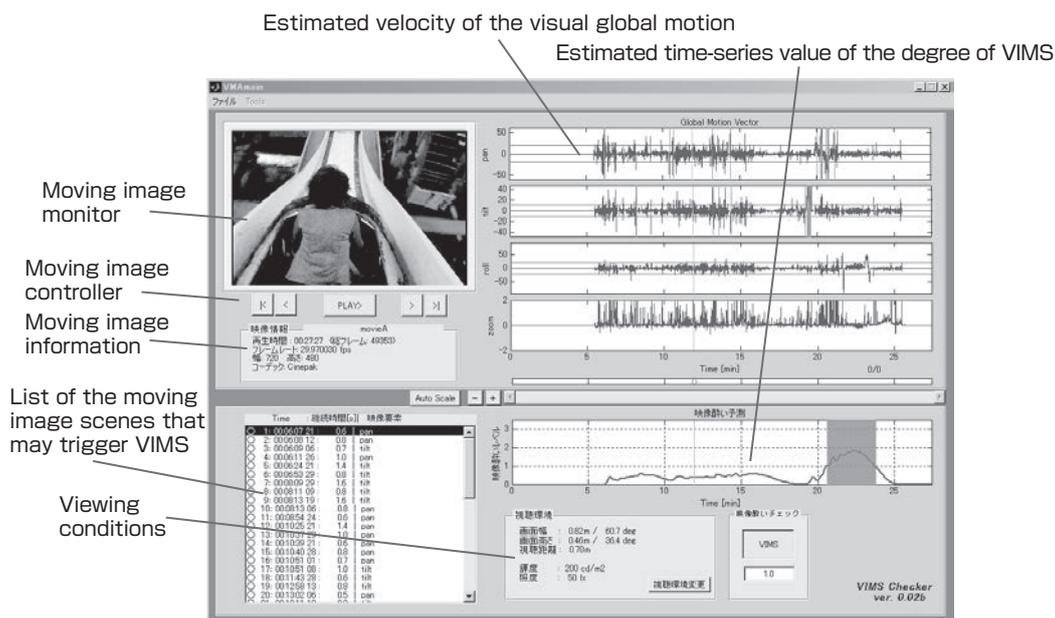


Fig. 6 Control window of the VIMS evaluation system

for over 200 participants in the experiment were accumulated for this system using live-action images, and we shall continue to estimate the percentage of people who show certain symptoms, and to estimate the level of symptoms that certain percentage of people may experience.

The international standardization of image safety is in progress as mentioned in the beginning, and the ISO standard proposal is considered for the VIMS guideline within 2010. Before the proposal is submitted, we shall promote the understanding for the VIMS issue by distributing this system to the image industry people, and we also plan to utilize this system to demonstrate the adequacy of the proposed standard in the standardization committee.

Moreover, we plan to expand this system to develop the 3D image evaluation system that enables the evaluation of 3D image safety. Since there is visual fatigue that occurs uniquely with 3D images, it is necessary to take sufficient measures against VIMS due to the increased realism of the images.

A solid 3D market is being formed with the hit of the Hollywood 3D movie in 2009 and the launch of 3D TV in 2010. In such a situation, the 3D image guideline and the abstract journal that will be the basis of such guideline were published by the collaboration of the 3D Consortium, Japan Electronics and Information Technology Industries Association, and AIST in April 2010. As a result, the social recognition for 3D image safety spread rapidly in a short time through various mass media. This was because the human network that was nurtured in the R&D for the VIMS evaluation system and its long process functioned effectively, the R&D process could be easily developed and applied to 3D images, and the passage to the activities for 3D image safety was formed as the collaboration and cooperation led to the understanding of the government organizations and various parties involved.

The 3D images have been said to have a 10-year cycle of rise and decline, but the main reason they failed to develop sufficiently in the past market is because the measures to reduce the discomfort caused by 3D images were insufficient. In the future, with the close collaboration with the external research institutes such as the universities and the industry people, we plan to increase the understanding of the biomedical effect of 3D images by joint R&D for a highly reliable 3D image evaluation system that is the expansion of the system discussed in this paper. At the same time, we would like to solve the issue of 3D image safety by enabling the evaluation of the 3D images.

Acknowledgement

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Author

Hiroyasu UJIKE

Completed the doctorate course at the Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology in 1991. Joined the National Institute of Bioscience and Human Technology, Agency of Industrial Science and Technology in 1995. Currently, leader of the Multimodality Research Group, Human Technology Research Institute, AIST. Engages in the basic research of motion stereopsis and depth perception based on the psychophysics of vision, and works to diffuse a comfortable image environment by engaging in the R&D for image safety. As part of such activities, the VIMS evaluation system was conducted under joint development with the university and industry people. Also engages in the activities for the international standardization of image safety, such as serving as the chairman of ISO/TC 159 (Ergonomics) /SC 4 (Ergonomics of human-system interaction) /WG 12(Image safety).



Discussions with Reviewers

1 Overall composition

Comment (Hideyuki Nakashima, Future University Hakodate)

This paper describes the author's research scenario clearly. Since the core of the paper is chapter 4 where the content of the research is described, the readers may want to get to that part more quickly. Since chapter 2 is written with a strong wish to obtain the understanding of the image providers because the research is targeted toward them, the paper will be easier to read if you make this point clear with concise descriptions.

Answer (Hiroyasu Ujike)

Thank you for pointing this out. Since the result of this research is meaningless unless it is used by the image providers who are the end users, chapter 2 became rather long because I wanted to emphasize this point. I made modifications to make it as brief as possible.

2 Overall picture of the research scenario

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

The goal setting of how you want the VIMS evaluation system to be used in society is stated in subchapter 2.2, and the point is clear as a *Synthesiology* paper. I think it will help if you add a diagram that shows the positioning of the developed system to clarify this goal setting for the reader. Also, as an evaluation of the result of the R&D, please describe any example where this evaluation system was used to improve some results.

Also, please write the evaluations from the users' side, like voices from the image providers that they want to try this system.

Answer (Hiroyasu Ujike)

I added Fig. 1 corresponding to the text of subchapter 2.2. For the results, I received numerous voices saying they want to try the system in the sessions where we presented the system, and I added this to the final paragraph of subchapter 2.2. The examples of actual improvements using the evaluation system are expected to occur in the future.

3 Factors of sickness

Question (Motoyuki Akamatsu)

Please state how each factor causes sickness under what conditions (such as frequency and size) for the factors shown in Table 1. Also, what is the degree of effect when compared to the global motion?

Answer (Hiroyasu Ujike)

For the conditions where the factors in Table 1 are likely to cause sickness, the degree of effect of the factors for visual global motion is not easy to answer because of the following points:

1. While the visual global motion is the factor (primary factor) that may trigger sickness due to its presence, basically, other factors are secondary factors that amplify or reduce the sickness that is occurring. The comparison is difficult since the quality of the effect on sickness is different.
2. For the secondary factors, the comparison is difficult since basically the units of parameters are different, such as the luminosity of the screen (unit: cd/m²) and size of the field of vision (unit: deg²).

Therefore, I shall describe the outline of the effect of major factors based on the findings we obtained and the reports available so far. Since individual difference is great for VIMS, please note the following description assumes a typical observer.

- Visual global motion: In the rotation in the three axes, it is known that the effect of roll is relatively great. However, in the rotation in one direction, the effect is largest at speed 30~70 deg/s in all rotations. In reciprocating oscillation, while there is some dependency on temporal frequency and amplitude, the speed ranges with large effects are different for each three types of rotation.
- Binocular stereopsis: The effect on sickness is shown to slightly increase by stereoscopic presentation of images and by adding depth information.
- Brightness of images: The degree of sickness is shown to decrease as the brightness of the screen decreases.
- Spatial frequency component of images: In the experiment using rotating drum with relatively simple vertical stripe pattern, it is reported that the symptoms of sickness increases by using stripe pattern with certain spatial frequency.
- Chromaticity of images: In the rotating drum experiment, it is reported that the sickness symptom increases by using colored patterns under the same brightness condition.
- Environmental illumination intensity: It is shown that the degree of sickness decreases when the environment is bright.
- Viewing distance and image size: It is shown that the degree of sickness increases as the apparent size of the image increases. However, there are reports that sickness is less likely to occur at a certain size or less (for example, 20 × 15 deg or less), and the degree of sickness is less likely to increase above a certain size (for example, 140 × 90 deg or more).
- Sensitivity to motion sickness: It is shown that VIMS is likely to occur in persons who tend to get motion sickness (or travel sickness).
- Gender and age: It is reported that women are likely to get motion sickness compared to men, and those in early teens

are relatively susceptible, and similar trends follow for VIMS.

4 Relationship to the 3D image that is in the recent news Question (Motoyuki Akamatsu)

After the submission of this paper, 3D movies and 3D TVs became topics in the mass media, and I think the consortium in which the author was active functioned effectively to spread the importance of image safety in society. I think you should add the fact that the transition to 3D could be made because of your research result, that the human network functioned well, and that the social recognition was gained through the support of the

government and others.

Answer (Hiroyasu Ujiike)

Thank you very much for pointing this out. After the joint press release (April 19, 2010) by the 3D Consortium, Japan Electronics and Information Technology Industries Association, and AIST, there were many inquiries. I think, as you mentioned, it is the result of various collaborative activities by many people in the development of this evaluation system and the process of development, that there was diffusion of awareness for 3D image safety through the mass media. I added this in the latter half of chapter 6.

Spinning process using robot technology

— Field-based bricolage of manufacturing technology —

Hirohiko ARAI

[Translation from *Synthesiology*, Vol.5, No.2, p.126-134 (2012)]

Metal spinning is a plastic forming method in which a rotating metal material is pushed by a roller to form a product. It is suitable for the production of a wide variety of products in small quantities owing to the low cost of forming dies. We have achieved the fabrication of noncircular shapes by using robot technology, which is difficult to realize by conventional methods. A prototype of a practical spinning machine has been developed in collaboration with a spinning machinery manufacturer. In this research, we have basically set our preference for commercial realization over academic contribution. This research was carried out in a bottom-up and trial-and-error manner, and the targets of this research were frequently modified depending on the situation. Bricolage, utilizing the combination of available and limited resources at hand, played a key role in the research activity. Decision-making reflected three-actuals theory, which values the actual field site, actual object, and actual situation. We included increased customer satisfaction in the criteria of value and carried out sales activities as a part of the research.

Keywords : Metal spinning, robot, metal forming, bottom-up, bricolage, san-gen-shugi

1 Outline of the developed technology

Metal spinning is a plastic forming method in which a metal blank such as a sheet or pipe is rotated by a motor and formed into a desired shape by pressing a roller tool against the material (Fig. 1).^[1] This method can be applied to various metal materials, including aluminum, iron, and stainless steel, as a method of creating hollow metal products. It is used widely in various industries including lighting equipment, cooking utensils, automobiles, electrical appliances, chemical plants, pressure vessels, aerospace parts, and architectural decorations. Manual metal spinning is called *hera shibori* in Japanese, and it is known as one of the most advanced craftsman's skills in manufacturing. The advantages of spinning are as follows: 1) the tooling cost is low since only a male die is necessary, 2) the yield rate of the material is better than that of a cutting process, and 3) the equipment is small and does not make much noise or vibration because the force required in processing is small.

The author has been attempting to introduce robot control technology to metal spinning to enable processing with high additional value.^{[2]-[6]} In particular, we have developed spinning machines and methods that enable the forming of noncircular shapes such as elliptical, polygonal, and eccentric shapes. Other than circular objects, which can be formed by regular metal spinning, conventionally hollow metal products have to be manufactured by sheet bending and welding, which is a complicated procedure, or drawing, which requires expensive dies. In the new process, in general,

only one die (= mandrel) is necessary, or in some cases a mandrel is unnecessary, meaning that the cost of tooling can be kept low compared with that of the pressed products and the production process can be set up quickly. Currently, the processing time necessary per product is several tens of seconds to several minutes, making it unsuitable for mass production. However, it is expected to be very useful in high-mix low-volume production, one-time special orders, and prototype fabrication.

To form noncircular shapes, two methods, force-controlled spinning and synchronized spinning, are used. These enable the forming of noncircular shapes that cannot be made by a conventional spinning machine for circular products or by manual metal spinning by a skilled worker. In force-controlled spinning, a mandrel of the same shape as the desired noncircular shape is used to form the product.^[3] By controlling the pushing force of the roller at an appropriate

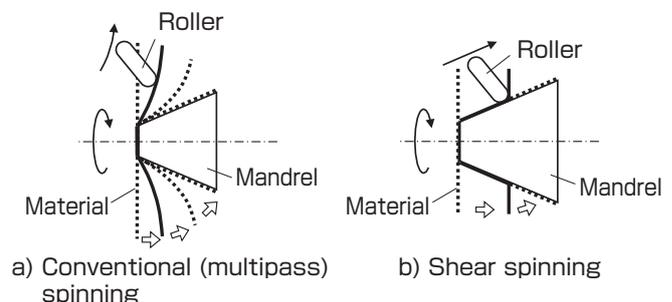


Fig. 1 Metal spinning (sheet)

Advanced Manufacturing Research Institute, AIST 1-2-1 Namiki, Tsukuba 305-8564, Japan E-mail: h.arai@aist.go.jp

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value, the material is pressed onto the rotating mandrel. Meanwhile, the roller is controlled by feeding at a constant speed in the direction parallel to the rotation axis of the mandrel. The roller moves along the mandrel to press the material firmly against the mandrel. As a result, a product that has the same noncircular shape as the mandrel can be fabricated (Fig. 2).

Initially, the roller was driven by ball screws in the spinning machine shown in Fig. 3 in our experiment. However, in forming the noncircular shape, it was necessary to move the roller in the radial direction very quickly along the surface of the mandrel. Therefore, we developed a new spinning machine where the roller was driven directly by linear motors (Fig. 4).^[4] Since the responsivity to force control is high and the roller follows the mandrel shape quickly, the time required for forming can be greatly reduced. Also, shapes with noncircular cross sections can be formed by open-loop force control without using a force sensor.

In synchronized spinning,^[5] the forming roller is numerically controlled by synchronizing the roller with the rotational angle of the workpiece. The spindle is driven by a servo motor in which the rotational angle can be controlled. The

spinning roller is moved back and forth in the radial direction according to the rotational angle of the workpiece, and the roller is moved so that the contact point between the roller and the workpiece tracks the desired cross-sectional form. The cross-sectional form is changed along the axial direction to form the entire workpiece into the desired shape. In this method, a noncircular cross-sectional shape can be formed without using a mandrel. This is particularly effective in forming a hollow tube with a noncircular cross section that is difficult to remove from the mandrel after forming. A prototype of a two-roller machine (Fig. 6) suitable for pipe forming by synchronized spinning was also developed.

A prototype of the practical spinning machine for noncircular shapes was jointly developed with Daitoh Spinning Co., Ltd., a specialist manufacturer of spinning machines (Fig. 7, Table 1).^[6] Both force-controlled spinning and synchronized spinning can be performed with this machine. Balanced-attraction linear motors, which cancel the magnetic attraction force between the iron-core coil and two magnetic track components, were employed to realize both increased propulsion and reduced friction. Steel sheets of 2 mm thickness and workpieces with diameters of 400 mm could be formed. Since its development, the machine

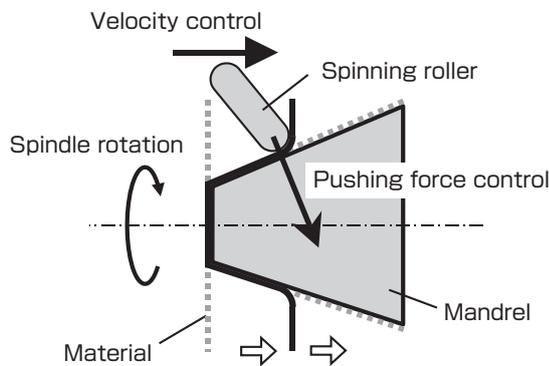


Fig. 2 Forming of non-circular shape by force-controlled spinning

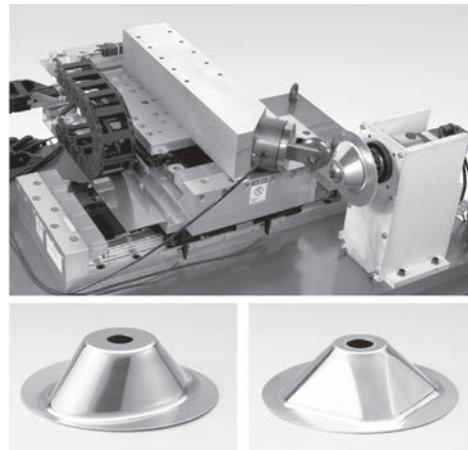


Fig. 4 Linear motor driven spinning machine (experimental) and product samples

http://staff.aist.go.jp/h.arai/linspin_j.html

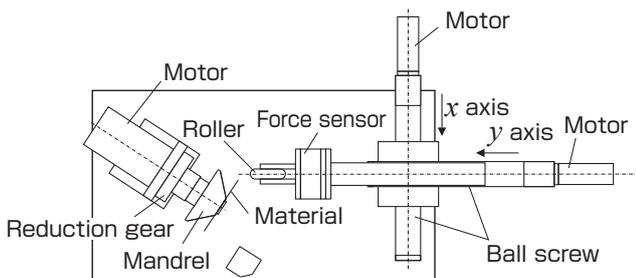


Fig. 3 Experimental spinning machine

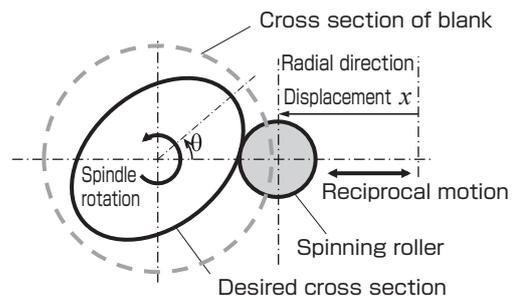


Fig. 5 Forming of non-circular shape by synchronized spinning

has been presented at various exhibitions such as the Japan International Machine Tool Fair and Ohta Industrial Fair, where the noncircular shape spinning was demonstrated. Daitoh Spinning started taking orders for machines based on this prototype. Only one order has been shipped so far, which was delivered to a sheet metal fabrication company called Papas Co., Ltd. (Fig. 8).

2 Background and motivation

2.1 Reflection of excessive emphasis on academism

This study was started around 2001 when AIST became an independent administrative agency. The beginning was a reflection of research in the robotics field (or the excessive emphasis on academism) that the author conducted during his time at the Agency of Industrial Science and Technology. For example, looking back at what we did, when explaining the objective of our research in the introduction of an academic paper, the goals set were impossible to realize in the near future and were fictions created to justify the academic research. Although the research objective of

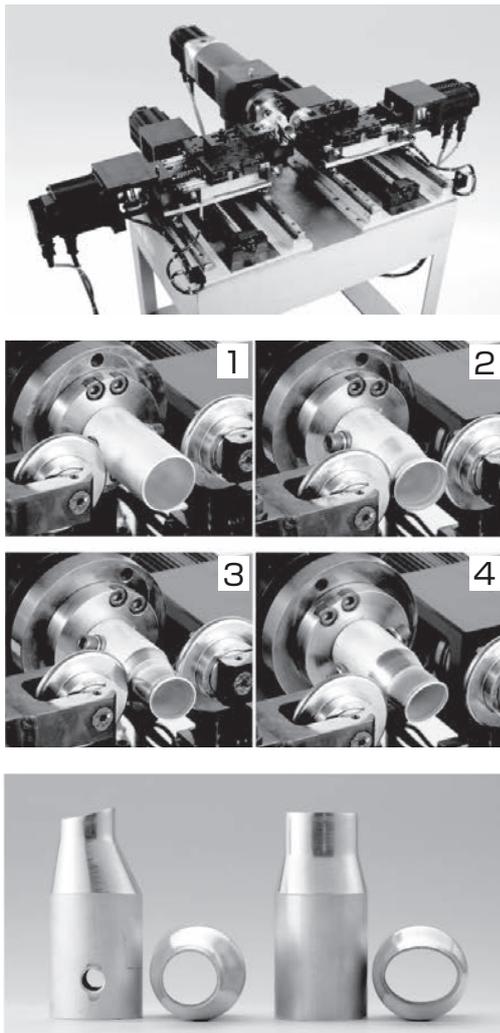


Fig. 6 Synchronized spinning using two-roller spinning machine

Table 1 Specifications of prototype machine

Dimension	Width 2875 mm × Depth 1820 mm × Height 1895 mm
X axis (radial direction)	Balanced-attraction linear motor, rated thrust 4000 N
Z axis (spindle direction)	Servomotor + ball screw, rated thrust 10000 N
Spindle	Servomotor + planetary gear, rated power 7.5 kW, rated speed 375 rpm
Workpiece	Maximum diameter 400 mm, maximum height 350 mm

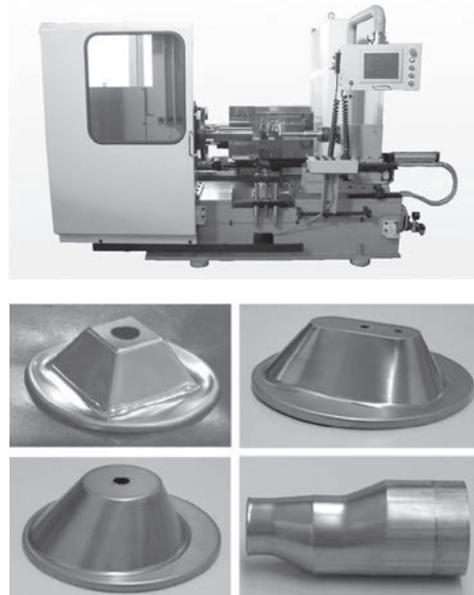


Fig. 7 Prototype of practical spinning machine for non-circular shapes



Fig. 8 Spinning machine for non-circular shapes introduced to a company

a paper is required to be somewhat plausible, stringent verification of its feasibility is not required, and this does not necessarily influence the judgment in the peer review process. On the other hand, once the paper is accepted for publication, the entire content of the research, including the research objective, which may be mere fiction, is authorized. Such a made-up research objective is useful for affirming the reason for the existence of the research, and the same reason is often carried over to the following research. The existence of a previous study may justify a subsequent study. As the citation of a research objective is repeated and spread among several researchers, the fiction turns into a verified truth and may exist on its own. I myself became apprehensive when a research objective that I wrote with full awareness that it was fiction was cited by other researchers.

When this research was started, industry and academia were separated in the robotics field. Although there have been many academic studies, the practical application of research results has been rare. A contributing factor might have been the problem of the fictionalization of research objectives. Until then, we had not been interested in industrial robots and manufacturing was not considered as an application target, which might have been the reason for not being able to do research on practical use. With this awareness, we started to seek topics of practical robot research in manufacturing.

2.2 Encounter with metal spinning

In August 2001, the first H2A rocket was launched successfully. As the nose cone of the rocket was fabricated by manual metal spinning, this procedure was broadcast repeatedly on television. There was a monozukuri or manufacturing boom at the time. The author became aware of metal spinning during this time, and because of what can only be explained as intuition, embarked on this research.

At first, the image was metal spinning carried out by a robot arm that consisted of a roller at the tip as an application of an industrial robot (Fig. 9), and it was considered as an

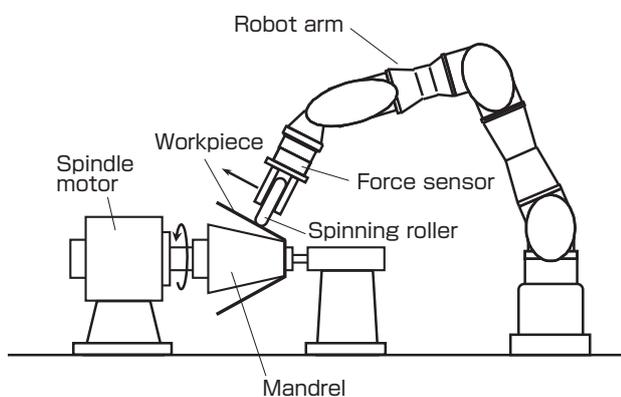


Fig. 9 Initial research concept (metal spinning robot)

example of engineering the artificial replication of skilled human labor. In robotics, force control of a robot arm has been studied for a long time, and considerable theoretical and technical know-how has been accumulated. However, since robot researchers were separate from the manufacturing industry, force control had been realized in only a few procedures such as assembly and grinding, and its effective application with high added value was still in the exploratory stage. In manual metal spinning, the sensory perception of the craftsman, particularly the perception of the force transmitted through the roller, plays a significant role. Also, since metal spinning involves incremental forming by partial deformation, the forming force is much smaller than that of other plastic forming processes. It was considered suitable for robots because of the many control parameters and the high degree of freedom. Since manual production was established as a business, it has been a high-mix low-production method with high added value, and we estimated that the profitability would be high if robot technology was introduced. Also in this research, there was a secondary intention of sending a message to other robot researchers. By presenting a specific case study of an excellent field of application where the advantages and potentials of robot technology could be utilized, we wished to arouse robot researchers' interest in manufacturing.

3 Research style and action principle

3.1 Bottom-up research style

For the author, this research was an outreach from the robotics field to the unfamiliar field of metal forming. Since we started with no preliminary knowledge, the research was commenced without preconceptions and progress took place in the dark. Therefore, we did not believe that the research goal would initially be set correctly, as mentioned in the previous section, and we took the stance that the goal was provisional. Therefore, we did not select a plan-driven method where a specific scenario for realizing a goal is set in a top-down style, and then the breaking down of the problem to the elemental technologies to be developed is carried out.

Instead, the strategy taken was to stay with a vague research goal and temporary scenario, go ahead and make something, and carry out revisions as needed, under the loose direction of "realizing a technology that may be useful for metal spinning by applying robotics technology." By operating an actual machine, the changes in the situation such as the progress of research, new inspirations, changes in awareness, and accidental external factors came into play. The research goal and scenario were changed frequently. For the elemental technology, whatever was available at the time was used, and the primary standard for the selection of elemental technology was that it was available and usable immediately. The technology developed was newly added to the inventory of elemental technologies. This was a bottom-up-style

exploratory approach, and rather than preliminary rationality through analytic planning, emphasis was placed on post facto rationality obtained by feedback of the results.^[7]

3.2 Direction of the research and action principle

The basic direction was to prioritize practical use with efficacy considered first rather than academic interest, and as mentioned earlier, effort was spent to eliminate the fictional element in the research objectives as much as possible. The action principle was characterized by 1) bricolage, 2) three-actuals theory, and 3) a focus on sales.

Bricolage is a concept introduced in *La Pensée Sauvage* (The Savage Mind) by the anthropologist Claude Lévi-Strauss^[8] as a primitive form of creative mental activity. Bricolage is a French word for “handiwork” and it means construction with whatever tools and materials are available. Although this concept is used frequently in the fields of art and education, recently, the practical value of bricolage in entrepreneurship and innovation has been discussed from the standpoint of technology management, knowledge management, and organization theories in the field of business administration.^{[9]-[14]} In the literature that discusses the role of bricolage in entrepreneurship under limited management resources,^[13] it is redefined as a “making do by applying combinations of the resources at hand to new problems and opportunities.” Here, resources are extended to a wider meaning including technology and people, not just physical resources such as tools and materials. The three main elements of bricolage are as follows: 1) to utilize the resources available at hand regardless of their originally intended use, 2) to generate new value from existing resources through combinations including usage outside the intended usage, and 3) to take action to resolve an issue without accepting the limitations. Although this research was carried out without consciously engaging in bricolage, it matches the above three elements.

Sangen shugi, or the three actuals, is a way of thinking that emphasizes the three *gen* (actuals) of *genba* (actual site), *genbutsu* (actual object), and *genjitsu* (actual situation). It is the basic stance that whenever a problem arises, rather than depending on theories, one should actually go to the site, take the actual object in one’s hands and look at it, and understand the reality of the situation. It is widely accepted as a code of conduct in Japanese companies including Honda and Toyota. This way of thinking is not unique to Japan and similar thoughts can be seen in Eugene S. Ferguson’s *Engineering and the Mind’s Eye*.^[15] In the success story of bricolage described in Reference,^[11] the development of wind turbine industry in Denmark was conducted with on-site emphasis. The three-actuals point of view is not merely about mentality, but it is effective in shortening the route from the final result to feedback and quickening the cycle of correction, and hence eliminating the noise and bias that may be added in the process. In this research, there were many cases where decision-making was based on the site, object, and situation

during the exploratory stage. However, AIST does not have a site of production where the developed result can actually be used. Therefore, several methods were devised to move as close as possible to such sites.

The researcher ultimately belongs to the service industry in the sense that the researcher engages in work to provide intangible assets. A service becomes meaningful and valuable only when it reaches the customer. Therefore, increased customer satisfaction was added to the value of the research, and we consciously made effort to gain awareness that sales activities were part of our research.

4 Progress of research

4.1 Start from handmade machine

We started by assembling a simple machine for actual metal spinning (Fig. 3). As an alternative to an expensive force sensor and servo drivers, junk parts from old machines were recycled, and the material cost was about one million yen. An old PC that was handed down from another researcher was used as the control PC. ISA bus I/O interface board was installed, and programming was done by using Turbo C++ in the DOS mode of Windows 98. Programs and control laws from past robotic research were used to drive the device. Although this configuration was outdated even at that time, real-time control with a 1 msec sampling interval was successfully achieved, and basic experiments on spinning using force control were conducted using this system.

4.2 Setback in robot arm application

On the other hand, the technological concept of realizing skilled techniques using an industrial robot failed at a relatively early stage. Metal spinning by a robot arm failed owing to the vibrations that occurred from the lack of rigidity, and although it was again attempted later,^[16] practical results have not yet been obtained. Another problem was that it was unclear who would be the customer for this technology. We were unable to decide on whether the customer would be manufacturers of industrial robots, user companies that process products using robots, or spinning machine manufacturers who would use the robot arm. Later we focused on adding higher functions to conventional machines with emphasis on the metal spinning lathe, rather than application to industrial robots. By doing so, the target of technology provision clearly became machine manufacturers.

4.3 Change in direction due to change in view of skills

As we learned about manufacturing in small factories from the books by Tomohiro Koseki, who is a former lathe worker,^{[17][18]} we became aware that the essence of skilled work is not the physical skills gained through repeated training but is in the creative thought process. There are skills best performed by humans and skills best performed

by machines, and it is meaningless to simply transfer human skills to a robot. Since the added value of a product obtained by skills is important rather than the skills themselves, the benefit of the machine should be explored rather than trying to copy human skills.

Since humans use machines on site, new skills required to master new technologies are born. In force-controlled spinning, the pressing force to be set is ultimately decided by the human personnel on site. Skill learning in manufacturing always includes a creative process.

Metal spinning started from making pots and pans, and the advanced skills required to create complex and precise products did not exist from the beginning. Even if muscles and hands are replaced by mechanical devices, the replicated skills are fixed ones. Human beings, who learn by trial-and-error and improve their skills on site, are still necessary. Therefore, rather than aiming to replace skilled workers, we aimed to develop a machine that would be an advanced tool and become effective only when utilized by a person.

4.4 Concentration on noncircular shape formation

On the other hand, the machine described in 4.1 was successful in forming noncircular shapes by the application of force-controlled spinning, and this became the selling point of the outcome of this research from then on. At that time, regular exchanges with companies started through the Collaboration Promotion Division. While we presented AIST's potential at meetings in which several companies in metal-spinning-related fields participated, the development target was narrowed down by listening to the companies' demands. Daitoh Spinning, a spinning machine manufacturer, participated in these meetings, and expressed their desire to carry out joint research as they became strongly interested in the forming of noncircular shapes. On the basis of this proposal, we obtained a joint research fund from the Small and Medium Enterprise Agency, and thus the prototype of the synchronized spinning machine was fabricated (Fig. 6).

In noncircular shape forming by force-controlled spinning, the important issue was shortening the spinning time. At that time, the author happened to visit the International Robot Exhibition and saw linear motors there. This generated the idea of using them in the spinning machine. In this study, effort was placed on patent application rather than academic publication. As a result of the patent application for the spinning machine using linear motors, we obtained funding for strengthening the patent from the Intellectual Property Division and were able to build the prototype of the linear motor machine (Fig. 4).

4.5 For the diffusion of the working machine

After repeated trial runs and metal spinning demonstrations

at exhibitions, we received a request for intellectual property licensing from Daitoh Spinning. Joint development of the prototype of the practical machine was conducted through the patent-related funding (Fig. 7). Meanwhile, the author moved to the Advanced Manufacturing Research Institute in 2009, and shifted his research from pioneering robot applications to actual processing technology. Daitoh Spinning started taking orders for the spinning machines that could handle noncircular shapes, but orders slowed down owing to the economic uncertainty after the Lehman Shock, and the company is now seeking ways to improve the situation.

4.6 Research and development that does not depend on a scenario

Looking back at the progress of research, it can be seen that there was no consistent scenario and that the research goal changed greatly owing to external and coincidental factors. As part of the positive external factors such as obtaining funding, exchange with companies, and participation in exhibitions, there were many instances where we were encouraged by the Collaboration Promotion Division and the Intellectual Property Division of AIST, and the roles played by such research-supporting sections in advancing the research were significant. Also in this research, the fact that the laboratories for the robotics and manufacturing fields were at neighboring locations, a legacy from the Agency of Industrial Science and Technology, worked positively, and this was particularly useful in gaining knowledge of the metal forming field.

5 Characteristic research activities

5.1 Synthesis by bricolage – bottom-up integration of elemental technologies

The construction of the experimental spinning machine described in the beginning of the previous section was typical bricolage, and bricolage at various levels was used in several parts of the research. Most elemental technologies can be organized as a hierarchical structure, and a function to be realized as seen from below becomes an elemental technology when seen from above. For example, we had the force control and position control technologies available as elemental technologies at the beginning of the research. These were combined to realize force-controlled spinning and synchronized spinning as functions of the spinning machine. In the next stage, these were combined as elemental technologies to conduct sheet and pipe spinning in actual parts. By building up the technologies from below, we filled our toolbox with an inventory of technologies (Fig. 10). The control laws that were the basic elements were derived from research done in the robotics field. For example, the impedance control used in the force-controlled spinning was modified from the control law used in a cooperative task between humans and robots.^[19]

While the linear motor that was employed to reduce the spinning time was a readily available, existing component, it was used in a slightly different way from the intended use. A linear motor stage is often used as a high-speed, high-precision positioning device, but in our research, it was used as a force control actuator with excellent backdrivability (the property of being pushed back flexibly in accordance with the applied force). The characteristic of bricolage where an attribute of a resource is utilized to realize novel functions can be seen here. Also, using the fact that a linear motor has no loss due to the transfer mechanism, for example, a ball screw, the force control was accomplished by open-loop control without use of a force sensor. This idea was obtained from the author's experience of the open-loop force control of a direct drive robot (a robot where a reduction gear is not used in the joint axis) carried out over 20 years ago.^[20]

Through the collaboration with Daitoh Spinning, we were able to increase our repertoire of elemental technologies rooted in on-site use. In the development of the prototype of the working machine, the practicality was enhanced by adding various peripheral functions that conventional spinning machines have, such as a tailstock rod to fix the metal material to the spindle, a blank holder, and a back-up roller that prevents wrinkles in the metal blank.

5.2 Accumulation of spinning know-how by trial runs – desire to approach the actual site, the actual thing, and the actual situation

In this research, trial runs as below to fabricate actual parts through joint research with companies played an important role. AIST does not have a site of production and we definitely lacked feedback to the elemental technologies based on the accumulation of experience. For example, even if we successfully formed a noncircular shape, it was merely a simple shape under specific conditions and for a specific material. It had to be extended to various metal materials as well as hot forming under heat, multipass spinning, and complex shapes with steps and constrictions. On the other hand, unnecessary effort would be made if we did not narrow down the priorities of which element should be developed.

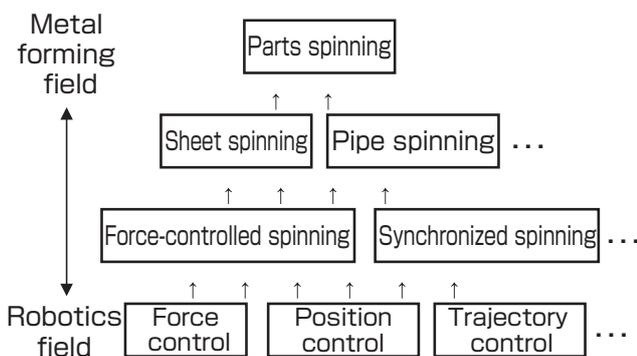


Fig. 10 Hierarchical structure of elemental technologies

To select the know-how worth developing and to do so efficiently, the shortest route is to collaborate with companies and to fabricate actual parts. The developed spinning technology will at least be useful for similar parts. It is possible to handle diverse spinning processes by increasing the available know-how and then combining it.

Upon receiving a request for trial runs from several manufacturing companies including those involved in sheet metal working, automotive parts, measurement equipment, and metal materials, we fabricated the parts as designated by the companies using our experimental spinning machines, and the know-how necessary for processing was developed (Fig. 11). There were about 10 tests actually carried out, and we received over 30 inquiries. Even if an inquiry did not involve testing, we were able to gain an understanding of which shapes were in demand through the process of meeting with the companies. In testing, since the development lead time was important, we were provided with materials and tools from the companies. We also obtained the necessary design data for improving the machine. The accumulation of sample products through these experiences also provided materials for advertising the spinning method. Although an actual shipment of the machine has not yet been realized, several user companies have requested estimates for the machines from Daitoh Spinning.

Through the trial runs, we recognized the importance of the knowledge of plastic working such as material properties. We realized it was necessary to provide the forming know-how as well as the machines to the users. As the number of types of tools and jigs at hand increased through repeated tests, it became easier to handle shapes and materials which used to be difficult. The laboriousness of the formable shapes increased to include square tubes, irregular-shaped pipes, and shapes with curved axis. The range of materials also increased and we were able to expand the know-how of forming noncircular parts. As we repeated spinning tests at factories, the opportunities to incorporate and utilize the on-site knowledge for development increased. The author found that the communication with on-site workers became smooth

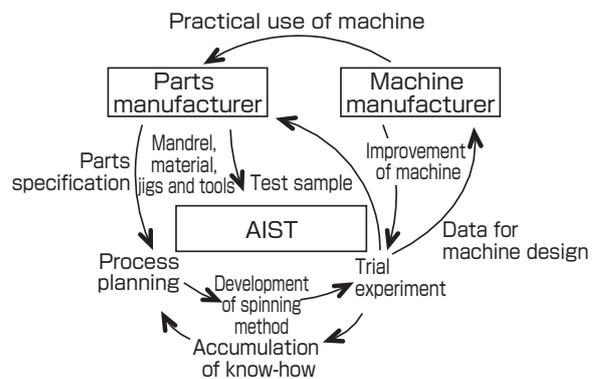


Fig. 11 Accumulation of spinning know-how by trial runs

as we became more like craftsmen.

5.3 Fusion of sales and research activities

5.3.1 Spinning demonstrations at exhibitions

In this research, the emphasis was placed on spinning demonstrations of the machine at external exhibitions, and we have participated in 11 exhibitions so far. Exhibitions are effective as a medium for advertising the results of our research, and they are also used as places to gain feedback from potential users. At large exhibitions where many specialist manufacturers participate, such as the Japan International Machine Tool Fair, we were able to obtain opinions and questions by presenting the metal spinning process to a wide range of professionals from craftsmen at small to medium-size companies to managers at large corporations. Including some extremely critical opinions, we obtained findings that were far more useful than comments at academic societies on issues that we had to tackle toward achieving practical use. The majority of the companies that requested trial runs were those that had witnessed the metal spinning demonstrations at exhibitions. On the other hand, few specialists visited and not much could be gained from the nonspecialized exhibitions that were held for the promotion of industry-academia cooperation.

5.3.2 Sales activities on the web

While trial runs and exhibitions were part of the sales activities, we also conducted sales and public relations activities on the web. When we started the research, we used a search engine to search for companies in metal-spinning-related fields to learn about the metal spinning business, regional distribution, examples of spun products, and so forth. We found 115 companies in Japan and 189 companies overseas, and we were convinced that this industry was sufficiently large to be the recipient of the developed technology. An online link called “Metal Spinning Links” was created.^[21] When we notified the companies of the link, we also sent an outline of our research at AIST. In addition, a list of contacts for the companies was created and invitations were sent to nearby companies when an exhibition was held. When companies showed interest at the exhibitions, we followed it up by sending printed materials, a CD containing a movie of our metal spinning technology, and sometimes sample products. When a Google search is carried out for the term “metal spinning” (in Japanese), our research site appears at the top, and the second item is the above link (about 29,000 hits as of January 2012). We received many contacts from companies that requested links and technological consultations, and made inquiries for trials through this page. Such sales activities may be considered as a type of bricolage in the sense that the results were obtained by combining the limited resources at hand. In fact, since cooperating with Daitoh Spinning, which has a wide sales channel in the metal spinning industry, such amateur sales activities have been decreasing.

6 Discussion and future development

The value of this research, which is composed of basic existing technologies, is that we were able to find a niche among the specialties that was overlooked. I consider that a breakthrough in noncircular forming occurred when we jumped into the area that no one had entered because of the difference in the way of thinking between robotics and metal forming. Robot researchers did not have high interest in manufacturing and failed to seek applications there, while metal forming researchers shied away from the application of novel control technology since their lack of knowledge of mechatronics was a barrier. Therefore, we fitted well in an area that had been overlooked by both sides.

Originally, bricolage appeared in the literature as a way of thinking that was in opposition to modern science and technology.^[8] However, bricolage played an important role in our research activity. Bricolage starts from existing and limited resources, but by recomposing the meaning of each resource, infinite combinations are generated and new values are created.^[14] In the development of a new product, the novel elemental technology is normally only part of the product and most of the product is synthesized from existing technologies, meaning that, bricolage is required. Also, in bricolage, elemental technologies that are readily available and familiar are used; thus, highly reliable and readily applicable technology can be obtained.^[11]

In this research, good results were obtained by altering the research flexibly in response to the feedback of results and external factors, without fixating on an initial scenario or core technology, and particularly by retreating quickly from paths that may have led to a dead end. The three actuals of site, object, and situation helped early decision-making.

At the present point in time, owing to the economic situation, the developed technology is not fully utilized at the sites of production, and I am disappointed by the fact that it is not yet a selling technology. We are looking toward follow-up research rather than the easy wrapping-up of this research, and we hope to be responsible for the research up to the final stage. Although the developed technology is advantageous for high-mix low-volume production, we found that the speed of metal spinning is important from exchanges with companies. Therefore, as a future development, we wish to work on increasing the speed and power of the machines and the issues that arise from this. Also, we are working on applications to materials that are difficult to process such as magnesium, for which we feel that fusion with the findings of material science is further needed.

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Author

Hirohiko Arai

Graduated from the School of Engineering, The University of Tokyo in 1982. Joined Honda Motor Co., Ltd. in 1982. Joined the Mechanical Engineering laboratory, Agency of Industrial Science and Technology, Ministry of International Trade and Industry in 1984. Leader of Skill and Dynamics Research Group, Intelligent Systems Research Institute, AIST in 2001. Senior researcher under deputy director in 2003. Senior Researcher, Low-Formability-Materials Processing Group, Advanced Manufacturing Research Institute, AIST in 2009. Professor, Graduate School of Systems and Information Engineering (Graduate School Cooperation), University of Tsukuba from 2005. Doctor (Engineering). Fellow of the Japan Society of Mechanical Engineers; fellow of the Robotics Society of Japan; and member of the Japan Society for Technology of Plasticity and IEEE. In this research, was in charge of the original concept, machine development, spinning trials, and sales activity.



Discussions with Reviewers

1 Composition of chapter 4

Question (Yasuo Hasegawa, AIST Tsukuba)

In chapter 4 that summarizes the results of the research, please clarify the flow of the original research development from the setback of robot arm application, the attempts to create an advanced tool rather than creating a robot that may replace a skilled worker, the success of the approach to improve the machine, and the development of force-controlled spinning that enables the production of high added-value products.

Answer (Hirohiko Arai)

Chapter 4 was broken down into subchapters, and the titles that represent their contents were added. The point I wanted to emphasize in chapter 4 is: "Looking back at the progress of research, it can be seen that there was no consistent scenario and the research goal changed greatly due to external and coincidental factors." This is closely related to the bottom-up, exploratory approach taken in this research. Several factors flowed in multiple streams in the process of R&D, various events occurred randomly, and flexible responses were taken for each event. I adopted such a style of description to reflect the reality of the rather chaotic research process.

2 Composition of chapter 5

Question (Yasuo Hasegawa)

Chapter 5 is the specific description of the action principles explained in chapter 3. Please create subchapters and titles for the three principles: bricolage, three actuals, and the sales mentality. I think it will help the reader's understanding if you insert a diagram for bricolage in R&D.

Answer (Hirohiko Arai)

I set the titles for the subchapters of chapter 5 as follows: 5.1 Synthesis by bricolage – bottom-up integration of elemental technologies; 5.2 Accumulation of spinning know-how by trial runs – desire to approach the actual site, the actual thing, and the actual situation; and 5.3 Fusion of the sales and research activities. I also made clear where in the activities of chapter 5 the action principles explained in chapter 3 are reflected. I also added the figure showing the “hierarchical structure of elemental technologies” to explain the synthesis by bricolage.

3 Achievement level and breakthrough of the developed technology

Question (Norio Matsuki, AIST Shikoku)

In the outline of the developed technology in chapter 1, please self-evaluate the level of achievement. For example, please discuss the developed technology compared to the metal spinning by conventional skilled workers with respect to the precision, work speed, and limitations. Also, please describe any breakthroughs possible only by the technology developed.

Answer (Hirohiko Arai)

In chapter 1, I added the description, “These enable the forming of noncircular shapes that cannot be made by a conventional spinning machine for circular products nor by manual metal spinning by a skilled worker,” and showed that this developed technology has advantage compared to the conventional spinning technology. For the noncircular formation

that can be considered the greatest breakthrough of this developed technology, there is no direct comparison in the field of metal spinning. Therefore, as a comparison to pressing, I added the expression, “Currently, the processing time necessary per product is several tens of seconds to several minutes, and it is not so suitable for mass production.”

4 Flow of R&D that generated the breakthrough

Question (Norio Matsuki)

It will become easier to understand if you contrast chapters 3 with 5 from the viewpoint of what kind of research style and action principle led to the breakthrough and characteristics of the technology. Similarly, in chapter 4, I think that it would be better to emphasize the viewpoint of how the newly achieved technology emerged.

Answer (Hirohiko Arai)

The activities of chapters 3 and 5 place more weight on the efforts of molding the breakthroughs into realistic solutions that can be actually used, rather than the activities to obtain the breakthroughs mentioned in chapter 1. To clarify where in the activities of chapter 5 the action principles explained in chapter 3 are reflected, I modified the titles of the subchapters of chapter 5.

In chapter 4, I primarily wanted to express the point: “Looking back at the progress of research, it can be seen that there was no consistent scenario and the research goal changed greatly due to external and coincidental factors.” I intentionally selected the description that reflected the reality of the chaotic research progress where several factors flow in multiple streams, various events occur randomly, and flexible responses are taken for each event. I think the factor that allowed new accomplishment of technology was “that we were able to find a niche that was overlooked among the specialties,” and I emphasized the descriptions of this point.

International cooperation for the utilization of earth observational data in an integrated manner

— Development of *de jure* standardization of the common infrastructure for the global earth observation system of systems —

Koki IWAO

[Translation from *Synthesiology*, Vol.5, No.3, p.152-161 (2012)]

While each country separately obtains, processes, and utilizes earth observation data, there is a pressing need for a common infrastructure to facilitate integrated use of these resources. At an intergovernmental meeting, an international agreement was reached to construct a common infrastructure for the global earth observation system. Several organizations have submitted components for this infrastructure. These submissions were fairly evaluated, and the most suitable components were recommended for inclusion into the infrastructure system, at the intergovernmental meeting. Recommendation of specific infrastructure components establishes *de jure* standards for the global earth observation system. Since Japan has not offered its own components, it has been able to take a neutral stance on formulating *de jure* standards. Consequently, the standards widely used as *de facto* in Japan have been selected as *de jure* standards. This experience could be a model case for the development of a strategy for international standardization activity.

Keywords : International standard, *de jure*, *de facto*, global earth observation system of systems, intergovernmental group on earth observations, GEOSS common infrastructure

1 Introduction

Several lessons were learned on the position of science and technology in the field of earth observation in the Great East Japan Earthquake. First is the importance of the worldwide collaboration for earth observation. Japan's Advanced Land-Observing Satellite (ALOS) stopped operation on April 22, 2011, only about a month after the earthquake. Japan lost one of its "eyes" from outer space. However, other countries conducted intensive observation of the earthquake area using their satellites, supplemented the missing data, and effective data sharing was done.^[1] Through such international cooperation and data sharing for earth observation, the reliability of the scientific data increased. On the other hand, there are criticisms that the scientific findings from such earth observations were not utilized fully in the earthquake countermeasure policy.^[2] The importance of a mechanism to reflect the findings of the earth observation data in policy-making became apparent.

2 Current situation of earth observation data use

In earth observation, various measurement devices including the observation network on land and sea, aircraft, and weather satellites are used. Based on the data obtained from the observations, prediction model, climate change scenario, and various information services are provided. The

objective of earth observation is to gather regional data to address biodiversity, energy, and health issues, as well as for global problem solving. Ultimately, the observations may be reflected in the decision-making process for environment and energy policies.

In the conventional earth observation, collaborations were conducted using land data and satellites for each subject observed such as land, ocean, and atmosphere. For example, the World Meteorological Organization built a global observation system and is trying to link the geostationary meteorological satellites, polar orbit satellites, and ground meteorological observation network.^[3] Also, the UN Food and Agriculture Organization constructed the global land observation system.^[4] Moreover, collaborations and adjustments were done among the global observation system and aerospace organizations that develop and operate the observation satellites under the Integrated Global Observing Strategy Partnership (IGOS-P).^[5] Collaborations progressed among individual fields or satellites observation systems.

However, at the scene of decision-making, there are many instances where various observation data must be combined. For example, when planning the construction of an offshore wind power plant, the oceanographic data is necessary as well as the atmospheric data. In conventional decision-making, such observations were often duplicated for different purposes.

Geoinformation Center, AIST Tsukuba Central 7, 1-1-1 Higashi, Tsukuba 305-8567, Japan E-mail: iwao.koki@aist.go.jp

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To accomplish international collaboration for integrated use of earth observation data that may contribute to policy and decision-making, it is necessary to establish an infrastructure that enables the common use of observation data and services that are conducted by various organizations for individual purposes. This is called the Global Earth Observation System of Systems (GEOSS) Common Infrastructure (GCI). Figure 1 shows the conceptual diagram for GCI.

The following three basic elemental technologies are needed for the common infrastructure (CI) system for earth observation data. One is the global earth observation web portal (GWP or WP). WP provides the web interface function that allows the user to use the data and services provided by various organizations. Second is the GEOSS clearing house (CL). CL provides the function that allows global search and utilization of the data and services that are dispersion-managed on the Internet. Third is the component service registry (CSR). CSR is the database to register the earth observation data and services. The system of earth observation information is configured by combining these three components. Figure 2 shows the overall configuration of the use system of earth observation data.

As of 2009, the WP and CL that are CI components were separately operated by three organizations including private companies respectively, and the registry was operated by the George Mason University under subcontract of the US Geological Survey (USGS). The users of the world combined the components provided by these organizations and accessed the earth observation data and services.

The multiplicity of the WP and CL is desirable from the perspective of system redundancy. However, for WP, there were problems of poor usability such as differences in maneuver and compatible operating systems or browsers, demand for unique plug-ins when using a certain browser, or operational instability unless extremely high spec PC is used. For CL, there were problems of comprehensibility where the existing data may not be reflected in the search result due to difference in search method, or that the data not in the registry may be reflected in the search result. To solve these problems, it was necessary to establish a scheme of international collaboration where the earth observation data would be shared and reflected in various policies. Such a scheme would be composed of both the provider of systems and the decision makers of various fields who are the users.

3 Scenario for the integrated use of earth observation data

To realize the integrated use of earth observation data, the most important issue was to create a common infrastructure (CI) that allowed the integrated use of various data and services provided by various earth observation organizations around the world.

There are currently enormous quantities and volumes of earth observation data and model results. For example, AIST has an archive of data gathered by an earth observation device called the advanced spaceborne thermal emission and reflection radiometer (ASTER), and the number and volume

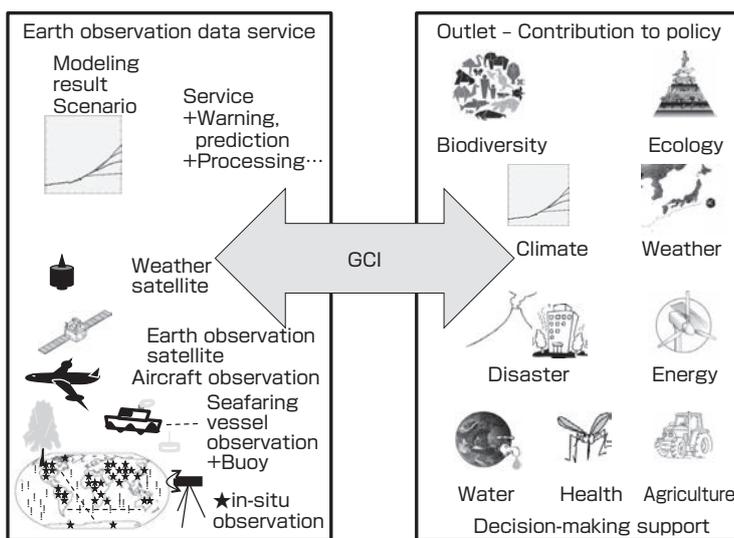


Fig. 1 Role of GCI in the integrated use of information and services
A system that supports the utilization of scientific findings in the policy-making of various fields, through the international collaboration of earth observation information and services

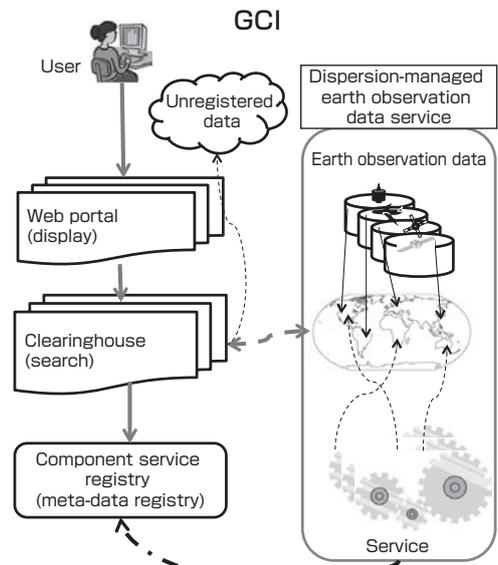


Fig. 2 Configuration of standardized CI and access to data service
The main components of the CI are web portal, clearinghouse, and component service registry. The actual component (data) and services are dispersion-managed and operated by individual institutes.

Table 1. History of international discussions on the collaboration for earth observation

Year held	Meeting (place)	Accomplishments
2002	World Summit on Sustainable Development RIO+10 (Johannesburg)	Emphasized the importance for the framework of international cooperation for earth observation in its action plan.
2003	G8 Evian Summit (Evian)	Former PM Koizumi proposed the "Global Earth Observation System."
2003	First Earth Observation Summit (Washington)	Adopted the declaration that emphasized the importance of stance commitment at political level, to initiate the action to develop the earth observation system composed of multiple, sustainable systems. Temporary earth observation work group was established, with EU, Japan, South Africa, and USA as joint chairman.
2004	Second Earth Observation Summit (Tokyo)	Adopted the framework document that defined the range and intent of the GEOSS.
2005	Third Earth Observation Summit (Brussels)	10-Year Implementation Plan for GEOSS was deployed. Intergovernmental Group on Earth Observations (GEO) and its secretariat were established.

of data from 2000 to February 2012 are about 2.5 million scenes and 150 terabyte, respectively. It is estimated that the number of earth observation satellites in the world may reach 200 in 2012.^[6] Multiple earth observation devices are installed on a satellite, and for example, there are five types of earth observation devices onboard the TERRA satellite on which ASTER is installed. Therefore, it is not realistic to aggregate and manage such voluminous earth observation data in one place. Such data and services are most reasonably dispersion-managed by the organization that collected and processed them. Instead, the information on the data and services offered by the organizations can be registered in one place, and the user can access the data and services of the individual organizations based on the registered information. By building a common infrastructure that allows access to the data and services that are already dispersion-managed by the individual organizations, it is not necessary to request updating the existing data and services to new specifications. Also, for the managerial and policy reasons, including the consideration for different policies for copyright and data management of the earth observation data, dispersion management is desirable.

The scenario that aims for the integrated use of earth observation data is explained using Fig. 3. As presented in chapter 2, the access to earth observation data and services that are dispersion-managed by individual organizations is enabled through the GCI. GCI is composed of three components. As requirements to build the CI, the operational robustness must be guaranteed for each component. In a case where one of the components fall into operational difficulty due to financial trouble, the GCI may cease to function. The requirements for the components include the technological requirements such as ease of access and comprehensibility of data, as well as being a system that is highly friendly to users who may have various purposes.

4 International collaboration activities

4.1 History of international collaboration

The importance of collaborations in earth observation and the discussions on reflecting the scientific findings in policies has been raised since the beginning of 2000s. Table 1 is the brief history of the international agreement on common earth observation network building. Mr. Koizumi (Prime Minister of Japan at that time) declared the need for the Global Earth Observation System of Systems (GEOSS) at the 2003 Evian Summit,^[7] and this kicked off the international collaboration movement for earth observation.

4.2 Global Earth Observation System of Systems (GEOSS)

The GEOSS proposed by former Prime Minister Koizumi aimed to build the "system of systems" or the global earth observation collaboration where all satellite, aircraft, and in-situ observations of earth, which were individually gathered

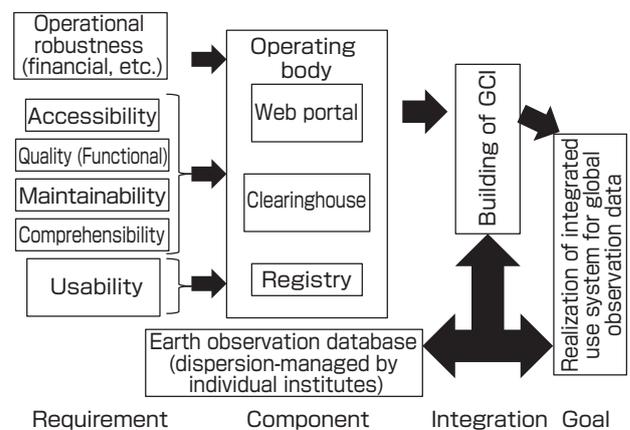


Fig. 3 Scenario for integrated use of the earth observation data

The components for building the GEOSS common infrastructure that aims to be the integrated system for using earth observation data and the requirements were summarized as a scenario.

by countries, and all observation systems, earth datasets, prediction models, and services for earth are combined. The *GEOSS 10-year Implementation Plan*^[8] was drafted in Brussels in 2005, and its ultimate goal was to reflect the scientific findings obtained through earth observation collaboration in policies. Specifically, nine societal benefit areas including disaster, health, energy, climate, weather, water, ecology, biodiversity, and agriculture were selected, and immediate issues that must be solved within 10 years were extracted.

4.3 Intergovernmental Group on Earth Observations (GEO)

To realize the GEOSS, the Intergovernmental Group on Earth Observations (GEO) was established under the international agreement in 2005. As its management body, the GEO Secretariat was established in Geneva, Switzerland. The mission of the Secretariat was to draft the *GEO Work Plan*,^[9] manage its progress, adjust the international investments in earth observation projects, and others.

Unlike the permanent United Nation organizations, GEO was set as a fixed-term organization to solve the issues by 2015. While the UN has certain binding force in its resolution, the resolution of GEO is not binding but is taken as recommendations. The GEO is operated by volunteers from the governments of 87 countries and 61 international organizations and institutions including the UN organizations, as of October 2011. The member countries of the GEO at present are shown in Fig. 4.

The member countries and participating organizations of GEO are represented by principals. For the government of Japan, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) is in charge, and the deputy director-general of the Research Promotion Bureau acts as the principal for the Japanese government in 2012. Although GEO



Fig. 4 Distribution of member countries of GEO (as of October 2011)

The darkened countries are current members and grey ones are non-members. Of the 193 countries that are members of UN (as of 2011), 87 countries, or about half, are participating. While there is participation by Switzerland that is not a UN member, the number of participating African countries is particularly low.

is a voluntary organization with no binding force, the member countries and organizations participate actively and contribute financial and human resources. One reason is because the GEO is positioned as an international function for the management and coordination of earth observation activities. The progresses on the issues are reported at the Plenary meeting of GEO held once a year, and at the ministerial level meeting held every three years. The resolutions at such meetings are reflected directly in the earth observation policies of the countries. In Japan, the Minister of MEXT attends the ministerial-level meeting. The other reason for the active participation by many countries, is while the methods used in each member country and organization are used as the *de facto* standard in various fields, the GEO may be the place to set the unified *de jure* standard. Therefore, the private companies as well as the government and public institutes may provide technological support to the GEO activities. However, private companies do not have membership. The public institutions for earth observation of various countries contribute as part of the member countries' participation to GEO. The organization of GEO is shown in Fig. 5.

The author participated in the activities of the GEO Secretariat as a scientific and technical officer from AIST for two years, from April 2009 to March 2011, through the Japanese government as part of human resource contribution to GEO. The Secretariat is located in the building of the World Meteorological Organization and the employees are equivalent to that of UN officers. During the author's appointment period, personnel were dispatched from the USGS and National Oceanic and Atmospheric Administration of the USA, European Space

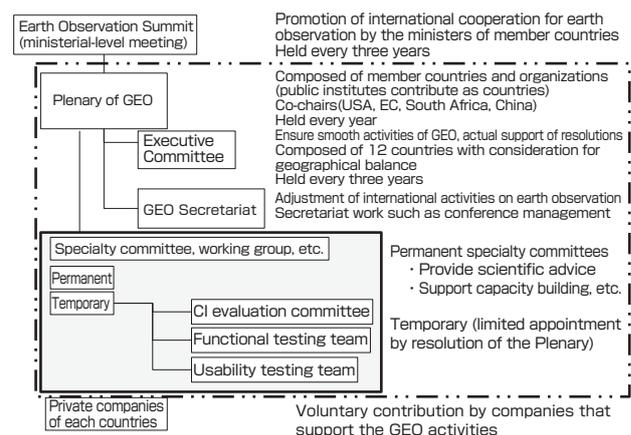


Fig. 5 Organization of GEO

The GEO promotes the international cooperation of earth observation in the annual Plenary in which all member countries and participating organizations, and in the ministerial-level meeting held once in three years. To ensure smooth operation, the Secretariat is established under the Plenary, to act as the coordinator. Permanent specialty committees that provide scientific advice and temporary committees that conduct evaluation and selection, as described in this paper, may be also set under the Plenary.

Association, Instituto Nacional de Pesquisas Espaciais of Brazil, Government of South Africa, China Meteorological Administration, Korea Meteorological Administration, and Japan Aerospace Exploration Agency. The Secretariat was composed of the personnel dispatched by the governments, as well as a few directly employed personnel including the chief secretary.

4.4 Common infrastructure (CI)

To realize the “system of systems” for global earth observation, the most important issue for the GEO was to construct the common infrastructure (CI) that enables the use of various observation data and services that are provided by the earth observation institutes around the world. In building the CI, the assumption was the dispersion management of earth observation data and services by the individual organizations as it has been done in the past. The information pertaining to the data and services provided by the organizations are registered to the CI, and one could access the data and services of the various organizations through the CI. The basic principle of GEOSS that does not require the integration of observation systems or information systems operated by individual organizations was enforced.^[10]

The CI was configured by three basic components along the scenario explained in chapter 3. The three components are web portal, clearinghouse, and service registry. By combining the components, the whole CI was realized as shown in Fig. 3.

4.5 Problems in building the CI

Ideally, the user should be able to use the same information and service no matter which combinations of WP and CL are used. However, in reality, there were many cases where the search result and the usable services differed according to the combination of the existing WP and CL, and there were some confusion among the users.

In response to such a situation, in the Plenary of GEO held in 2009, it was resolved that the cause of confusion must be clarified, and the organizations described in chapter 2 providing the existing WP and CL offered would be evaluated, and to recommend the WP and CL for the common infrastructure.^[11] The period allotted for the selection task was short, and it was to be done by the ministerial-level meeting of GEO in 2010.

In this paper, the cause of user confusion, the evaluation method employed to build the CI, and the results will be described. Also, the relationship between the building of the CI and *de jure* standard established for the earth observation field will be explained.

By building the CI, it is expected that the integrated management of earth observation data will become easy, the

comprehensive search will become possible, and the user confusion will be resolved. Moreover, the experience of establishing the *de jure* standard will provide a model case for Japan in establishing the international standard in the future.

5 Requirements and synthesis method

5.1 Requirements for evaluation and selection of the components of CI

In evaluating and selecting the components of CI, the following requirements were considered. First was to guarantee the fairness of the evaluation result. To conduct the evaluation and selection of the organizations that developed and operated the WP and CL on a voluntary basis, it was necessary to obtain an international agreement for fair and equal evaluations and results. Second was time limit. The evaluation report had to be submitted to the member countries and organizations before the GEO ministerial-level meeting. Therefore, the cause of confusion and the evaluation of components had to be investigated in a period less than one year. Third was the establishment of the standard used for evaluations. In the traditional system evaluation, technological evaluation standard such as response time required for displaying the search result would be set. The technological evaluation standards were set for this evaluation also.

On the other hand, the users of the nine societal benefit areas would be actually using the CI. The purpose is diverse, and the combination of technological evaluation does not necessarily enhance the usability for the users. It was expected that the usability of CI would differ between the users of countries with well-established Internet and the users of developing countries where the speed of the Internet connection was limited. In ordinary Internet search, only the search result of the text would be obtained, but in the CI, satellite images and maps would be handled. Particularly in a case where some special function was added to the image display, the smoothness until the search result was displayed would differ by WPs. Also, in WPs that required installation of special plug-ins, different usability and smoothness were expected depending on the performance spec of the PC used. Therefore, it was necessary to set up the evaluation standard for the usability of the users of nine societal benefit areas, including the users of developing countries with limited work environment such as Internet availability. Moreover, the CI has to run stably during the active period of the GEO, or at least up to 2015. Since the CI will not function even if one function such as the WP or CL becomes short, it was necessary to establish an evaluation standard that guaranteed a stable long-term operation.

5.2 Synthetic method to build the CI

To build the CI, a CI evaluation committee was set,

officiated by the GEO Secretariat. To guarantee the fairness of the evaluation result, the participation to the evaluation committee by specialists from all member countries and organizations of GEO was requested. In obtaining the international agreement, importance was placed on geographical balance. The provision of the components was solicited from the institutes and organizations of Europe and the USA. The request for participation to the evaluation committee from regions with high interest in the diffusion and standardization of their original technology was expected from the inception. Meanwhile, there was no organization that offered the components from Asia, Oceania, or Africa. Moreover, in the developing countries, it was expected that troubles will occur in using a system that was decided mainly by Europe and US, since there might be speed limit of Internet connection or lack of spec of the PC used. To ensure wide diffusion of the recommended system to all member countries, active participation was solicited from the developing countries in particular, to guarantee international agreement. However, the evaluation committee members were limited to the members officially recommended by the principals. This was done to ensure the results would reflect the representatives of the member countries and organizations of the GEO. The committee members were composed of the members recommended by the following countries and organizations. The number in the parenthesis shows the number of personnel, and there is no parenthesis when there was only one person.

Member countries: Australia, Austria, Brazil, China, Finland, Germany, Italy (2), Japan (3), Madagascar (3), Pakistan (2), USA (5), and EU (2).

Member organizations: Committee of Earth Observation Satellites, European Space Agency, The Federation of Earth Science Information Partners, European Organization for the Exploitation of Meteorological Satellites, The Institute of Electrical and Electronics Engineers, Inc., US Environment Protection Agency, EU Joint Research Center, Open GIS Consortium, Inc., and World Meteorological Organization.

In addition to the 30 committee members, two members of the GEO Secretariat, including the author, joined the evaluation committee. The functionality and usability testing teams that included the committee members were established under the GEO Plenary. These two teams conducted actual investigation based on the evaluation items for technology and usability created by the evaluation committee. The functionality testing team was composed of the staff from Brazil and the Joint Research Center, while the usability investigation team was composed mainly of people from the EPA. For example, the evaluation committee set the search response time as a technological evaluation item, and the functionality testing team considered the conditions and

methods for measuring the response time and conducted the actual evaluation. The fairness of evaluation result was enhanced by reporting the results to the evaluation committee.

When the evaluation committee members were solicited, there were applications from organizations with conflict of interests, namely the European Space Agency that provided the WP that is the component of the CI and the USGS that provided the CL. Since the GEO assumed voluntary participation, they could not be completely eliminated, but in a case where the organization itself would be the subject of investigation, the committee member belonging to that organization was eliminated from the discussions. On the other hand, Japan did not provide any components for the CI, and was expected to have increased say due to its fair standpoint. Therefore, additional three specialists were dispatched from AIST, and discussions could be held with the cooperation of the AIST specialists, with the author acting as a coordinator.

About two months were required from the GEO Plenary in late November 2009 to the official selection of the committee members. When the committee members were determined and preliminary exchanges were done by telephone conference and e-mails, the first meeting of the evaluation committee was held in February 2010 at the GEO Secretariat. At this meeting the "Terms of Reference" of the committee was drafted, and the three items, functionality, usability, and long-term operability were set as the target of evaluation. Also, as shown in Fig. 6, the overall flow was set toward the creation of a report of the evaluation result.

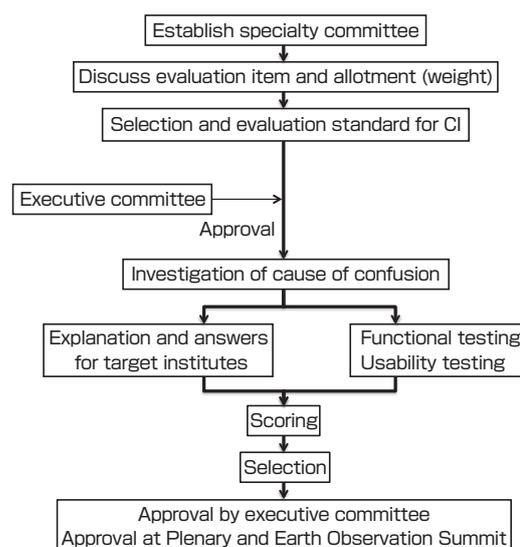


Fig. 6 Flow to the CI selection

The flow of evaluation and approval conducted by the evaluation committee is shown.

Table 2. Selection and evaluation standards for CI

Evaluation item	Weight (%)	Outline	
Functionality	25	Evaluation result of the technology investigation item list	
Usability	25	Evaluation result for usability	
Long-term operation	Financial aspect (supporting organization)	10	Promise for financial support as organizations for 2010-2015
	Financial aspect (country or member organization)	20	Endorsement from member countries and organizations for financial support
	Functional aspect	10	Promise for the response to the mandatory requirement items
	Release of rights to the system	10	Release of rights in case of transfer of system to a third-party organization

Prior to the evaluation, the clarification of the cause of confusion was done, the discussion on the investigation standard was continued by weekly telephone conference, and the evaluation items for functionality and usability were listed. The evaluation committee conducted the final scoring based on the results of the investigation items and the general evaluation for long-term operability. The details of the scores of each evaluation item were submitted in the form of advice from the evaluation committee to the GEO, and the work progressed after seeking approvals.

To conduct evaluation of the CI, it is necessary to evaluate the action when the elemental technologies are combined, as well as the evaluation of the individual elemental functionality. Therefore, since there were three organizations respectively that were offering the WP and CL, it was necessary to conduct the tests for nine combinations. However, in conducting the investigation of the problem where the search results were different according to the combination of the WP and CL, it was found that the CI would function only under a certain combination. Therefore, due to time constraints, a two-step process was taken where the CL was evaluated and selected first, and then the WP was evaluated and selected. For the evaluation tests, particularly for the usability, preparations were done quickly to submit the report to the GEO Work Plan Symposium held in May 2010, as there would be attendance of many users participating in the GEO. By conducting the usability test during the symposium, the differences in usability could be clarified, such as use for different purposes under the same conditions of networks and browsers. Also, participation of the users of developing countries who could not regularly attend the meetings was encouraged. Moreover, since the meeting was held in a developing country with limited Internet connection speed, the participants could evaluate the usability of the CI under such conditions. For the usability evaluation, the online evaluation system on the Internet was made available to solicit wide range of users to evaluate from all social beneficiary fields.

For the evaluation standard, it was determined that general

evaluation would be done from the three perspectives of functionality, usability, and long-term operability, but it was also necessary to determine the weight of the scores. Table 2 shows the evaluation items determined by the committee and the score weighting. Upon discussion in the committee, functionality and usability were given 25 % each. The remaining 50 % were items for long-term operability.

The functional testing was composed of the mandatory items and optional items. Over 100 evaluation items were listed. For usability evaluation, separate evaluation items were listed to evaluate the usability for all nine societal benefit areas. Four items were set to guarantee the stable, long-term operation. The first item was the promise for the financial support from 2010 to 2015 by the organization that offered the provision of the CI components, and 10 % was allotted. The second item was the endorsement from the GEO member countries or organizations to the organization that offered provision of the CI components, and this was given 20 %. In the case where the components were provided by private companies, it was required that a GEO member country or organization would guarantee the operation (endorsement). The third item was promise for response to the mandatory item by the organization offering the GCI component, and 10 % was allotted. The WP and CL selected by the general evaluation did not necessarily satisfy the mandatory items. Therefore, demand was made to each organization to promise quick compliance to the mandatory items of the WP and CL. The fourth item was the release of license of the system that the organizations developed as the WP and CL, and 10 % was allotted. In a case where the organization providing the WP or CL could no longer manage them for some reason, this ensured the smooth transfer of the system to a third party.

For the item pertaining to the release of license, several requests were made to disclose the whole system as an open source. However, open sourcing was not sought, and the agreement was written to guarantee the situation that allowed transfer in case operation became impossible. This was done to take into account the participation of private companies. On the other hand, the request for the

endorsement of financial support from the member countries or participating organizations of GEO in the second item was disadvantageous to the private companies that did not necessarily belong to the member countries or organizations. Ultimately, it was considered important to guarantee the stable operation of the core system of the GEOSS by obtaining the promise for financial support from the member countries or organizations, even if the organization or private company that provided the component lost the financial guarantee. Therefore, this item was given the weight of 20 %.

The result of scoring was not disclosed to the public. However, the scoring results were disclosed by request to the organizations that were screened, including the organizations that were not selected.

6 Evaluation result

When the cause of user confusion was clarified, it was found that the CI functioned only with the combination of certain WP and CL. This was identified as one of the causes of different search results. As individual organizations developed and advanced original systems for search and display, the system linkage with other organizations was not realized. Also, it was found that for the registry that was provided officially by only one organization, some organizations that provided the CL made the search of their own data possible. These two were the reasons that the search result and the usable service differed according to the combination of the WP and CL. It can be said that the universality was lost when the originality and convenience of the function were pursued by adding functions and original data particular to the organization.

As a result of the general evaluation of functionality, usability, and long-term operability, the WP offered by the European Space Agency and the Food and Agriculture Organization, and the CL offered by the USGS were selected. The combination including the registry offered by the USGS was recommended as the CI of the GEO. The *GCI Coordination Team Report*^[12] was accepted at the Earth Observation Summit held in Beijing in 2010. As a result, the European and American organizations that lead the global earth observation were selected.

The evaluation and selection of the elemental functions of the CI resulted in the specification for accessing the earth observation information and services to be selected as *de jure* standards, rather than being left as *de facto* standards. Considering that the principle of GEOSS is not to seek integration of the observation and information systems that are managed by different organizations, it is desirable that the *de facto* standard is implemented as the users actually use the system, and the technology with low universality is eliminated. However, in establishing the standard that may

develop into conflict of interest among the countries and organizations, it is believed that the approach of selecting the *de jure* standard was effective.

For the WP, the display method of the geospatial data including the earth observation data was standardized, while for the CL, the definition of the metadata of earth observation data, the method for mutual use of data in various formats, and the data search method were standardized. In the process of the evaluation and selection of the CL, these *de jure* standards were clearly established.

7 Discussion

Looking back at the process by which the *de jure* standard for the earth observation field was established, the points to note in creating the international standard are summarized.

First, care was taken to form a community to promote international agreement in discussing the *de jure* standard. To ensure the wide and international use of the technology, the practitioners and users, including those of the developing countries, were highly influential, as well as the technology specialists representing the countries.

Second, consideration was given to temporal speed. The fact that there was a necessity to set the *de jure* standard indicated that there were diverse original technologies existing in the world, and that might have caused the confusion among the users. To clear up the confusion quickly, a clear timeline was set, the optimal *de jure* standard was decided in the limited time, and this turned out beneficial to the users.

Third, care was taken to ensure fairness in the evaluation process. In this case, the guarantee of fairness of the evaluation result was maintained carefully by establishing a separate investigating team from the evaluation committee, and by conducting the actual evaluation and screening only after the approval of the evaluation index by the GEO executive country committee. The result was widely accepted because of fair processes such as the independency of evaluation and the transparency of individual screening, in the process of selecting the international standard. In fact, the private companies that were not selected this time did not express unfairness in the selection and continues to support the activities of the GEO to present. This is because fairness was maintained in the evaluation process. The evaluation and selection processes could be positioned as the guideline when evaluating the voluntary participation of the private companies. For the private companies, the evaluation result was obtained based on the evaluation by users in various fields around the world, and it provided useful information for reviewing the usability and issues in their products.

From the standpoint of conducting an international

technology development, the weight of scores of the evaluation item determined in the process of evaluation and building of the CI presented one guideline in considering the international standard. In the system such as CI that is used widely and internationally, the emphasis is placed on universality rather than technological excellence, and the format is highly likely to become the international standard once it is employed.

The evaluation and building of the CI can also be positioned as a successful case of international agreement for *de jure* building for earth observation recommended by Europe and USA. For example, in the Seventh Framework Programme (FP7), which is the science and technology R&D system of the EU, it is determined politically that all research projects on earth observation must be adopted under the condition that they may contribute to the GEO. The FP7 not only supports the R&D for CI but is active in supporting the R&D for data and services, and as a result, succeeds in producing the *de jure* standard from the technology developed in the FP7. In Japan, it is necessary to build a system for international standardization in which the public R&D support system is involved.

On the other hand, for the specialists who participated from Europe and USA, there were cases where the system offered by the organization to which they belonged would be the direct subject of investigation. Therefore, the voice of Japan which was capable of taking the third-party stance became important. In fact, several technologies were already widely used in Japan and have become the *de facto* standard. In the international standard selection, while the fair and equal evaluation according to the international movement is necessary, the fact that the technology that was widely used in Japan was employed as *de jure* standard could be a guideline for the Japanese activities in the flow of the international standardization led by Europe and the USA. However, it is difficult to follow all of the points among the voluminous conference material while in Japan. Although regular meetings were done over the telephone, they were held late in the evening in Japan, due to regional time differences. International negotiation is not settled in one meeting, and continuation of dialogue is important. This time, it was possible to incorporate the elemental technologies that had become the *de facto* standard in Japan as the *de jure* standard in the international standardization discussions by dispatching personnel to the office that integrated and arranged the entire project, and maintaining a system where appropriate and fair comments could be issued in particularly important meetings. If Japan were to join in the discussion for international standardization, it is necessary to set up such a system.

Acknowledgements

I was given the opportunity to participate in the activities for an international arrangement and international standardization through the two-year dispatch to the international organization. I am grateful to AIST and the government of Japan that granted me this opportunity. This would not have been successful without the collaboration with the three specialists from Japan: Dr. Satoshi Sekiguchi (currently, vice research supervisor, Information Technology and Electronics), Dr. Yoshio Tanaka, and Dr. Isamu Kojima of Information Technology Research Institute, AIST. I express my thanks. Finally, I am thankful to Dr. Rob Koopman with whom I worked as a coordinator at the GEO Secretariat, GEO Director José Achache, the staff of the Secretariat, as well as all the members who were involved in the selection process.

List of acronyms

Acronym	Official title
ALOS	Advanced Land Observing Satellite
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CL	GEOSS Clearinghouse
CSR	Component and Service Registry
ESA	European Space Agency
GCI	GEOSS Common Infrastructure
GEO	(Intergovernmental) Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GWP	GEO Web Portal
USGS	US Geological Survey

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Author

Koki Iwao

Completed the courses in Civil Engineering, School of Engineering, The University of Tokyo in 1996. Obtained doctorate (Engineering) at the Graduate School of Engineering, The University of Tokyo in 2000. Post-doctorate positions at the Asian Institute of Technology (Bangkok); Research Institute for Environmental Management Technology, AIST; and National Institute for Environmental Studies. Joined the GEO Grid Research Group, Information Technology Research Institute, AIST in 2007. Dispatched as Scientific and Technical Officer to the Intergovernmental Group on Earth Observations Secretariat (Geneva, Switzerland) for two years from 2009 to 2011. Senior officer, Geoinformation Management Office, Geoinformation Center, Geological Survey of Japan, AIST from April 2012. Specialty is the creation and verification of global data set (such as land cover maps) using satellite remote sensing and GIS technology.



Discussions with Reviewers

1 Overall

Comment (Akira Ono, AIST)

This paper is about building an information system where users can comprehensively make use of various earth observation data gathered and processed individually by different countries and organizations. I think it is an excellent *Product Realization Research*. As the author expresses the completed product “system of systems” the process of which the product is made by integrating various elements, it is suitable for *Synthesiology*.

2 Importance of the integration of earth observation data

Comment (Koh Naito, Center for Service Research, AIST)

Many readers may not sufficiently understand the importance of the integration of earth observation data. Therefore, please explain this point in the “Introduction” at the beginning of the paper. In the Great East Japan Earthquake, many scientific data were not used in policy-making.

Answer (Koki Iwao)

I added the chapter of “Introduction” and mentioned that the scientific data were not fully used in policy-making in relation to the Great East Japan Earthquake.

3 Addition of technological viewpoint

Comment (Koh Naito)

I understand that the efforts explained in “Synthetic method” is the most important point of this paper. While the text contains the explanation of that method, please describe what kind of efforts were made, what were the points including the technological viewpoints, and finally how the international agreement on selection result was reached.

Answer (Koki Iwao)

As you mentioned, the “synthetic method” is the most important point. In working on this project, I summarized the

technological requirements, described the work done for the corresponding requirements, and re-synthesized the items that led to the agreement of selection results. In revising the “synthetic method,” I also revised the results and discussions so the correspondence will become clear.

4 Description of the scenario

Comment (Akira Ono)

In the text, it is written that the author joined the GEO Secretariat, was given a framework, created scenarios, and then executed them. In *Synthesiology*, the topic is not limited to what the author handled directly. The author can describe a larger scenario from the author’s viewpoint, including the accomplishments of the GEO Secretariat and GEO itself. I think the readers of the journal will be able to grasp the whole picture, and that will be beneficial for them.

Answer (Koki Iwao)

I added Fig. 3 to explain the whole scenario, and provided an explanation in the paper.

5 Comparison with the database integration of other fields

Question (Akira Ono)

I understand the main point of this paper is the creation of a system where multiple databases built by various entities with different standards can be used by the users as if using a single database.

The demand for integrated use of multiple databases is also frequently heard in areas other than earth observation. Comparing with other fields, can the author offer some opinion about the issues or solutions that characterize the earth observation field?

Answer (Koki Iwao)

As you indicated, the main point of the paper is to build a common system that links the database managed by multiple institutions, and to realize a system that could be used comprehensively.

Comparing to other fields, taking the example of multiple database integration, I mention the case described in AIST Press Release “Opening of integbio.jp, a joint portal site of bioscience database of four ministries (in Japanese)” (released December 12, 2010: http://www.aist.go.jp/aist_j/press_release/pr2011/pr20111212/pr20111212.html).

In this article, it is explained that the integration of the bioscience database is accomplished in four steps: catalog, cross search, archive, and reconstruction.

In the earth observation field, the aims were catalog and cross search. I think the catalog (list of links by database) corresponds to the registry in our project. The cross search function (keyword search of multiple databases) corresponds to the clearinghouse. Even in different fields, there are similarities in the database integration steps. On the other hand, there is a slight difference in archive (integration of database format and consideration of rights), the third step in database integration of the bioscience field. In the earth observation field, rather than integrating the database format, the differences are absorbed in the CL. In this case, the characteristic of earth observation data is that almost all data contain time and location information, and that allows narrowing down the search condition.

The consideration of the rights of earth observation data is positioned as an important issue. A specialty committee is established under the Plenary to draft the principle of data sharing (promotion of earth observation data sharing). However, currently, there is the thinking that all data should be actively disclosed (free and open), and also the thinking that rights should be respected. The thinking of respecting rights is dominating, and the rights related matter is not sufficiently organized yet. The USA is promoting free and open data. It is actively releasing data, starting

with the completely free release of the Landsat earth observation satellite data (LANDSAT DATA DISTRIBUTION POLICY: http://landsat.usgs.gov/documents/Landsat_Data_Policy.pdf). The GEO named the free and openly available data as GEOSS Data-CORE and is asking the member countries and organizations to supply data. Therefore, the rights matter (active free release) is expected to progress further. However, the types and rights of data are diverse, from the local observation data collected by individual researchers to satellite images on a national scale, and

more time is required to organize this matter.

In the reconstruction (advanced search) activities in the fourth step, while this was not explained in this paper, we are organizing the ontology and the terminology used in the nine societal benefit areas. I expect there may be effects similar to the reconstruction in the bioscience database integration. Also, in earth observation, we aim for linkage of services, not just data. For example, in the activity called Model Web, multiple models are bound together to be used for some new purpose. (<http://www.uncertweb.org/>)

Development of a pressure sensor using a piezoelectric material thin film

— Application to a combustion pressure sensor for mass-produced cars —

Morito AKIYAMA *, Tatsuo TABARU and Kazushi KISHI

[Translation from *Synthesiology*, Vol.5, No.3, p.162-170 (2012)]

In this paper, we show the process of research and development of a combustion pressure sensor using an aluminum nitride (AlN) thin film, which we developed for the first time in the world. At the time we envisaged the R&D in 2003, most sensors used a piezoelectric single crystal. The research of a combustion pressure sensor using an AlN thin film was an unexplored field, and the usefulness of an AlN thin film was not yet well recognized. However, since we started the R&D, domestic and foreign auto parts companies and universities showed interest, and we carried out joint research with a domestic company and a university toward practical use of the sensor. Consequently, we have succeeded in developing a sensor of small size, high sensitivity, and without the need of cooling. We now conduct research to resolve the problems such as stabilization of sensor signals and simplification of the sensor structure for practical use.

Keywords : Combustion pressure sensors, mass-produced cars, aluminum nitride thin films, piezoelectric type, laminate structure

1 Introduction

1.1 Necessity of the combustion pressure sensor in mass-produced cars

The improvement of fuel efficiency and measures for low pollution in automobile engines are urgent issues that must be tackled to counter the global warming caused by carbon dioxides and the elevated price of crude oil that started around 2008. Various regulations pertaining to the emissions from engines will gradually become effective around the world, such as the “Fuel Economy Standard for Heavy Duty Vehicles” from 2015 in Japan, the “Euro VI” from 2014 in Europe, and the enforcement of new gas emission standards in the United States. As measures to such regulations, the automobile companies are engaging in R&Ds for various new cars, including those with direct-injection engine, green diesel, biofuel, hybrid, electric, hydrogen, fuel cell, and others. However, at least for the next 10 to 20 years, automobiles with engines that use oil as fuel will remain the mainstream. Along with the increased performance of tires and reduced body weight, active researches are done for increased combustion efficiency, filtering technology for gas emissions, and the technologies for electronic combustion control. Various measurement technologies for pressure, temperature, flow rate, vibration, and others are necessary to develop such technology. Particularly, there are great expectations both in volume and quality of the information that can be obtained from pressure measurement, judging from the necessity, installability, precision, responsiveness, and economic feasibility of sensor development. Especially

for the high-precision control of combustion in the combustion chamber, it is necessary to develop a new inter-cylindrical combustion pressure sensor with heat resistance of 400 °C or more that allows direct, high-speed measurement of the pressure in combustion chambers.^[1]

1.2 Situation of the combustion pressure sensor

The piezoresistant semiconductor pressure sensor, which is the most prevalent type of pressure sensor, is small, highly sensitive, highly befitting for mass production, and dominates 83.2 % (quantity base) of the market.^[2] However, its service temperature limit is about 120 °C. To increase the heat resistance, researches are being done to insert heat-insulating barrier (alumina) in the lower part of the gage, to use sapphire diaphragm, or to use chromic oxide and silicon carbide (SiC) that are highly heat resistant as the material for the gage. However, sufficient heat resistance has not been achieved.

In 1992, Toyota Motor Corporation installed a semiconductor pressure sensor for the first time in the world as the combustion pressure sensor in its mass-produced car, by maintaining the maximum temperature of the sensor element to 120 °C or lower by devising the sensor structure and layout, but this system is currently not used. From 2009, BorgWarner BERU Systems GmbH of Germany provides a glow plug with a function of the semiconductor pressure sensor incorporated into the combustion pressure sensor. Although this has been installed in some of the green diesel cars of Audi AG and Volkswagen AG, it is not yet used widely.

Measurement Solution Research Center, AIST 807-1 Shuku-machi, Tosu 841-0052, Japan * E-mail : m.akiyama@aist.go.jp

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On the other hand, the piezoelectric sensor that detects the charge of electric polarization of piezoelectric body is commonly used in the laboratories of universities and companies. In the piezoelectric sensor, the engine cylinder pressure received by the diaphragm is detected by the piezoelectric body. It has advantages of being small, having high response speed, and having excellent heat resistance.^[1]

Crystal (SiO₂) is used as the piezoelectric material of the general-use piezoelectric combustion pressure sensor. However, since the phase transition point of crystal is 573 °C, the service temperature limit is about 350°C, and cooling is necessary for measurements at 400 °C or above. Therefore, new piezoelectric material with excellent heat resistance is being sought. As shown in Figure 1, material with high piezoelectric property tends to have low service temperature limit, and it is not easy to find an optimal piezoelectric material with high piezoelectric property and heat resistance. Around 1997, a product that used gallium phosphate (GaPO₄) monocrystal with theoretically estimated Curie temperature of 930 °C was realized,^[1] and around 2003, the product that used langasite (La₃Ga₅SiO₁₄) monocrystal that does not have Curie point (phase transition point) to 1470 °C was realized.^[3] Recently, a product that uses zinc oxide (ZnO) monocrystal is being proposed. While the combustion pressure sensors that use such monocrystals may have excellent heat resistance, they are generally expensive, have poor durability against mechanical impact, and have low sensor output, and therefore, are not used in mass-produced cars.

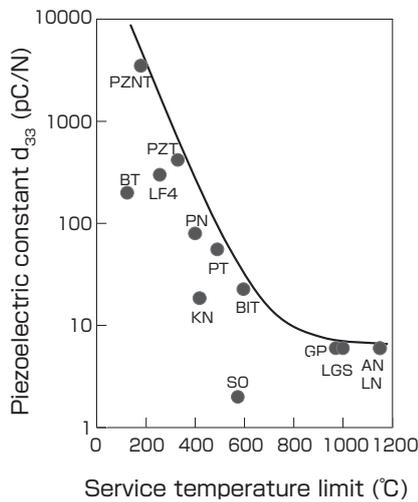


Fig. 1 Relationship between piezoelectric constant d_{33} and service temperature limit

AN: AlN, BT: BaTiO₃, BIT: Bi₄Ti₃O₁₂,
 GP: GaPO₄, KN:KNbO₃,
 LF4: (K_{0.44}Na_{0.52}Li_{0.04})(Nb_{0.86}Ta_{0.10}Sb_{0.04})₃,
 LGS:La₃Ga₅SiO₁₄, LN:LiNbO₃, PN: PbNb₂O₆,
 PT: PbTiO₃,
 PZNT: 0.92Pb(Zn_{1/3}Nd_{2/3})O₃-0.08PbTiO₃,
 PZT: Pb(Zr_{0.52}Ti_{0.48})O₃, SO: SiO₂

As shown above, to realize a high output, low priced combustion pressure sensor that shows heat resistance at 400 °C or over and excellent durability (at least 10 years or more), completely different technological development is necessary in all aspects, including the piezoelectric material, element structure, and sensor form.

With such a background, the authors simultaneously engaged in research for heat resistance, durability, high output, and low price of the combustion pressure sensor. With the objective of developing a combustion pressure sensor for mass-produced cars, we started to engage fully in the research with support from the AIST High-tech Manufacturing Project in 2003. This research was not a revision or improvement of an already existing combustion pressure sensor, but was a R&D of the world’s first combustion pressure sensor in that it employs a structure in which the sensor elements were laminated to achieve high output, by using thin films as the detecting material rather than using the conventional monocrystal, to realize durability and low cost.

2 Scenario for developing the combustion pressure sensor for mass-produced cars

Figure 2 shows the scheme of the integrated scenario for the development of a combustion pressure sensor for mass-produced cars set as the final R&D goal and the necessary elementary technologies.

We set the following five points as topics to focus on in the first stage of R&D, with the issues (heat resistance, durability, high output, low cost) confronting the conventional combustion pressure sensors in mind.

- Development of the technology to fabricate piezoelectric thin films
- Development of the technology to evaluate the electric

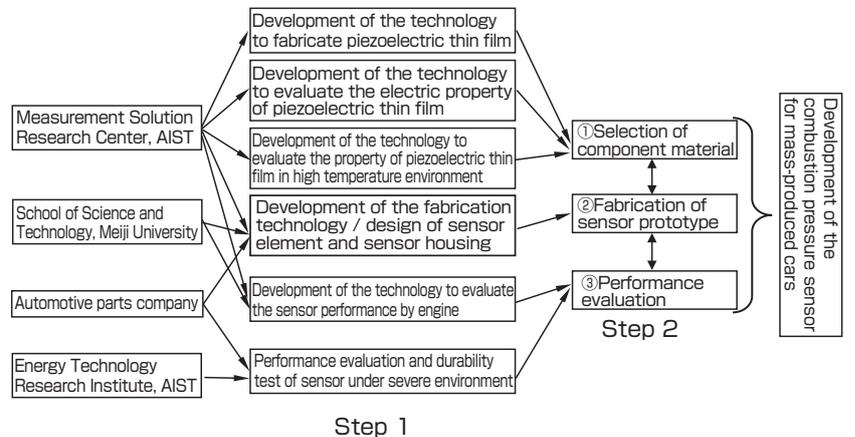


Fig. 2 Elemental technologies for development of combustion pressure sensors for mass-produced cars and scenario for integration

property of piezoelectric thin films

- Development of the technology to evaluate the property of piezoelectric thin films in high temperature environment
- Design of sensor element and sensor housing
- Development of the fabrication technology
- Development of the technology to evaluate the performance of the sensor by engine

The second stage is currently in progress, and the selection of the component materials for the combustion pressure sensor for mass-produced cars by the integration of these elemental technologies, prototype sensor fabrication, and performance evaluation tests are being done. In the above scenario, we hope to contribute to the development of control technology for the next-generation high-performance engine.

At the beginning of the R&D, it was assumed that the development of a combustion pressure sensor for mass-produced cars would progress by replacing the piezoelectric parts, which is the detecting material of the commercial combustion pressure sensor, if the piezoelectric property of the AlN thin film could be clarified. However, when the actual joint research was done, the automotive parts company did not have much experience in studying the piezoelectric combustion pressure sensor. Therefore as the research progressed from the development of the technology to fabricate the piezoelectric thin films to the development of the technology to evaluate the electric property of piezoelectric thin films, the development of the technologies to evaluate the property of piezoelectric thin films in high temperature, to design and fabricate the sensor element and housing, and to evaluate the sensor performance with an engine were conducted concurrently, with the cooperation of the automotive parts company and the university.

In the performance evaluation test, the commercial piezoelectric combustion pressure sensor was set as the evaluation standard. Since the output (sensitivity) of the piezoelectric combustion pressure sensor is largely affected by the form of the sensor, the evaluation was done based on how close the product approached the response waveform of the commercial sensor, rather than directly comparing the sensor output values.

Since the sensor output in a certain set range is necessary for installment in mass-produced cars, the R&D was done considering the structure that allowed adjustment of the sensor output after the performance evaluation. At the same time, the practical issues of the prototype sensor that were not considered during the initial performance tests were investigated, and revisions and improvements were conducted to create the combustion pressure sensor that was as close to the completed product as possible.

The above R&D was conducted jointly by AIST, the

Table 1. Comparison of major characteristics of piezoelectric material

	AlN	SiO ₂	Pb(Zr,Ti)O ₃	GaPO ₄	LiNbO ₃	La ₃ Ga ₃ SiO ₁₄
Piezoelectric constant d ₃₃ (pC/N)	6	2	250	6	35	6
Service temperature limit (°C)	1200	350	250	920	1200	1000
Ease of fabricating the thin film	Excellent	Impossible	Possible	Impossible	Good	Impossible

automotive parts company, and Meiji University. The individual specialties and experiences were gathered for the technologies for thin film fabrication, analysis of the property and phenomenon in high temperature environment, dynamic analysis, sensor design, and others. The team from the Measurement Solution Research Center, AIST was in charge of the development of technologies to fabricate the piezoelectric thin films, to evaluate the electric property of piezoelectric thin films, to evaluate the property of piezoelectric thin films in high temperature, to design and fabricate the sensor element and housing, and to evaluate the sensor performance with an engine. The Meiji University team worked on the development of technologies to design and fabricate the sensor element and housing, and to evaluate the sensor performance with an engine. The automotive parts company team worked on the development of technologies to design and fabricate the sensor element and housing from the standpoint of auto-parts manufacturing, and conducted the performance and durability tests of the sensors in severe environments. The team from the Energy Technology Research Institute, AIST was also in charge of the performance and durability tests of the sensors in severe environments.

In this R&D, a place for sharing the information and exchanging opinions were set for the teams and members. Mutual attendances to the performance tests and application tests were arranged, to take advantage of the joint project as much as possible.

The following section of the paper is the outline of the development of the core elemental technology and the performance evaluation of the prototypes, in the R&D of the combustion pressure sensor.

3 Fabrication and evaluation of the piezoelectric thin films

3.1 Selection of the piezoelectric material and thin film fabrication

The authors' team selected aluminum nitride (AlN) as the detection material for the following reasons: 1) shows highest service temperature limit at 1200 °C among the piezoelectric materials, 2) does not contain hazardous elements such

as heavy metals, 3) shows three times the piezoelectric characteristic of crystal, and 4) has high elasticity coefficient (Young's modulus: 314 GPa) and piezoelectric linearity is maintained at high pressure.^[4] By selecting AlN as the detecting material, the issue of heat resistance was easily cleared.

We considered using the thin film instead of monocrystal as the structure of the detecting material because, if the charge generated by the piezoelectric material is used as the output signal of the sensor, the sensor output will not be dependent on the thickness of the piezoelectric material. By using the thin film, the disadvantage of the fragility of the monocrystal can be overcome, and high durability against mechanical impact can be obtained. Moreover, it will be possible to use the semiconductor process that is readily mass-producible, and low cost can be achieved. Compared to other hopeful piezoelectric materials, there are less number of elements in AlN, and therefore it can be readily made into thin films. Hence, the authors' research team employed the AlN thin film as the detecting material of the combustion pressure sensor for the first time in the world, and embarked on the development of technology to fabricate the AlN thin film.

To investigate whether the AlN thin film showed the piezoelectric response as reported, an AlN thin film was fabricated on a silicon monocrystal substrate using the reactive sputtering method, and the piezoelectric responsiveness of AlN thin film was studied. The piezoelectric response of the fabricated AlN thin film showed good linearity in the pressure range of 0.1~1.6 MPa, and also showed good frequency property in the 0.1~100 Hz range. Therefore, it was confirmed to be an adequate candidate of the sensor material (2005).^[5] The analysis of the basic property was conducted by the electric model of an AlN thin film, and good linearity similar to the combustion pressure of the engine was obtained in the 0.4~8.0 MPa range. Since the measured values and the electric model matched, it was shown that the AlN thin film could be used as the detecting material for the combustion pressure sensor

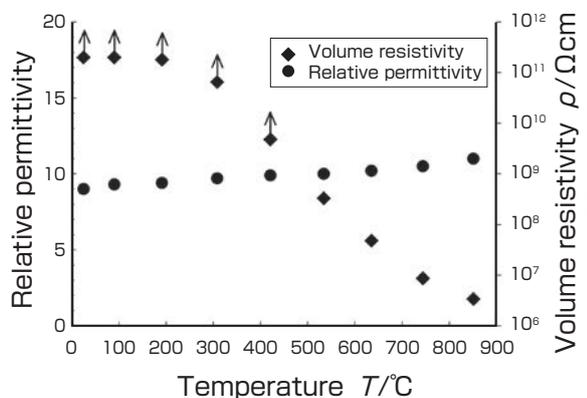


Fig. 3 Temperature dependence of the relative permittivity and volume resistivity of AlN thin film

(2005).^[6] The electric resistance of AlN thin films decreases dramatically as the temperature increases, according to the Arrhenius equation. When the resistance decreases, the charge generated in the piezoelectric material diffuses before it can be detected by the measurement system so it cannot be measured. Therefore, we studied the volume resistivity of the AlN thin film and the temperature dependency of relative permittivity. Figure 3 shows the results. The volume resistivity of the AlN thin film was 10⁶ Ωcm or more at 851 °C, and the permittivity increased only slightly. Therefore, it was found that measurement was possible for the AlN thin film at 800 °C or above (2006).^[7]

However, since the monocrystal silicon substrate was used, the sensor element was weak against mechanical impact, and it was necessary to develop a sensor element with good

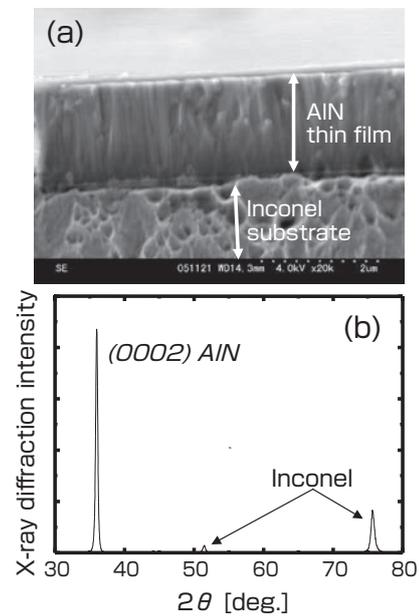


Fig. 4 (a) Cross sectional SEM photograph and (b) XRD pattern of AlN thin film fabricated on Inconel substrate

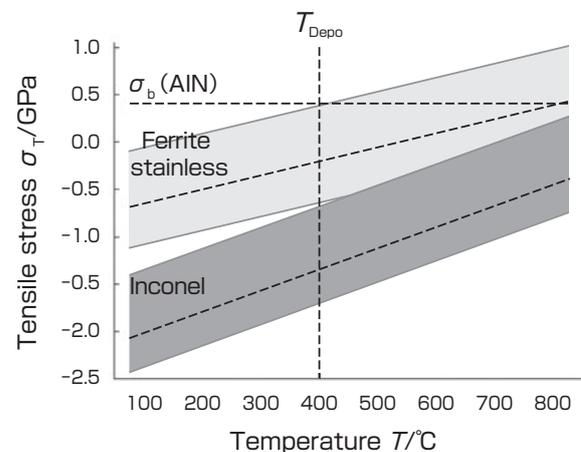


Fig. 5 Temperature dependence of internal stress of AlN thin film formed on various substrate materials

durability. The authors fabricated the AlN thin film on a metal substrate to increase the durability against mechanical impact. For the metal substrate material, we selected Inconel, a nickel superalloy with excellent heat resistance. The AlN thin film was fabricated on the multicrystal Inconel substrate by the sputtering method, and we successfully fabricated the thin film with crystalline orientation (2006).^[8] Figure 4(a) shows the SEM photograph of the cross section of the AlN thin film fabricated on the Inconel substrate. The XRD pattern of this thin film is shown in Fig. 4(b). From the cross section of the AlN thin film, it was observed that it was composed of fine crystal particles with fibrous structure, in which the thin film grew vertically against the substrate surface. Although the Inconel substrate is multicrystalline, the AlN thin film showed only the diffraction peak of 0002 face of wurtzite type AlN, and presented the c-axis orientation. The piezoelectric constant (d_{33}) measured using the piezometer was 2.4 pC/N, which was about half the value of monocrystal AlN, but we were able to fabricate the AlN thin film with piezoelectric property on the Inconel substrate.

Figure 5 shows the bending strength $\sigma_b(\text{AlN})$ and the temperature dependency of in-plane stress that occurs in the AlN thin film fabricated on the ferrite stainless and Inconel substrates. With both substrates, it was found that the stress distribution range was wide, and a clear difference was seen between the two substrates. Both were fabricated at 400 °C, but after fabrication, about twice the compression stress was working on the Inconel material compared to the stainless one. Also, since the coefficient of thermal expansion of AlN was smaller than those of the two alloy substrates, the tensile stress increased by heating. As a result, stress surpassing

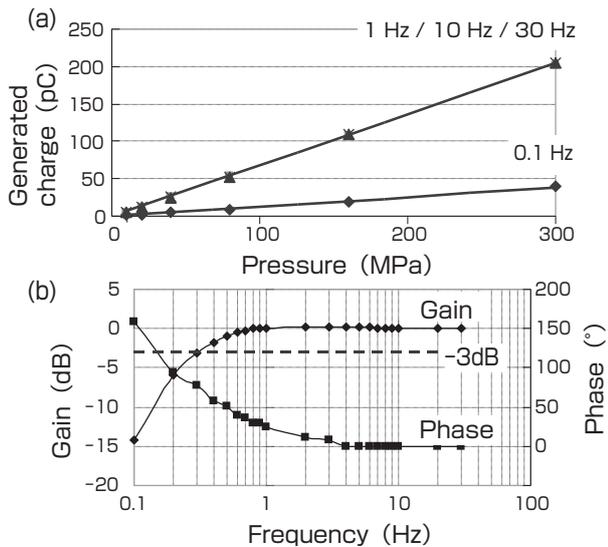


Fig. 6 (a) Pressure dependence of generated charge of AlN element for frequency between 0.1~30 Hz, and (b) frequency response of gain and phase of AlN element against pressure change of 150 MPa

the rupture strength of the AlN thin film might occur locally when 400 °C was surpassed in the stainless sample. On the other hand, rupture strength of the AlN thin film was not surpassed even at 800 °C in the case of the Inconel sample. From these results, it was found that the choice of the metal substrate material is important to prevent the rupture of the AlN thin film.

3.2 Evaluation of the electric property in high temperature environment

The piezoelectric property of the AlN thin film fabricated on the Inconel substrate was studied in a high temperature environment. Figure 6(a) shows the amplitude change of the charge generated by the AlN thin film when the oscillation amplitude was varied by applying pressure at a constant frequency. The AlN thin film showed linearity at a high pressure range of 10~300 MPa. It was found that the AlN thin film had sufficient pressure resistance as a combustion pressure sensor, since the maximum pressure inside the combustion chamber of a standard car is several tens of MPa.

Figure 6(b) shows the frequency response of the AlN thin film at sine wave oscillation amplitude of 300 MPa for the applied pressure. Here, the gain of the AlN thin film is standardized as output value Hz. The gain was mostly flat at high frequency range (3~30 Hz) and the phase shift was small. It was found that the AlN thin film had sufficient

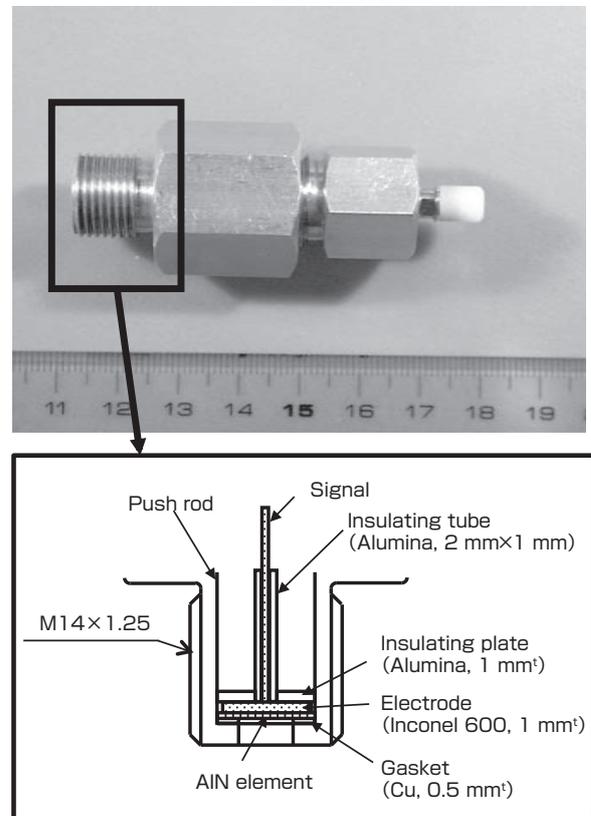


Fig. 7 Appearance of AlN sensor and schematic diagram of interior structure

frequency responsiveness, since the revolution of the car engine is several thousand rpm (several ten Hz). When the measurements were done in a high temperature environment, it was confirmed that the piezoelectric response of the AlN thin film did not change at all for 54 h at 450 °C (2006).^[9]

4 Fabrication of the sensor prototype and its evaluation

4.1 Performance evaluation with an engine

Since we obtained a prospect of using the AlN thin film element, we fabricated a prototype of the combustion pressure sensor (2007).^[10] Figure 7 shows a photograph of the combustion pressure sensor fabricated with the AlN thin film and the schematic diagram of the sensor structure. The pressure receiving part of the sensor had a simple structure where the AlN thin film element was held with a discoid internal electrode to receive the charge with the signal wire. An alumina plate and an alumina tube were used to insulate it from the housing. To investigate the combustion pressure response property of the AlN sensor, single cylinder two-cycle engine (HONDA LEAD 90, HF05)

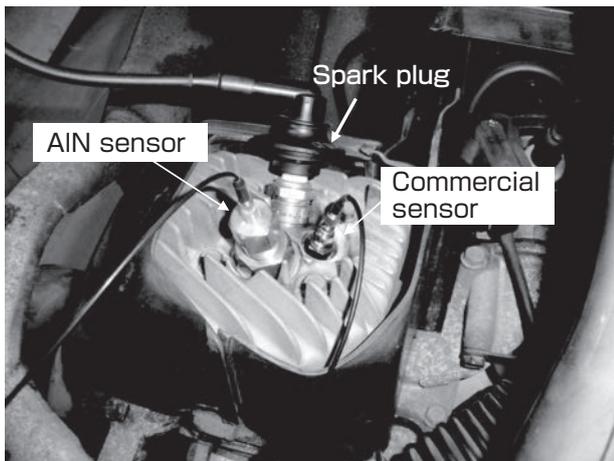


Fig. 8 Attachment of sensor to two-cycle engine

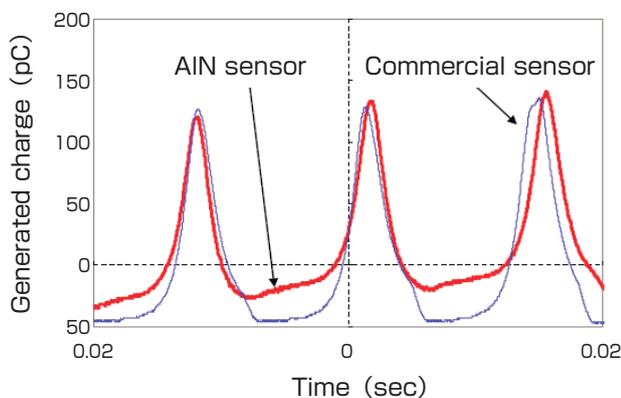


Fig. 9 Output waveform of sensor during operation of two-stroke engine
Engine revolution: about 4000 rpm

was used. As shown in Fig. 8, the sensor was installed near the apex of the cylinder head to measure the pressure of the combustion chamber. To conduct performance comparison, the combustion pressure sensor (No. 6001) of Kistler Corporation was used because this was most widely used in engine research. The output of the AlN sensor when the engine revolution was set to about 4000 rpm without load was compared to the commercial sensor. The result is shown in Fig. 9. Since the generated charge of the commercial sensor was 140~160 pC, the pressure inside the combustion chamber was 1.1~1.2 MPa. There was almost no external noise in the output wave of the AlN sensor, and almost the same waveform was observed as that of the commercial sensor.

To evaluate the durability of the AlN sensor, the change of sensor output when the engine was repeatedly run at about 2000 rpm for 20 min, cooled, and then run for 20 min again is shown in Fig. 10. Since the revolution of the engine could not be kept constant accurately, there were variations in the output value for each measurement, but a fairly constant output was obtained. There was almost no decrease in output after a total of 40 hours, and stable operation continued.

The initial objective was to confirm whether the measurement of combustion pressure was possible in a real engine, and to obtain the output waveform close to the commercial sensor. We were able to obtain almost similar response waveform as the commercial sensor and the initial objective was achieved.

The commercial sensor is made by finely processing fragile crystal monocrystals and then combining the monocrystal pieces. Since it has a complex structure where the small crystal plates are cut out by orienting the crystal axes and then combining them, high cost and technique are required to fabricate the element. In fact, the commercial sensor used for comparison cost several hundred thousand yen. On the other hand, the AlN sensor developed by the authors has a simple structure where the AlN thin plate fabricated on the metal plate is held with electrodes, and we aim for the price of 10,000 yen or less, as the sensor for mass-produced cars.

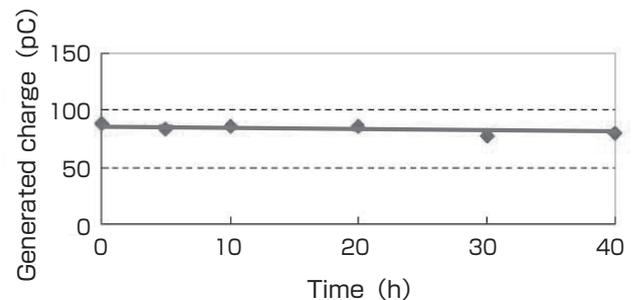


Fig. 10 Dependence of AlN sensor output on engine run time
Intermittent run at engine revolution 2000 rpm × 20 min

4.2 Downscaling for mounting in automobiles

As the research progressed, we faced the problem that the charge amp that were used in the lab could not be installed in mass-produced cars due to difference in power source, severe use condition, price, and others. Therefore, an amp that was already installed in the car for a different purpose was used, but the sensor output several times higher was necessary to use that amp. The recent high-performance engines have become increasingly complex in structure due to the employment of the high-pressure fuel injection system and increased number of valves, and there was no space to mount the combustion pressure sensor with a large housing as used in the above experiment. Therefore, we had to downscale the housing. In case of the piezoelectric material, since the generated charge was proportional to the pressure receiving surface area, it was necessary to increase the pressure receiving surface to increase the sensor output. However, when the pressure receiving surface was increased, the size of the sensor element increased, and this in turn, meant it could not be installed on the engine.

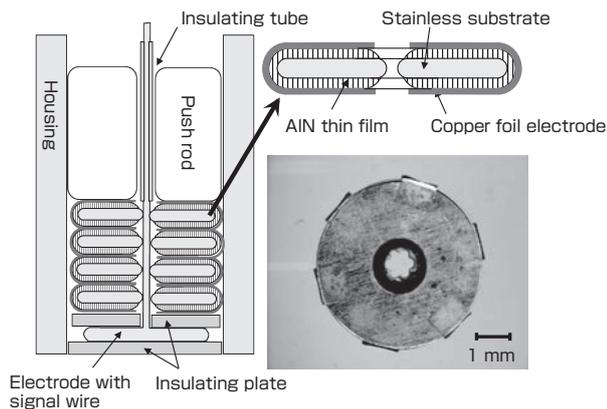


Fig. 11 Diagram and photograph of laminated structure of AlN thin film sensor element

The authors considered the ways to decrease the volume while increasing the sensor output, and devised a way to decrease the volume by increasing the surface area of the sensor element, by stacking the sensor element vertically. However, to realize such laminated structure, the lamination had to be done without having the thin film surface or the substrate contacting the housing. Therefore, the authors devised the element structure shown in Fig. 11.^[11] In this structure, a hole was punched in the center of the circular metal substrate, AlN was formed on the entire surface except that part, signal wires were passed through the central hole, and the elements where the AlN surface was covered with copper foil were laminated. Since AlN is an insulator, if the signal wire is insulated from the housing, the substrate side of the AlN thin film and the surface will not come in contact. The commercial sensor and the AlN sensor are compared in Fig. 12. The exterior diameter of the AlN sensor was 4.6 mm, and the thickness of the sensor element was 0.2 mm and AlN was formed at about 3 μm thickness on both sides of the metal substrate. This was wrapped with a copper foil electrode of 10 μm to fabricate the element shown in Fig. 11, and was

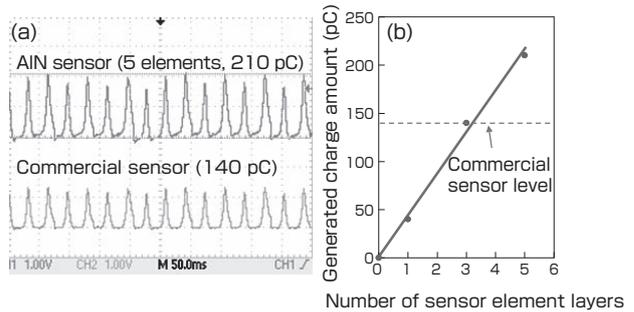


Fig. 13 (a) Response waveform of AlN sensor, and (b) dependence of generated charge amount on number of sensor elements

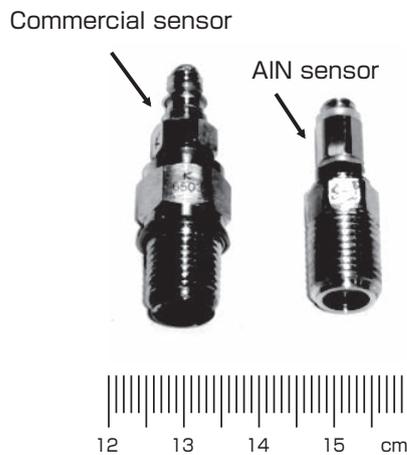


Fig. 12 Appearance of fabricated AlN sensor prototype

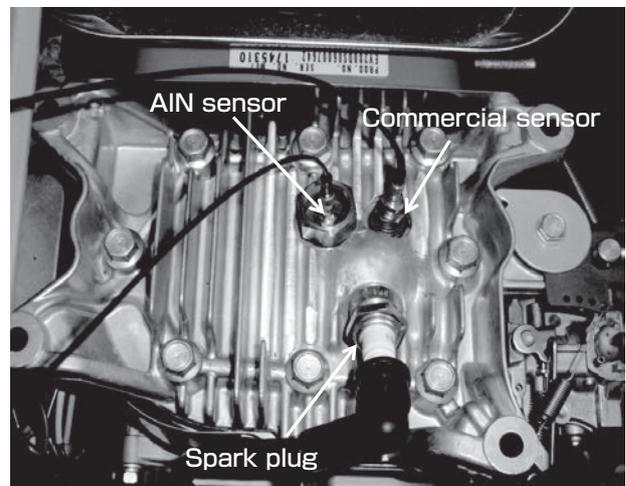


Fig. 14 Appearance of four-cycle engine with sensors attached

assembled as shown in Fig. 12. The AlN sensor housing was a screw of external diameter of 10 mm and 1 mm pitch, and this was attached to the engine. The appearance was similar to the commercial sensor (Kistler 6001) installed using the engine mounting adapter.

The AlN sensor and the commercial sensor were installed on an engine, and the combustion pressures were measured. The output waveforms of sensors with one, three, and five layers of AlN elements were measured. The output waveform of the sensor with five layers is shown in Fig. 13(a). A waveform similar to the commercial sensor was obtained, and the generated charge was higher. Figure 13(b) shows the dependency of the generated charge on the number of layers. The output of the element was 40 pC with one layer, 140 pC with three layers, and 210 pC with five layers. The generated charge increased linearly as the layers increased, and about the same output was obtained with three layers as the commercial layer. It was determined that the minimum sensitivity as an actual sensor onboard a car was satisfactory if the generated charge was the same level as the commercial sensor. Using this housing, a maximum of 15 layers of the element with thickness of 0.2 mm can be installed, and the output of 4.5 times higher than the commercial sensor can be obtained when 15 layers are used.

The two-cycle engines are used in motorcycles and scooters since there are problems of fuel efficiency and exhaust gas. Four-cycle engines are used in mass-produced cars, and evaluation using the commercial four-cycle engine (Robin Engine EY28DS manufactured by Fuji Heavy Industries Ltd.) was conducted. As shown in Fig. 14, the AlN sensor was installed on the cylinder head valve side of the engine using an adapter, the commercial sensor was attached directly on the right side, and the measurements were taken. For this AlN sensor, three layers of the AlN thin film with increased

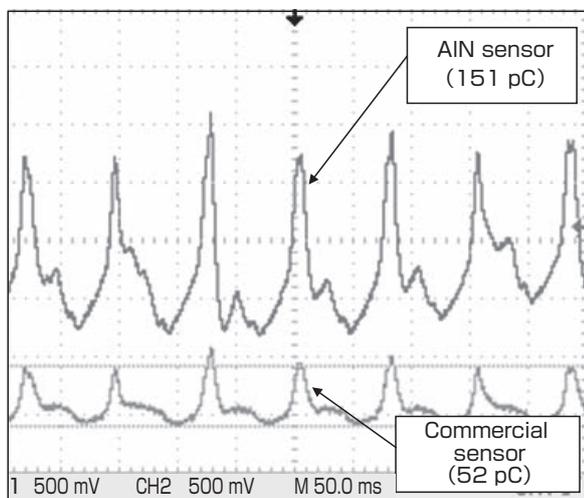


Fig. 15 Response waveform of AlN sensor in four-cycle engine

sensitivity achieved by adding Sc was used.^[12] Figure 15 shows the outlet waveforms of the AlN sensor and the commercial sensor. The output of the commercial sensor was 52 pC and the output of the AlN sensor was 151 pC, three times the output of the commercial sensor. If the maximum of 15 elements were used, 15 times the output of the commercial sensor can be expected. The slight pressure change at exhaust that could be seen as broad peaks in the commercial sensor could be observed as clear peaks in the AlN sensor. From these results, it can be expected that the AlN sensor may greatly exceed the performance of commercial sensors, and will perform as a practical combustion pressure sensor.

5 Conclusion

In this paper, the history of the R&D of combustion pressure sensors was described, where the authors used the thin film piezoelectric material for the first time in the world. In the field of combustion pressure sensors before the ideation of this R&D (before 2003), the thin film piezoelectric material was an unknown field and its usefulness was not recognized. However, since the start of this research, the automotive parts companies and universities of Japan and overseas became interested, and joint research was done with the Japanese automotive parts company and Meiji University. Before this thin film combustion pressure sensor can be installed in the mass-produced cars, there are still several more issues that must be solved such as the demonstration test of environment resistance and durability, stabilization of sensor signals, achievement of high output, simplification of sensor structure, and others. It is still in the “valley of death.” However, through the cooperation with various people, the issues are being overcome one at a time, and we have been able to move forward one step at a time. With the actual use and diffusion of this thin film sensor, the exhaust gas volume of the cars that are running around the world may decrease dramatically, hence it will contribute greatly to the environment and energy fields. Also, the potential is high for application to the engines of vessels, special vehicles, and generators, and the ripple effect can be infinite.

Acknowledgement

I express my gratitude to the following people: Dr. Yasukata Tsutsui and Dr. Hiroshi Tateyama of AIST who promoted this R&D; Professor Kazuo Tsuchiya of the Meiji University who instructed us on the sensor design and the evaluation method using an engine; people of the automotive parts company with whom we conducted the joint research; Dr. Hiroaki Noma, Dr. Kazuhisa Shobu, Dr. Yasunobu Oishi, Dr. San’yo Takahashi, and Dr. Hirohide Furutani of AIST; and all other people who were involved in this project.

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Authors

Morito AKIYAMA

Completed the doctorate course at the Interdisciplinary Graduate School of Engineering Sciences, Kyushu University in 1993. Doctor (Engineering). Joined the Kyushu National Industrial Research Institute, Agency of Industrial Science and Technology (currently AIST Kyushu) in 1993. Visiting researcher at the University of Liverpool, UK in 1997. Leader of High



Sensitivity Thin Film Pressure Sensor Coalition in 2001-2003. Assistant professor of the Graduate School, Saga University in 2003-2006. Part-time lecturer at the Kyushu University in 2011. Leader of research team, Measurement Solution Research Center, AIST from 2007. Engaged in researches for piezoelectric thin film pressure sensor, vibration sensor, biological information measurement sensor, and others. In this paper, was in charge of the fabrication of piezoelectric thin film, evaluation, and overall supervision.

Tatsuo TABARU

Completed the doctorate course at the Graduate School of Engineering, Tohoku University in 1997. Doctor (Engineering). Researcher of the Core Research Institute, Institute for Material Research, Tohoku University in 1997. Special Researcher of Science and Technology, Japan Science and Technology Agency in 1999. Joined the Kyushu National Industrial Research Institute, Agency of Industrial Science and Technology (currently AIST Kyushu) in 1999. Visiting assistant professor, Graduate School, Saga University from 2006. Senior researcher, Measurement Solution Research Center, AIST from 2007. Engaged in researches for heat resistant alloy, oxidation resistant coating, heat resistant AE sensor, abnormal discharge detection, and friction and abrasion. In this paper, was mainly in charge of the high temperature property evaluation of the piezoelectric element.



Kazushi KISHI

Graduated from the Industrial Chemistry, Faculty of Engineering, Ehime University in 1979. Joined the Fertilizer and Feed Inspection Station, Ministry of Agriculture, Forestry and Fisheries in 1979. Joined the Kyushu National Industrial Research Institute, Agency of Industrial Science and Technology in 1980. Currently, Senior researcher of the Process Measurement Team, Measurement Solution Research Center, AIST. Doctor of Engineering. In this paper, was in charge of the prototype fabrication, development of layer structure, and evaluation by engine.



Discussions with Reviewers

1 Installation of combustion pressure sensor to the commercial automobile

Question (Masahiro Okaji, Chino Corporation; Shuji Abe, AIST)

(Subchapter 1.2) As an example of the installation of the combustion pressure sensor to the engine of mass-produced cars, you give the Toyota Motor's piezoresistant sensor, but you also write, "This system is currently not used." What was the reason that it was discontinued? Do you mean that this is the only case in the past, and there is no other example where it was installed in mass-produced cars (including foreign auto makers)?

Answer (Morito Akiyama)

I do not know the exact reason why Toyota Motor's piezoresistant sensor was discontinued. After careful survey, I did find that the piezoresistant glow plug type combustion pressure sensor that was jointly developed by BorgWarner BERU Systems GmbH, a German spark plug company, and Texas Instruments Inc. of the United States had been installed in the green diesel

cars of Audi AG and Volkswagen AG from 2009, and these cars are sold in Europe and North America. I revised part of the text and included this point.

2 Disadvantage of the piezoelectric sensor

Question (Masahiro Okaji and Shuji Abe)

(Subchapter 1.2) You wrote that the piezoelectric sensor “has disadvantages such as that absolute pressure measurements cannot be taken.” Does this pose any practical problem?

Answer (Morito Akiyama)

Since the combustion pressure of an automobile engine changes rapidly, it is possible to take measurements with a piezoelectric sensor. However, to prevent misunderstanding, I eliminated the expression “has disadvantages such as that absolute pressure measurements cannot be taken,” as this is an irrelevant comment.

3 Reason for continuing the research at AIST

Question (Masahiro Okaji and Shuji Abe)

(Chapter 5) You write, “...There are still several more issues that must be solved.... It is still in the ‘valley of death.’” However, it seems that the demonstration test for durability, for example, entered the phase where it should be carried on by private companies. Is it still in the phase where R&Ds must be continued at AIST and universities? Since I get the impression that the

research stage at AIST has passed, I think you should clearly state the reason why AIST should still continue the research.

Answer (Morito Akiyama)

The demonstration test for durability and others have entered the phase that should be done by private companies. However, to increase the integrity of the sensor, there are points that must be improved such as the stabilization of sensor signals and achievement of high output, as well as simplification of the sensor structure. I added this comment at the end of chapter 5 as projects that must be undertaken by AIST.

4 Comparison of the studied sensor and commercial sensor

Question (Masahiro Okaji)

(Subchapter 4.2) As shown in Fig. 13, the discussion progresses by comparing the studied sensor and the commercial sensor. If the generated charge is at the same level as the commercial sensor, will it satisfy the condition for the car-mounted sensor?

Answer (Morito Akiyama)

I added the sentence, “It was determined that the minimum sensitivity as an actual sensor onboard a car was satisfactory if the generated charge was the same level as the commercial sensor.” to subchapter 4.2.

Novel functional gels and their commercial distribution as chemical reagents

— New development of functional soft-materials —

Masaru YOSHIDA

[Translation from *Synthesiology*, Vol.5, No.3, p.171-178 (2012)]

We have recently developed novel gel-forming materials based on organic electrolytes. The organic electrolytes can be prepared by a simple one-pot reaction applicable to large-scale production. The materials show the following remarkable characteristics. (a) They can be used for gelation of not only water but also electrolyte solutions of polar organic solvents including ionic liquids. (b) Rapid self-healing of the formed gel is possible even after collapse by mechanical stress. (c) The formed gel can be used as an efficient dispersant for single-walled carbon nanotubes. The materials have been commercially distributed as chemical reagents for gelation.

Keywords : Gels, electrolyte, electrolyte solution, ionic liquids, chemical reagents

1 Background of research

Among the diverse materials that support our daily life, the organic polymers that form the light and soft plastics belong to the generally called “soft materials.” Whereas the inorganic solids generally have hard and tough nature, soft materials are based on the flexible characteristic of organic materials. One of the soft materials called “gel” has an intermediary property between solid and liquid. It is used widely in society in various fields including the bio fields such as drugs and medicines due to its high biocompatibility, foods and cosmetics, and as viscosity regulators of several coating materials such as paints and inks (Fig. 1).

In general, a gel is a quasi-solid material in which a large amount of liquid is trapped in a chemical or a physical network structure formed by relatively small amounts of coexisting materials, and then the apparent fluidity is lost. The hydrogel where the solvent water has become quasi-solid is represented by jelly and konjac starch that are foods, hyaluronic acid used in cosmetics, and absorbent polymers used in hygienic products. The widely known example of gels made of solvents other than water is the oil-fixing agent where the food oil, a kind of organic solvent, is quasi-solidified. Considering the gel in terms of its function as a material, in addition to its water-absorbing and moisture-retaining properties, there are other applications such as for absorption and separation, various sensing functions, anti-vibration and cushioning materials, and dynamic energy converting materials such as actuators.

Active researches are being done in the academic field both

in Japan and overseas for the “functional gels” that are given various functions, and they are expected to be useful in advanced fields in the future. One example is the “functional gel” for which the importance is indicated as one of the core materials that support the environment, life science, and IT fields, as mentioned in the “Nanotechnology and Materials Research” in the “Technological Strategy Map 2010” edited by the Ministry of Economy, Trade and Industry (METI).^[1] Moreover, in the “International Comparison of Science and Technology R&D in Nanotechnology and Material Field for 2011,” a report by the Center for Research and Development Strategy, Japan Science and Technology Agency (JST-CRDS), it is written that Japan excels in the field of soft materials (supramolecules) compared to other countries,



Fig. 1 Various products in which gels are used

Nanosystem Research Institute, AIST Tsukuba Central 5, 1-1-1 Higashi, Tsukuba 305-8565, Japan
E-mail: masaru.yoshida@aist.go.jp

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and it is pointed out that “several breakthroughs have been achieved in functional gels investigations in Japan, and those have raised the level of the researches.”^[2] Therefore, the important issues are how to increase the excellence of the core research level of Japan and how to develop the functional gel to practical industrial applications.

While further advancement of functions is necessary to increase the excellence of functional gel development, the new materials must be mass-producible using a simple method, from the industrial perspective. From this perspective, the author embarked on problem solving from the synthetic chemical approach and engaged in new material manufacturing that realized the two points, achievement of novel function and simple synthesis. As a result, the “ionic gelator,” a material group that was totally unknown before, was originally developed. In this paper, the development process, efforts for the commercialization as a chemical reagent, and current issues will be explained.

2 Process in the development of a new gelator and the research goal

Gels can be roughly divided into two categories, the chemical gels and physical gels, and each has its characteristics. For example, chemical gels generally have high elasticity and excellent dynamic property but are weak against strain, because the network structure of the gel is composed of the covalent bond. On the other hand, with physical gels, because the network structure is stabilized by the non-covalent bond interaction (such as hydrogen bond or π - π interaction), it is known that they undergo reversible sol-gel transition upon heating and cooling. The material showing the physical gel forming property is normally called a “gelator,” and both the natural-occurring and artificial gelators are used industrially. Table 1 lists the characteristics of the two gelators. The natural gelators, the most well known being agar and gelatin, are highly safe, are commercialized as food additives to add starchiness, and are available at a reasonable price. However, it is known that there is restriction in the gelation, such as the acidity of the solution must be neutral, and it is not usable in acid or alkali conditions since disintegration occurs. Also, since it does not dissolve in ordinary organic solvents, there are extreme restrictions in the gelatable solvents.^[3] On the other hand, for the chemically synthesized artificial gelators, it is possible to add various functions unseen in natural gelators, by appropriate structural control and functional group introduction. However, multiple steps are usually necessary for the synthesis and refining processes of the artificial gelator. Therefore, unless a certain yield can be obtained at each step, the total yield would be low. Also, the isolation process such as column chromatography that uses large amounts of organic solvents may be inappropriate for large-scale production. As a result, although active R&Ds are done at the academic level, in most cases, the scale of

Table 1. Types of gelators and comparison of characteristics

	Natural gelators	Artificial gelators
Examples of compounds	· Agar, gelatin, etc.	· Various synthetic polymer gels, etc.
Usage	· Utilization of biocompatibility in foods, drugs, etc.	· Absorbing material, separation chromatography, actuator, etc.
Advantages	· Available at low cost · High biocompatibility	· Chemical modification is possible · Functions such as stimulus response can be added · Abundant basic research
Issues	· Unstable in acid condition · Unsuitable for gelation in solution other than water · Addition of function by chemical modification is difficult	· In general, synthesis requires multiple steps; manufacturing process design is necessary for mass-production · Only a few types of solvents can be used

synthesis remains at the laboratory level (with only a few grams of yield at most). In addition, there have been few researches on “amphiphilic gelators” that gelate in both water and organic solvents, and the gelation of multiple solvents with one gelator has been a major challenge.

The author first became involved in gel material research by coincidence, as an extension of the research of dendritic polymer called the dendrimer, during the two-year study in the United States from 2002. The material used at the time was a system that was not suitable for mass production because multiple steps were required for synthesis. Also, the gelatable solvent was limited to only the organic solvent, and gelation was impossible for water that was the most common solvent (liquid). Upon returning to Japan, the author started research to develop a new material with a gelation function that could be manufactured using a commercially available starting material and which involved as few number of steps as possible, as well as the synthesis technology that was suitable for mass production and commercialization.^{[4]-[7]}

3 Molecular design as synthesiology: Use of organic electrolyte as a gelator

From the chemical perspective, a new material is a new *molecule*, and one of the optimizing methods to achieve the new molecular design and synthesis is a way of “synthesiology.” In that sense, the author paid attention to physical gelators in which the gel formation is possible through relatively weak interaction. The spontaneous aggregation of the molecules during gel formation and the formation of three-dimensional network structure are phenomena that are drawing attention in the current nanotechnology fields, as the “self-organization” of synthetic molecules. It is thought that gels with diversity from both the structural and functional aspects can be developed if this self-organization can be finely controlled. Also, the physical gelator can dramatically alter the viscosity of the basic solvent at extremely small amounts like a catalyst during a reaction, while maintaining the basic physical property of the solvent. Therefore, if gelation that could not be accomplished

before in a certain solvent system becomes possible through the development of a new gelator, it is expected to expand the gel application further.

The author's thoughts on the guideline for the specific molecular design of a new material are shown in Fig. 2.

In this research, we focused on the "organic electrolyte compound." Hydrogen bond between the functional group and hydrophobic interactions are generally known as the intermolecular interactions that act as the driving force of molecular self-organization, and are actually used in the gelator system (Fig. 2 "Conventional gelator"). On the other hand, the self-organization of organic electrolyte compounds that easily combine the interactions is actively investigated from the perspective of biology, in extremely complex natural systems such as the double helix structure of DNA and its further hyperaccumulation. However, the self-organization in the artificially synthesized organic electrolytes had not drawn much attention compared to the neutral compounds. In the preparation of hydrogel where the solvent is water, it is important for the gelator to have both the hydrophilic and hydrophobic sections to be amphiphilic. For conventional gelators, the hydrophilic property was mainly borne by the corresponding functional groups such as the hydroxyl group or the carboxyl group. On the other hand, the characteristic of organic electrolytes as represented by various ammonium salts is to show hydrophilic property due to the salt structure (cation and anion in pair) of the molecule, even without the functional groups. We set this nature as an important element of the molecular design. While the polymeric electrolytes are expected to be applied widely to the electrolyte and separation membranes of batteries, we expected the gelation would occur by incorporating a functional group capable of interaction to such organic electrolytes, and

then oligomerizing to add multiple functions (lower part of Fig. 2). As a method to easily achieve this new concept, the one pot self-condensation reaction (reaction that takes place in one flask only, where the molecules spontaneously condense to gain relatively high molecular weight) that used commercially available starting materials was devised, as shown below. As a result, the synthesis of new organic electrolyte with oligomeric structure with a gelation property (electrolyte gelator) was established (Fig. 3).

It was found that this material actually possessed various characteristics including: 1) acid resistance, 2) solvent compatibility, 3) self-healing property, 4) complexation with carbon nanotubes, and 5) antibacterial property. These comprise the main points of synthesisology, as "functions that occur in the appropriate molecular design." The details will be explained in the following chapter.

4 Property of the electrolyte gelator (ionic gelator)

4.1 Synthesis

The polymer with a quaternary ammonium structure in the main chain is called the ionene polymer, and this is normally synthesized by the copolymerization of two monomers, diamines (nucleophilic) and dihalogen compound (electrophilic). We thought the synthesis of the new functional organic electrolyte compound would be possible by the molecular design of an amphoteric monomer with a rigid structure, where the electrophilic and nucleophilic sections coexist within a molecule, and in which intramolecular quaternization reaction will not occur. Based on this strategy, as shown in Fig. 3, we conducted synthesis by chemical reaction involving the mixing of two types of reagents (4-aminopyridine and 4-chloromethylbenzoic acid chloride) that were purchasable as chemical reagents, in

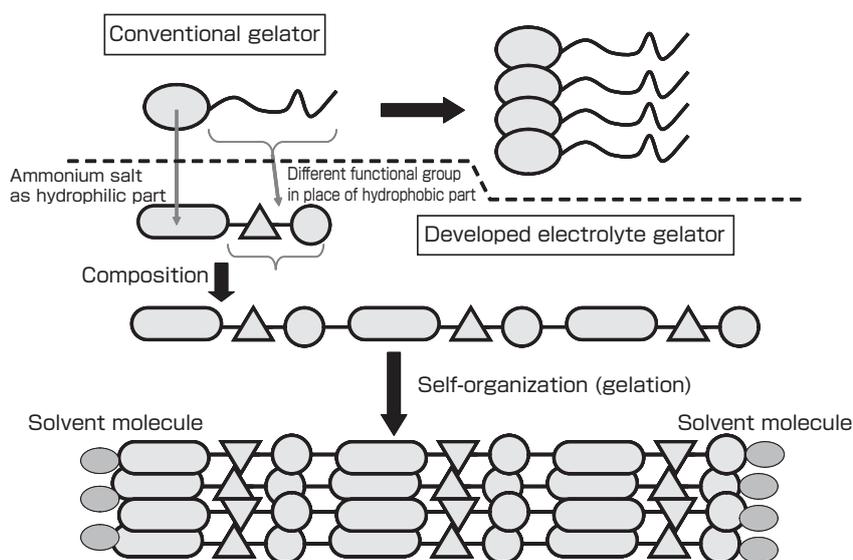


Fig. 2 Molecular design for new gel material

presence of an appropriate base under refluxed condition. To realize a new material that could be mass-produced, as mentioned before, one of the synthesiological elements was “to use the commercially (easily) available starting materials.” Precisely said, this reaction occurs in two steps of primary amidation and the following intermolecular quaternization reaction. However since the reactivity of the intermediate produced in the first reaction is high and the second step reaction ensues quickly, it looks like a single step “one pot reaction.” It is known that the material is the “oligomer” (polymer with relatively low molecular weight) with average degree of polymerization (n) of 10 to 20.^{[4][5]} There is very few case of synthesis of organic electrolytes by self-condensation, and this is a novel synthetic approach that is totally different from the conventional polymerization where two types of monomers must be prepared beforehand. This is characterized by “a small number of steps” needed to solve the problem, and can be considered an important element of synthesiology.

4.2 Gelation behavior

A hydrogel can be easily made from the organic electrolyte oligomer obtained, using a method similar to that for the conventional physical gelators. The powder is added to the water at a concentration of 1 weight % or more, the process of heating \rightarrow dissolution at high temperature \rightarrow cooling (by leaving at room temperature) is done, and the water can be gelled (Fig. 4 left).

As a general characteristic of the physical gel, this gel undergoes thermal and reversible gel-sol transition, and the once quasi-solidified gel becomes a solution without high viscosity by heating. Although the clear mechanism of gelation is not yet clarified, it is likely that the electrostatic interaction plays an important role, and other diverse interactions are involved in a complex and complementary manner. As mentioned later, this gelator possesses affinity to carbon nanotubes (CNTs). Therefore, complexation with CNTs can be done easily, and we were able to prepare a

CNT-containing gel by only the electrolyte gelator (Fig. 4 right).

4.3 Numerous functions of electrolyte gelator

The oligomeric electrolyte has interesting characteristics that were difficult or could not be achieved at all by existing gelators, as shown below.

4.3.1 Acid resistance

In naturally derived gels, the gel cannot be made using an acid solution because the main molecular structure disintegrates under acid conditions. However, it was projected that the new material would be acid resistant because it does not possess the acid labile functional groups. By using this material, the gelation of an acid water solution with about pH=1 was achieved, and application may be possible for the quasi-solidification of acid waste liquids that used to be a challenge (on the other hand, since the solubility of the gelator decreases in the base condition, gelation has not been successful).

4.3.2 Solvent compatibility control by anion exchange

The electrolyte gelator is composed of the organic part with cation and the corresponding anion, and the initial anion after the preparation is the chloride that is the same as common salt (sodium chloride). By replacing the anion with a different anion, it is possible to control the solubility (compatibility) of the gelator. This can be applied to solvents other than water, by controlling the gelator compatibility as the chloride ion of the parent compound is replaced with hydrophobic fluorinated anions such as $N(SO_2CF_3)_2$ and PF_6 that are typical counter ions in ionic liquids known as the new functional solvents.^{[4][5]} This can be used for the gelation of various organic solvents and the aforementioned ionic liquids, not just water (Fig. 5). Therefore, the characteristic distinct from the conventional artificial gelators is that the solubility can be easily adjusted even after synthesis by the counter anion exchange, and in the sense that it possesses a single molecular skeleton, it is the realization of an “amphiphilic

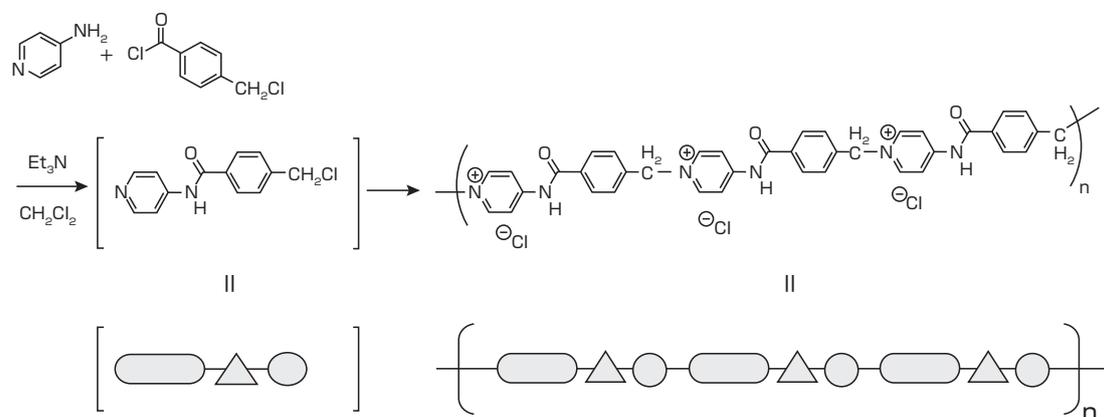


Fig. 3 Synthesis of the electrolyte gelator

gelator.” For the gelation of, for example, ionic liquids, it has been shown that the ion conductivity decreases only a few percent after gelation and is maintained.^{[4]-[6]} In conventional ionic liquids with low viscosity, there was a trade-off where the conductivity increased as the ion mobility increased in the less viscous ionic liquids but it became likely to leak in sealed conditions due to the low viscosity. On the other hand, the highly viscous ionic liquids did not leak readily but had decreased conductivity as the ion mobility decreased due to the high viscosity. For this issue, we realized a new technology using this gelator that allowed the adjustment of viscosity only while retaining ion conductivity. Therefore, it can be used in electrochemical devices (dye sensitized solar cells, capacitors, etc.) that use ionic liquids as the electrolyte solution, and application in the coating process, increased lifespan of the operation time by preventing leakage, and other improvements in performance can be expected.

4.3.3 Self-healing gel

In general, because gels have soft forms, their structures are easily destroyed by mechanical stress. Relating to the response under the mechanical stress, some gels show the “thixotropic property (thixotropy).” This is a property where the viscosity changes in response to applied stress, the substance changes into fluid sol under high stress conditions, and then returns to gel when the stress is removed. Generally, a long time is needed to return from sol to gel, and the only exception reported was the quick structural recovery of hydrogel composed of block copolymer that possesses cation charge on the side chain.^[8] The authors looked at the structural similarity between the case studies and the electrolyte gelator, and investigated whether a similar characteristic could be observed. As expected, it was found that the new material had an interesting self-healing property where the storage elasticity modulus, which indicates the solidity of gel, recovered at extremely high speed (in a few seconds) after the destruction of the gel structure.^{[4][7][9]} This structural recovery occurred at higher speed as the concentration increased.



Fig. 4 Photograph of hydrogel in inverted sample bottle (concentration at 1 wt%)

Left: Pure water gel; Right: Gel containing single walled carbon nanotubes (From Reference [5])

As a side story, the author at the time had no experience in the rheological measurement of gel elasticity, and we asked a measurement device manufacturer to measure the sample. It left a strong impression when the engineer who had experience in measuring numerous samples looked at the measurement of our sample and said, “I think this is a very rare phenomenon.” From the crystal structure analysis of the model compound (unpublished data), we believe this phenomenon occurs by the recovery of gel network by long-distance electrostatic interaction that arises from the fact that the electrolyte gelator is charged, rather than a short-distance interaction like the hydrogen bond. Since the once broken gel structure recovers instantly, this gel can be considered as a type of “indestructible gel,” and applications in various fields can be expected such as the impact absorbing material that utilizes high-speed structural recovery property. The author’s report was the precursor of the above high-speed self-healing gel, and many examples followed. In the functional gel “Aqua Material” that was jointly studied by Professor Takuzo Aida, Specially Appointed Assistant Professor Justin Lee Mynar (currently of King Abdullah University of Science and Technology, Saudi Arabia) of the University of Tokyo, and the authors, the formation of a water gel was observed by the interaction of clay derived nanoparticle and dendrimer that each possessed complementary charges. Since the high strength and self-healing properties were observed in this gel, the importance was again indicated of the electrostatic interaction that drives the gelation and allows self-healing.^[10]

4.3.4 Complexation with carbon nanotubes (CNTs)

The electrolyte gelator is found to be a specific “dispersant” to CNTs, which is gaining attention as the next-generation material in the field of nanotechnology, as well as having the gelation function described before.^[4] This result was found by inference from the previous example^[11] of a similar polymer electrolyte for which only one report was known. In this case also, the authors had no experience in CNT research at that time. However, there were researchers involved in CNT

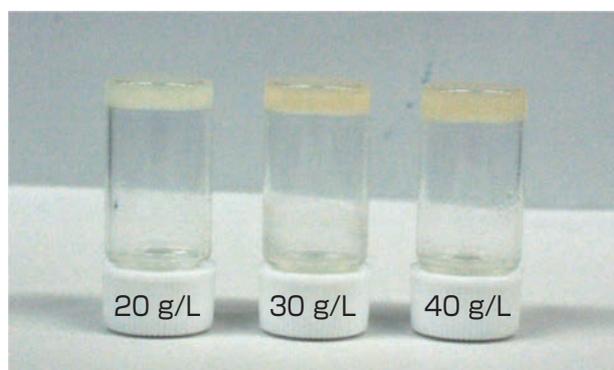


Fig. 5 Ionic liquid (EMIm-PF₆) gel in an inverted sample bottle {from Reference [4] (Supporting Information) (permitted by ACS)}

research in the same institute, and we were able to ask for a supply of CNTs and to request the evaluation of the dispersion degree, and this led to the discovery of the phenomenon. Without the presence of such researchers in a totally different field nearby, I think the discovery of this phenomenon would have been greatly delayed. In fact, it is possible to dissolve (isolated dispersion) the water insoluble single-wall carbon nanotubes (SWCNTs) by simply mixing the material with SWCNTs and then applying ultrasonic irradiation using the common ultrasonic irradiator for cleansing. In the CNT dispersion, we think organic electrolyte oligomer interacts with the π surface of the SWCNT, resulting in the dispersion in water by the surface wrapping, as in the example in Reference [11]. This solution is a highly stable solution where no precipitation occurs over a long time, and this liquid can be used to fabricate the SWCNT thin film or to prepare the SWCNT dispersed hydrogel under the condition where the concentration is maintained above a certain level. This is likely to make contributions in the preparation of CNT ink for printable electronics and the fabrication of carbon film for transparent electrode as an alternative to ITO, which is expected as a promising application of the nanocarbon material.

4.3.5 Antibacterial effect

The compound that possesses the cationic pyridinium group in the molecular structure is known to be an antibacterial agent, and is actually used. Since the new gelator also possesses a similar pyridinium group in the main chain, we subcontracted an external lab to evaluate the antibacterial property. A antibacterial effect was observed in both the Gram-positive bacteria (*E. coli*) and Gram-negative one (*S. aureus*).^[12] The minimum growth inhibitory concentration was 32 $\mu\text{g/ml}$ and 64 $\mu\text{g/ml}$, respectively, or sufficiently low, and these values were equivalent to the general surfactant-type antibacterial material.

5 Work on commercialization of the reagent considering the industrial technology application

The gelator materials with various characteristics described above were initially studied using the management grant (fund given to AIST from METI) as a core research. After obtaining a certain level of results, the research was selected for the 2005 Grant for Industrial Technology Research (Nanotechnology Material) of the New Energy and Industrial Technology Development Organization (NEDO), which greatly accelerated the research and led to further developments. At the time of application to NEDO, although we had a few patents filed, we had no published paper. So we were very lucky that we received high scores in the screening process even at an initial stage of the research. With the grant from NEDO, we participated in activities such as AIST press releases, exhibitions for nanotechnology (Nanotech 2008, 2009, and 2010; Orga Techno 2008), and AIST open

labs to publicize our research. While we had experience in the publication and discussion at academic societies, the experience of discussing specific technical issues directly with the people from companies at such exhibitions was quite invaluable. Through the buildup of such activities, we received several technical consultations about gelation from various companies, and we signed agreements to provide samples to conduct gelation performance tests with some companies. One of the major Japanese chemical reagent companies with particular experience in manufacturing and sales of ionic liquids had shown interest in the commercialization of the gelator material from the initial stages of the research, and we were able to actively exchange views and ideas. Later, a formal license agreement was signed with this company through AIST Innovations (at the time), and production was subcontracted to provide samples to companies that requested sample licensing agreements. In autumn of 2009, the product was commercialized as a chemical reagent. Initially, the authors only had experience with synthesis reaction at small-scale laboratory level of about 10~20 gram yield, and much effort was needed in optimizing the condition for large-scale reaction even if it was for a reagent. However, with the perseverance of the corporate researchers, the reproducibility and yield were improved, as the experimental conditions published in the papers were revised. As a result, commercialization of the several gelators with stable performance became possible, including the various anion exchangers (Fig. 6). In writing this paper, I sought comments from the companies on the “condition for commercializing a new reagent.” The emphasis was placed on 1) novelty, where things that could not be done before can be done, and 2) prospect, where things that did not exist before will be created. In creating the reagent of the gelator that we developed, several people commented that it could be used for electrolyte in batteries, electroconductive materials, viscosity enhancer in ink, and for research in wide-ranging areas such as cosmetics. For reference, according to the Chemical Abstracts Service that provides the database of all chemical substances managed by the American Chemical Society, at this point, there are over 65,360,000 chemical substances registered, including organic and inorganic compounds. On the other hand, in the reagent database of Sigma-Aldrich Corporation, one of the leading reagent companies in the world, there are 187,000 reagents registered and marketed. Assuming that about three times this amount is used as reagents including those of other chemical companies, the “percentage of reagents among all chemical substances” is calculated to be 0.86 %, and I think the readers can appreciate the fact that only a few compounds become available as reagents worldwide. In such a situation, our product was fortunate to become a commercially available reagent, and now it can be tested for performance by researchers of various industries, academic fields, and governments. I also think it has become widely known as a novel material.

6 Future perspectives

Although chemical reagents is a somewhat niche market, it was very encouraging for the author to see the material that we developed draw attention and then become actually commercialized, as stated in the research goal. As the reagent went on sale, it is now readily available to the external research institutions for R&D purposes, but the practical application is still in the budding stage. As a basic issue, “gelation” itself is an extremely fundamental chemical phenomenon, and this is rarely recognized to be a simple industrial technology where some specific product can be directly imaged from this phenomenon. On the other hand, through technical consultation with various companies, I am convinced that there is high expectation for the core technology of “gelation”, and I feel that sufficient contribution can be made to industry and society by advancing this “gelation” technology. Specifically, in actual industrial application, in most cases, the solvents or solutions that people wish to gelate contain various solutes, and it is necessary to fine-tune the performance of the gelators individually through feedback from the corporate users. On this point, mutual understanding cannot be obtained

merely through only the sales of the reagent, and I think it is necessary to establish a communication system between us and company researchers to promote understanding to further the practical application of the product.

In terms of the technological view, the critical issues are to increase the efficiency of gelation and the number of gelatable solvents. We are actively working on the preparation of a new electrolyte gelator, and various derivatives are prepared by a co-polymerization method using two types of monomers, and high gelation capacity has been observed.^[13] For the CNT dispersion function, we succeeded in enhancing the function such as addition of further optical responsivity by developing a material dedicated to the dispersal function,^[14] and joint research has been started with a company for industrial realization using CNTs. On the other hand, by using the gelator that was commercialized by an independent research group, an extremely fascinating phenomenon unseen before, that is the asymmetric environment (circular dichroism activity) dependent on the stirring direction of the solution, has been reported (different CD activity is observed in the solution by right- or left-rotational stirring). Interestingly, this asymmetric field can be fixed by gelation.^[15] It is becoming clear that the material that was initially developed for the objective of a new gelator discovery has diverse functions, and we wish to engage in further research for future practical applications with collaboration with other researchers inside and outside of the institute. In writing this paper, I realized that “synthetic strategy” thinking where individual elements are optimized and built up is important in developing a new material from the chemical viewpoint that involves trial-and-error of molecular design and synthesis methods. I hope this paper will be of some help for the other researches in the future.



Fig. 6 Pamphlet for the reagent (created by Kanto Chemical Co., Inc.) (top) and the commercial reagent (bottom)

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Author

Masaru YOSHIDA

Completed the doctorate course at the Department of Chemistry, Faculty of Science, Tohoku University in March 1994. Doctor (Science). Joined the National Institute of Materials and Chemical Research, Agency of Industrial Science and Technology (current AIST) in April 1994. Visiting scholar at the Department of Chemistry (Professor J.M.J. Fréchet Lab), University of California at Berkeley during 2002-2004, under the Institutional Program for Young Researcher Overseas Visits, Japan Society for the Promotion of Science. Leader of the Smart Material Research Group, Nanosystem Research Institute, AIST since October 2008. Specialty is the development of new functional material using organic chemistry.



Discussions with Reviewers

1 Synthesiology and molecular design

Comment (Hisao Ichijo, Tsukuba Center, Inc.)

In *Synthesiology*, you are required to describe the elemental technologies to realize the research goal, the relationships among the elements, and the process of their integration, to help the succeeding researchers. I think this paper will be valuable to the readers if you follow these points.

Comment (Toshimi Shimizu, Nanotechnology, Materials and Manufacturing, AIST)

The synthesis of chemical substance is based on diverse utilization and combination of various functional groups, and I believe the trial-and-error in molecular design and synthesis methods is the practice of synthesiology. Therefore, to rearrange the descriptions to fit the synthesis as stated in *Synthesiology*, I recommend that you discuss the scheme of molecular design that was done for the goal of achieving higher function and simplified synthesis unseen before in conventional gelators. Also, please show a diagram that breaks down the molecular structure of the gelator by elements, show how the elements of conventional gelators were converted in your research, and indicate why the new elements were added to solve which issues in executing the molecular design.

Answer (Masaru Yoshida)

The point of view of “molecular design and the synthetic approach” = “one form of synthesiology” is very informative. I created diagrams from that perspective and added descriptions to the overall text.

2 Outlet as a chemical reagent

Comment (Toshimi Shimizu)

You present the outlet for new practical use i.e. sales as a chemical reagent. If possible, please state the decisions or standards that the chemical or reagent companies use when

deciding which reagent should be commercialized. Many organic compounds have been synthesized around the world, but not all became reagents. What is the percentage of the synthesized chemical substances that became reagents (how many percentages of synthesized chemical substances become commercialized as reagents), and what is the market scale of the reagent industry? Please provide these figures as reference information.

Answer (Masaru Yoshida)

The person in charge at the reagent company mentioned that the important factors in considering reagents are: 1) things that were not possible become possible (novelty) and 2) things that did not exist before are created (prospect). A chemical substance

with novelty and prospect can be used widely in actual R&Ds as a reagent, and has the potential of generating a market.

For the percentage of chemical substances that become reagents, there are over 65,360,000 chemical substances registered in the database of Chemical Abstracts Service. On the other hand, there are currently 187,000 reagents registered in the reagent database of Sigma-Aldrich Corporation, one of the leading reagent companies in the world. Assuming that about three times this amount is used as actual reagents, the percentage can be calculated as follows: $56.1/6538 = 0.86 \%$. It can certainly be said that only a very limited number of chemical substances become reagents. This information was added to the paper.

Evaluating the effects of actions taken to attract visitors to sightseeing areas

— An Open Service Field behavior survey technology —

Yoshinobu YAMAMOTO

[Translation from *Synthesiology*, Vol.5, No.3, p.179-189 (2012)]

Every year, actions are taken to attract more visitors to sightseeing areas, yet the effects of these actions are rarely evaluated. Basic data for assessing effects can be obtained by measuring the change in visitation patterns upon the introduction of actions. We did not have the technology, however, to track the migration behavior quantitatively and successively with reasonable cost. To address this problem, we developed an Open Service Field Point of Service (OSF-POS) method that is practical and cost-effective. A case study of this method for the Kinosaki spa resort (Hyogo Prefecture, Japan), highlighting collaboration with local authorities, business circles, and engineering experts, is reported in this paper.

Keywords : Open Service Field, pedestrian research, questionnaire survey, POS

1 Purpose of this study - Optimum design loop for service quality improvement:

The service industry accounts for 70 % of Japan's gross domestic product (GDP). Therefore, it is important to improve productivity in this industry to revitalize Japan. To accomplish this objective, it is necessary to introduce an optimum design loop to enhance service quality based on actual data, replacing the traditional method of attempting to improve service quality based on hunches and experience.^[1] In general, sightseeing areas conduct promotional events every year in an effort to attract more tourists. However, objective data are rarely collected to assess the impact of scheduled events on tourism. Promotional events and investments are selected based on hunches and experience, making it difficult to focus on more effective events and cancel events for which the impact is uncertain. This may lead to an increase in the number of events and is a major concern for the parties involved.

In this case, it is necessary to create an optimum design loop in order to invest more resources in highly effective events, and the loop must be maintained on a long-term basis.

Sightseeing areas are designed to provide people with particular tastes and experiences.^{[2][3]} Therefore, fluctuations in the number of people and their movements in these areas are taken into account. However, pedestrian surveys^[4] conducted in the past showed that there are difficulties in creating the loop on a broader scale on a mid- to long-term basis (primarily due to high costs). It is also difficult to investigate each event.

Hence, in April 2009, in a typical spa resort area in Kinosaki, we started a project aimed at the practical realization of implementing technology to continuously and quantitatively observe tourists' activities.

In this study, a general theory of an objective sightseeing area or "open service field" is defined. The reasons for the difficulties encountered in conducting the survey on the open service field are then explained. Next, we present our approach to providing incentives in our research system in order to avoid the known difficulties. We then explain the open service field point of service (POS), which we developed ourselves.^{[5]-[7]} Finally, we consider the interaction of local concerned parties and engineering experts, which played an important role in the practical realization trial.

2 Pedestrian survey on the sightseeing area

2.1 Definition of "open service field"

We generalize and specify sightseeing areas based on the following conditions:

1. Many small-sized service providers exist competitively in adjacent areas. They have equal footing; no master-servant relationship exists among service providers.
2. The service field has no fixed entrance or exit; thus, customers may enter and exit from anywhere. Service providers are not aware of customers' entering and exiting.

The area possessing the above characteristics is called an “open service field.”

Examples of open service fields possessing the above characteristics include shopping streets, shopping malls, local sightseeing areas, and so on. A service complex operated by a single body, however, is not considered an open service field. Most prominent theme parks are not open service fields.

2.2 Surveys in open service fields

Investigations are not always conducted to determine the effectiveness of promotional events in attracting more customers to sightseeing areas.

Many service providers operate independently in an open service field. No downward communication is possible; therefore, the consent of each business operator is essential.

The following structural factors contribute to the reasons why local business operators are reluctant to conduct surveys in a positive manner.

(a) There is a lack of interest and concern, as well as difficulties in evaluating the appropriateness of the required cost.

Local business operators are agreeable to the project, which may lead to a direct increase in customers and sales. However, survey work is not directly connected to boosting sales. An increase in business is dependent on each promotional step, while surveys only measure the results of each step. The objective of this project is to increase effective measures, while non-effective measures will be discontinued so that more effective investments can be made in the future. Though we have spent considerable time explaining the significance of this project to local concerned parties, their reaction was quite weak, as this project is not directly linked to sales. It is also difficult to evaluate whether the required cost is appropriate when compared to the increase in sales.

(b) Difficulty of equal burden sharing

Though the project is found to be beneficial to the entire area and the cost is reasonable, it is not easy to agree on equal burden sharing. Due to the competition present in the open service field, economic disparity exists among business operators and equality is not commonly understood. Small business operators believe that large business operators should take on a considerable portion of the burden, while large business operators believe this idea is not fair or equal.

(c) General concern regarding the use of data

Analysis is required to use the obtained data, and it is generally considered that this analysis requires special knowledge and skills. This leads to the argument that

additional costs must be incurred to solicit the help of a specialist.

Because the use of obtained data is not necessarily clear at times, a specialist may hesitate to undertake the analysis, while the cost is significant for local sightseeing areas.

(d) Psychological anxiety when introducing a new methodology

New technologies and new ideas are not always welcome. Many business and hotel owners with considerable experience are not prepared to learn a new concept such as service engineering. Only a few people will aggressively accept a new idea that is different from the existing one. It is, in a way, understandable that successful shopkeepers are conservative.

In forming a consensus, the principle is one man, one vote. Therefore, this means that it is difficult to obtain a majority to introduce a new idea where people are conservative.

3 A proposal of the survey system with incentives

The purpose of the project was to introduce a tourist behavior survey system in sightseeing areas that can be maintained on a mid- to long-term basis. However, it was foreseen that this system might not readily be accepted. Hence, some incentives are required to persuade business operators to accept this survey system. Any actions that lead to customer satisfaction can be incentives, although specific measures differ according to the service areas.

Ogawa^[8] indicates that two solutions are required in order to create innovation: need design and technology design. Need design is a solution for finding out users' problems and translating them into function elements. Technology design is a solution for creating a combination of element technology that includes production technology. In need design, the services that will lead to customer satisfaction have to be determined. Hence, it is apparent that this will be best conducted by business operators in the field rather than by IT researchers working in Tokyo.

Still, it is difficult to achieve our objective by simply understanding what has been requested in the field. Therefore, we had to build a system to function as a survey technology and to introduce structures designed to please customers.

Therefore, we have focused our attention on a POS (point of sales) system. At retail shops, POS is used to determine when, where, and what customers bought. In the service field, however, this system is not recognized as a survey system but instead is considered a tool to efficiently handle day-to-day business.^(Note 1) Leading from this, we have defined POS

as point of service to determine where, when and what kind of service customers can receive and as a survey technology used to learn the movements of tourists in a sightseeing area. For this purpose, we developed cloud service to establish services at POS (point of service), which are required in sightseeing areas, as well as a small terminal to access such services. This terminal is called an OSF-POS (Open Service Field Point of Service^(Note 2)) (Fig. 1). In addition, we asked hotels and shops about the kind of services they wanted within this POS system in sightseeing areas.

3.1 Turning up unaware needs design

While explaining the physical functions of printers, displays, audio playback, non-contact IC card readers, and so forth, as well as the outline of software-oriented functions (such as creating member cards) of OSF-POS, we did a hearing investigation with local entities concerned about the kind of services they wanted to provide to customers.

Credit cards accepted under town management

The first request was to accept credit cards under town management. At Kinosaki Spa Resort, a “buy and sell on credit” culture has taken root. Tourists in yukata (summer kimono) can enjoy shopping and dining on credit. Such payment is settled when customers check out of the hotel.^(Note 3) The person who presented this idea had plans to expand this service even to small purchases such as ice cream and juice so that more tourists can enjoy the credit service.

Computerization of out-spa tickets

In addition to the request for credit payments, many local entities asked for computerization of out-spa tickets. At Kinosaki Spa Resort, the out-spa tour^(Note 4) is a major attraction, and almost all hotel guests receive such tickets from the hotel and then tour the town (Fig. 2).

Conventional out-spa tickets are printed on paper, and tourists are required to have a ticket for each spa. There are



Fig. 1 OSF-POS

several problems with these paper tickets. Hotels and inns and the Toyooka City Office, which administers the out-spa tour, experienced several disadvantages^(Note 5). Moreover, there were disadvantages for the tourists as well.

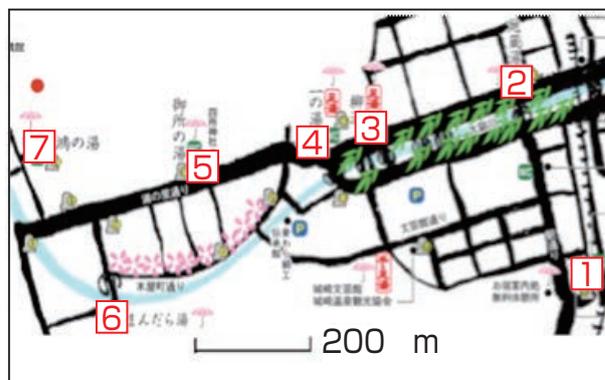
The tickets are available at the hotels' front desks. Hotel guests may take as many tickets as they want. However, some guests only take a few tickets, thinking that that will be enough. When guests run out of tickets, they are sometimes denied entrance to the out-spa, resulting in disappointment and dissatisfaction. Some imprudent guests take many tickets and sell them on the Internet. To avoid these problems, it became necessary for tourists to provide identification. This was accomplished by having hotel guests wear a yukata (summer kimono) with the hotel logo emblazoned on it. However, this restricted use of spas by hotel guests causes inconvenience to hotel guests, as they are not able to wear the yukata after they check out of the hotel.

Based upon the abovementioned requests, computerization of the out-spa ticket was requested.

Proposal for other applications

We had several meetings with local entities to hear their requests for applications even after the demonstration experiment started, and some hotels started issuing tickets on a trial basis. Among the requests was an application for sightseeing guidance. At Kinosaki Spa Resort, there are Kinosaki guides who are voluntary local guides. However, this system was not very popular because it requires advance booking. Moreover, the system was not able to accommodate the increase in the number of foreign tourists. The service was then expanded to provide sightseeing information by authenticating the out-spa ticket via the OSF-POS system.

In addition to the above, there were requests to create Kinosaki member cards, applications for a rental-cycle system, and so on.^(Note 6)



1.Satonoyu 3.Yanagiyu 5.Goshonoyu 7.Kounoyu
2.Jizouyu 4.Ichinoyu 6.Mandarayu

Fig. 2 Kinosaki Spa Resort and locations of out-spa

3.2 Technology design for cost reduction

In the open service field, technology is required for cost reduction. To install technology designs presented in the open service field in the future, we prepared a structure for cost reduction in the OSF-POS system.

Reduction of ID distribution costs

Providing IDs to customers is essential for upgrading service and providing better-quality service. This makes it possible to collect and analyze detailed individual movements. The total number of IDs used on a given day shows the total number of guests for the day. The movement data of each ID shows whether the guest is a repeat visitor or not, making it possible to provide special incentives to repeaters. It is also possible to know, by paper stamp note, whether the guest is a repeater or not. However, the ID system can provide a technically advanced point system. For example, distribution state of points are instantly identified, and the market value of the points are correctly determined. Providing points to IDs helps to control the possession of points. The transfer of points to other persons can be limited. Points may be given to others as a gift in order to create more prospective customers. As this system clarifies customers' movements, a new system in which shops support each other can be introduced, such as "X is presented to customers who visited Y shop."

ID distribution is beneficial to customers. Customers are entitled to receive incentives as frequent visitors, and it is unnecessary to carry a bunch of coupons and tickets; by bundling all the rights in a membership card, the customer is able to exercise his or her rights by simply showing the membership ID card. In the event the card is lost, it is easy to reissue it because the necessary information is controlled by the ID. Furthermore, services for particular individuals are available anonymously, as the customer is not required to disclose personal information to service providers. For instance, by bundling credit card numbers with random ID numbers at hotels, customers can enjoy shopping in the area without the need to disclose their credit card numbers or real names. If an unreliable shop does exist in the area, the customer's personal information will not be disclosed.

Thus, providing an ID is a forceful means to maintain good service infrastructure. Therefore, shopping malls and department stores can provide membership cards and simultaneously make an investment to maintain customers.

However, most tourists visit sightseeing areas infrequently; many may come only once a year. In this case, the provision of a plastic card would increase operational costs and would not be economically realistic.

Hence the OSF-POS system utilizes customers' existing numbers as their ID. For example, the production number of FeliCa may be used as an ID number. FeliCa is a non-contact

IC card device that is used as a mobile phone with a credit function, public transport ticket IC card, and so forth. More than 70 % of mobile phones have a credit function in Japan.^[11] According to research conducted in August 2010, 98.6 % of the population are holders of electronic money in the Tokyo Metropolitan area, while this figure is more than 60 % in the Kinki, Sapporo, Fukuoka, and Tokai regions.^[12] It will be quite helpful to reduce the cost of ID issuance if the production number of FeliCa is used as an ID.

For customers who do not have mobile phones, the OSF-POS system has a ticketing function. When the customer receives the first service in a sightseeing area, his or her customer ID is printed on the ticket. Such ID shall be electronically readable (by barcode or a similar function). The required cost for this service is quite low, encompassing such expenses as consumable paper and the like.

Reduction of software development costs

As a large variety of services exists in OSF, it is not practical to develop software individually. Hence, we propose to divide various services in OSF into ascertained claim-type services and updating claim-type services.^{[6][7]} By organizing applications and relegating them to one of the above services, the required software module is specified, leading to more efficient software development.

(a) Ascertained claim-type service

This service is designed to provide a service after a customer's ID has been identified as valid. This type of service is used in facilities such as cinemas and museums, where the service is provided after a large number of customers congregate. An OSF-POS system is installed at the entrance.

(b) Updating claim-type service

This is a service in which information is updated every time the customer receives the service. For example, electronic money requires an information update every time the customer's right changes (such as a change in the deposit balance). In the event that ID media is not writable, a change of rights must be reported to the server every time.^(Note 7)

These two types of services require different response times. The ascertained claim-type service requires a quick response, as many tourists come simultaneously. It is too time consuming to communicate with a server after the customer has shown his or her ID. Therefore, for application (a), data on the server is cached in the terminal for a quick response. As for application (b), customers stay longer in front of the terminal. Therefore, the customer may accept being kept waiting while his/her ID is being checked with the server each time his/her ID is presented. For example, let us suppose a customer stays at a cash register longer than ten

seconds when shopping. Payment by credit card still requires that the customer wait several seconds, which is within an acceptable time frame. If this is applied for (b), such logic can be implemented on the server. This will minimize the logic required by the OSF-POS system, reducing the required cost of the hardware as well as the maintenance costs for different kinds of terminals (if any).

Reduction of consensus-building costs

Many people have different ideas for service improvements in the area. Many creative ideas are presented through individual hearings. However, these ideas are seldom proposed at large meetings in the area. One of the reasons is that there is a burden of consensus-building costs. Although the idea is presented, it is not an easy task to obtain consensus in the area. Therefore, people become hesitant to propose ideas, resulting in their relinquishing the idea.

The OSF-POS system, then, has a function of partial operation. When a shopkeeper wants to introduce a booking service by utilizing the provided ID, this can be implemented at his or her shop only, not placing any undue influence on the existing service. This does not require a consensus. If somebody else wants to introduce the same service, it can easily be accomplished. This kind of framework is necessary for IT in area development.

3.3 The bridge between need design and technology design

The work required to apply need design to technology design was done primarily by researchers. Trial production and use were repeated many times by researchers and local people concerned until the time when the final interface was fixed. The details of the concrete case are reviewed in subchapter 5.2. Figure 3 shows the scene of credit shopping with the OSF-POS system.

4 Presentation of examples (data application)

After the introduction of the OSF-POS system, the information obtained was made available to everyone, such



Fig. 3 Shopping at OSF-POS

as the number of entries to out-spas, congestion, and the amount of proceeds in the whole area. An example of data application is presented below.

4.1 Configuration analysis of the visitors

People departing from the same hotel and touring the same area around the same time will be considered as the same group of people. According to the data analysis conducted in December 2011, it is known that single tourists account for 3,561 (12 %) of all tourists; the number of people in two adult groups (including couples) is 11,424 (40 %); adult couple groups is 8,284 (29 %); three to five adult groups (men and women mixed) is 6,155 (21 %); and three to five people groups (adults and children mixed) is 3,262 (11 %).

In order to investigate the adequacy of this estimation method, we conducted a questionnaire survey from December 16 to 19. The survey was conducted at all exits of all out-spas (total: 7) by providing questionnaires to visitors. The number of provided questionnaires was 2,444, whereas the number of returned questionnaires was 1,619 (66 %).

For a group that was estimated as a family with a child (or children), the estimate accuracy (accuracy rate) was 92 %. Thus, we concluded that the data analysis of the OSF-POS system provides us with the estimation of the group configuration with practical accuracy.

The question is whether the ratio of 11 % for families is reasonable or not. According to a document,^[13] the ratio of family travelers for a domestic sightseeing tour is 51.4 %. This is the largest figure compared to other compositions (Data from Travel Current 2009 by Japan Travel Bureau). A family does not always include children, and families with children tend to avoid leaving the hotel, so 11 % is probably too low. Up to then, Kinosaki Spa Resort displayed only two types of advertising posters. One shows a young couple, and the other shows a mature couple. A new poster of a family with children has also been created for this year, based on the data.

4.2 Analysis of stay and route

Out-spa occupancy data obtained by the OSF-POS system is directly used. A luggage store checks the ratio of men and women in the neighboring out-spa and displays the bags for men or women use accordingly.

The OSF-POS system installed at the entrance can only record the time of entry. Regardless, an accumulation of the time of entry makes it possible to assume the duration of stay at each place. Figure 4 (left) is a graph showing the number of people who moved from Satonoyu to another out-spa, as well as the time spent traveling from the entry to Satonoyu to the entry of another spa. Figure 4 (right) shows similar data of movements from Jizoyu to other out-spas. Thus, a similar graph can be made for each location. This graph shows

that most of the tourists from Satonoyu traveled to Jizoyu. The time spent traveling from Jizoyu to Satonoyu was 49 minutes, whereas it was 76 minutes from Satonoyu to Jizoyu, which is 55 % longer. It is considered that tourists stay 55 % longer at Satonoyu.

Through the analysis of these data, it will be possible to construct a congestion forecast.

4.3 Off-time analysis

For the vitalization of the area, it is desirable to attract more tourists at lunchtime.

Figure 5 shows the number of entries to the out-spa from 7 a.m. to 11 p.m. (accumulated total for December 2010). There are a certain number of entries to the out-spa before breakfast, but there are none after 10 a.m. Because most of the tourists check out of their hotels at 10 a.m., promotional measures should be taken to keep them in the area until lunchtime. Now the discussion has started to provide out-spa tickets to hotel guests that are only valid once between 10 a.m. and 2 p.m.

4.4 Event Evaluation

Figure 6 shows data from August 2011. The upper graph shows the total number of overnight guests, while the lower graph shows the total sales amount of the town. The number of overnight guests from August 13–16 was the highest, as this period is a Bon public holiday in Japan. The sales amount, however, is not that high compared to the number of overnight guests. The highest sales amount was recorded on August 26, 2011. However, the number of overnight guests is not very high on that day. Fireworks were displayed on fair-weather weekdays in August, but this did not significantly contribute to sales. On the other hand, Toronagashi was performed on August 26, 2011. Toronagashi is the traditional observance of lighting floating lanterns in the river to send off the spirits of ancestors. People enjoy walking slowly to watch the lanterns float down the river. The cost required to observe this event is lower than the cost of fireworks. Therefore, Toronagashi is considered to be an event that contributes to an increase in sales more so than the fireworks display.

5 Consideration

After a one-year trial operation, Kinosaki Spa Resort decided to continue operating the constructed system. As of January 2012, computer terminals have been installed and operated at all hotels and inns (87), all out-spas (7) and 35 shops and sightseeing spots.

So far, our explanations regarding this project have primarily been presented from an engineering standpoint. However, we believe that users have contributed a lot to the implementation of this project. Therefore, in this chapter, cross-interaction and the division of the roles between users and the engineering side are considered.

5.1 Division of the roles and adherence of the knowledge of innovation

When a number of individuals have conducted the joint project, each role is defined according to each individual's knowledge. Regarding this, Ogawa's discussion [adherence of knowledge] is interesting.^[8] The adherence of knowledge is a concept that represents the mobility (transfer to other areas) of locally learned and acquired knowledge (know-how, recognition of problem points). When such knowledge is easily transferrable and practically usable in other areas, its adherence is low. Meanwhile, the out-spa ticket issue at Kinosaki Spa Resort is not easily applied to other areas; thus, this adherence is very high. Knowledge of how to make use of IT technology prevails, thanks to the popularization of PCs and the Internet; and this adherence is relatively low. Such a case, innovation is explained to take place in the neighborhood of the knowledge of high adherence. The result of this project, which has been completed in Kinosaki, fits in with Ogawa's discussion.

In addition to the concept of "adherence," Ogawa^[8] indicates other concepts of "needs push" and "technology pull." Needs push means that users conduct needs design, and technology pull implies that users conduct technology design. He points out that the tendency for technology pull grows when the adherence of technology information is low.

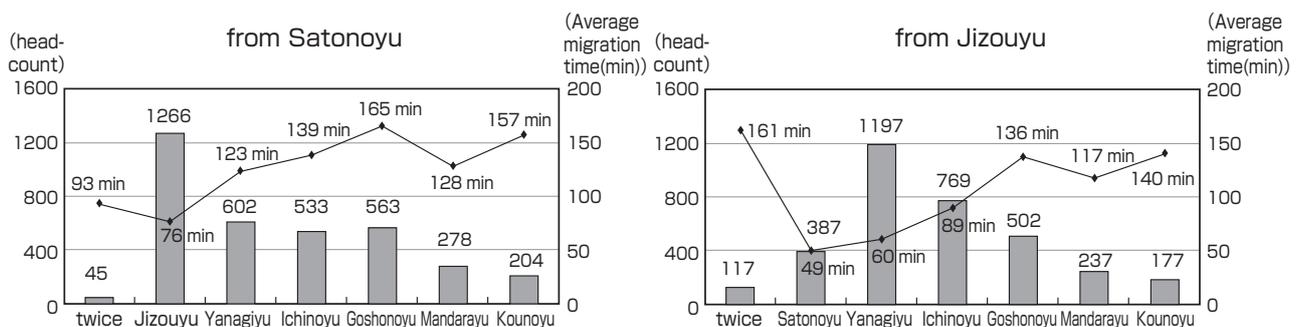


Fig.4 Movement from Satonoyu (left), Movement from Jizoyu (right)

The technology design of this project was generally entrusted to engineers (no technology pull happened). The proposed needs design would be implemented in various ways. Non-engineers could specify the implementation method by finding similar examples. However, it is necessary to understand the difficulty involved in each technology to find the best solution for cost reduction. This is very dependent on the engineers' skills and capability. Therefore, this is considered to be high adherence.

5.2 Coordination of a contact point between users and engineers

To install needs design in a technology design framework, coordination is required. The contact point between needs push and technology pull from the user side and technology development from the engineering side has made a considerable impact on both technology design and needs design.

As previously mentioned, trial productions and operations were reciprocally repeated by both users and engineering experts to achieve a better interface (usability on-site). This was repeated until the final configuration was installed. In cases where users are able to describe the needs push completely (to write down completely with specifications), this represents a needs push as well as a technology pull. When users have no idea about relevant technology design, the user's need has to be realized in trial production and operation. Joint work is required to duplicate the same scenario to discover the problem, if any, and review solutions for improvement. Mutual interaction between users and engineers has made an impact on needs design and technology design. The following is a specific example.

Operational interface at hotels

At the initial stage, computerization of out-spa tickets was requested by concerned local entities; however, no request was made for an interface. We then expected that additional information, such as age-demographic data and so on would be input when issuing out-spa tickets at hotels. Data entry is important for the data analysis, and we considered that this

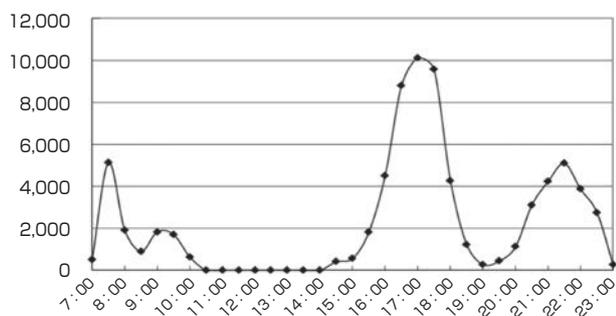


Fig. 5 Number of visitors to out-spa between 7:00–23:00 (accumulated total of December 2010)

would be feasible at Kinokuniya hotels since such data entry is ordinarily performed at convenience stores by young and old people alike.

However, no data entry interface was adopted for additional information. For instance, we created the system so that the out-spa ticket could be issued by reading the ticket barcode from a list of commands. We also designed the system so that the customer's non-contact IC card, such as a mobile phone, is entitled to an out-spa ticket by simply touching the OSF-POS system at hotels. In the event that guests stay over more than two nights, the number of overnights is entered by barcode. A child's ticket is issued by reading the [child ticket barcode] first.

Due to the importance of the research function, we have tried to keep the data collection capability in the trial interface as much as possible, while simultaneously making efforts to simplify the operation. However, local people who were concerned asked us every time to make the operations much simpler. Many elderly people work as hotel clerks, and they experience anxiety when learning a new technology, such as the ticketing process at hotels.

Though the proposed needs design was indefinite at first, this became concrete in the course of matching technology design and needs design.

Needs design of out-spa tickets

The OSF-POS system has a function to utilize mobile phones with credit functions or non-contact IC cards as IDs. However, the penetration rate of the above is not 100 %. Therefore, a method to print a barcode on a receipt must be adopted as well. A question then arose as to whether the printed out-spa ticket alone would function well enough.

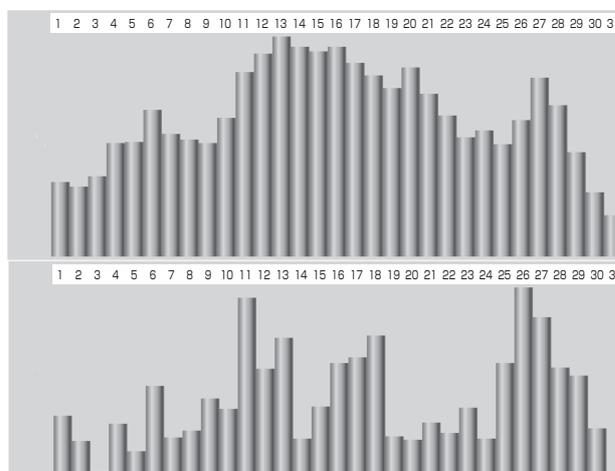


Fig. 6 Number of overnight guests by day (upper) and amount of sales by day (lower) in August 2011

However, both the non-contact IC card and the printed receipt were to be used together for the following two reasons.

First, the promotional message “a mobile phone is used as an out-spa ticket” was considered to be a very appealing new technology. A mobile phone is one of the most familiar IT technologies. Making use of such a technology at a spa resort is welcomed as a cutting-edge approach that has never been attempted by other resorts. Moreover, this approach is expected to be highly popular with the tourists. While enjoying an out-spa tour wearing a yukata, tourists try to minimize their belongings as much as possible. However, mobile phones are known to be an exception. “A mobile phone is used as an out-spa ticket” is a good point that should appeal to tourists.

Another reason the two are to be used together is that it may help prevent the unauthorized use of a ticket. At the time, Kinoshita was planning to issue a one-day pass to be used for unlimited entries to out-spas on the purchased day. However, their hesitance was caused by their concern that one ticket might be abused by several people. It is expected that tickets will not be abused if tourists’ mobile phones are used as the out-spa ticket.

Therefore, the application of FeliCa was positively incorporated into the needs design, though the cost was comparatively higher than the barcode-only system, which points to the fact that some part of technology pull was effectuated by users.

Out-spa ticket with a credit function

Credit service increases the burden on hotels. They are obliged to explain the system to hotel guests and settle the bill at checkout time. There is no merit to hotels at this point; credit service is offered to the area as a whole. Therefore, it is at the hotel’s discretion to issue or not issue the out-spa ticket with a credit function.

In order to save time and work for the hotels, it was arranged so that out-spa tickets came equipped with a credit function by simply entering the room number. The room number is essential to settle the hotel bill. Therefore, engineers considered that this would be the final form, as it is not possible to reduce the operational work any further.

After the introduction of the OSF-POS system, many hotels prepared printed out-spa tickets before their guests arrived in order to avoid congestion at check-in time. However, hotels were obliged to discard the prepared tickets and reissue them if the guests requested a credit function. This is because the out-spa ticket with a credit function requires inscribing the room number before the ticket can be issued.

With this fact in mind, engineers have added a function

whereby the credit function can be added to an already-issued ticket by entering the room number. This function has been well accepted and has become a major trend in Kinoshita. Hotel clerks had a difficult time imagining that the new function could be added on to an already-prepared ticket later. In addition, hotels that issue out-spa tickets with a credit function are cooperating with the efforts of the area. Therefore, it is believed that those hotels were able to endure some inconveniences. This shows that engineers are sometimes expected to extract the needs.

Pass code

It was required that pass-codes be provided (from 1–3 digits), as guests may lose their out-spa ticket with the barcode; hence, a pass-code is given when issuing the ticket. Allowing guests to choose their own pass-code was not implemented in order to avoid congestion at the front desk. Throughout the trial, some guests contacted the hotel to ask for a forgotten pass-code, and hotels were obliged to respond which was troublesome at the time.

In response to this, a specific number of pass-codes was allocated to each hotel and was made available to all guests for that day (the same pass-code number for all guests) in addition to the abovementioned system. This system in which all hotel guests were to use the same number for the day seemed very risky. (No engineers would likely recommend this system). However, many hotels used their specific number in a practical way, which can be considered part of the technology pull.

As the reason for the OSF-POS system being introduced in a considerably short period of time, frequent dialogue or interchange between users and engineers were particularly noted. The users’ requirements were taken into consideration, and technological improvements were implemented (and sometimes new functions were added) and returned to the site. These reciprocal actions were conducted in approximately two weeks in each case. This interaction created new knowledge of a more user-friendly system and contributed a lot to making needs design much more attractive to the local entities involved.

5.3 Supporting users’ awareness

The most difficult challenge was answering the question of who would conduct the analysis of the collected data. One option was to employ a consultant; however, this option was not affordable for many sightseeing areas. The ideal option was to build a structure in which the local people involved could freely exchange ideas.

For people to be able to exchange a variety of ideas, they would need more opportunities to review data. Therefore, we presented push-style data, where we sent a graph to shopkeepers and so forth, showing the number of guests as

well as the total sales amount in Kinosaki. In addition, a system was constructed to discuss items on the mailing list.

The event evaluation mentioned in subchapter 4.4 was pointed out by a hotel owner on the mailing list.

He commented, “My hotel had eleven credit payments yesterday, amounting to 21,625 Japanese yen. Eleven credit payments were the largest ever. Credit payments in the area were also the largest. Though the number of guests at Bon time (religious ceremony celebrated in summer) was larger, there were more credit payments at the time of Toronagashi. This data suggest that many people enjoyed walking at Toronagashi” (extracted from an e-mail received from a hotel owner on August 26).

It is presumed that this owner first noticed the large number of credit payments by guests of his hotel and then noticed that the entire area had the same experience. It then reminded him of the effect the event had on credit payments.

In order to encourage the people involved to remain aware, it is meaningful to review data daily. The impression that “something is different today” will instantly fade away. Therefore, minor changes will not be noticed if reviewing the data is troublesome.

In order to accelerate the awareness of people concerned, one measure is to reduce the cost for checking data like that used in this project in data push style. Another option is to arrange the data so that shop and hotel owners want to check them (for instance, a graph showing the sales amount of the hotels and shops in the same business).

Apart from the measure to increase the opportunity to review data, it is important to arrange data in a way that will encourage awareness. Local business operators are clearly aware of what occurred on that day; however, they sometimes do not pay attention to changes that occur over the mid- and long-term. Therefore, it is effective to present a graph on a monthly or annual basis. At 7-Eleven stores, POS data is provided on a graphic terminal so that the shop owner may make use of this data.^[8] Differing from 7-Eleven, data from the entire area does not have a direct impact on each hotel and shop. However, providing chronological changes of the area on a graphic mode will help people understand signs of real changes.

5.4 Local project implementation structure

Presence of the key person

Though local people at Kinosaki had no prior opportunities to work with engineers on a joint project, we could conduct demonstration experiments, which led to continued operation. This owes much to the presence of the key persons who have actively cooperated with us. Key persons in this

sense refer to those persons who have strongly influenced the decisions made in the area. In Kinosaki, fortunately, several key persons recognized the value of this project, talked about the needs in a constructive manner, tried to understand the technology, and took on the practical work of consensus building. Since consensus building is a time- and cost-consuming task in the open service field, the presence of key persons is essential for joint project implementation.

Increase in the number of people involved

The presence of a key person does not necessarily mean that consensus building will be easy in the area. It is important that the key person receives broad support. Hence, meetings were frequently held for local coordination. Here, we would like to point out the significance of the interactions mentioned in subchapter 5.2, in which users generated ideas that were put into operation. The repetition of the above work in a short period of time contributed much to users being able to recognize that their ideas were reflected upon and incorporated into the system. Recognition widely spread that not only people who had offered ideas but other people were taking initiatives to create projects as well. This has led to the commitment (involvement) of many people.

Another factor contributed to a large commitment (involvement) of the people. People were bestowed with the task of naming the system. The unique name “Yumepa,” which is the “Kinosaki spa-tour pass,” spread quickly and became popular. Scientific causal connection is not clear at this stage; however, it is presumed that bestowing naming rights evokes recognition of their initiatives.

Creating an administrative organization

Creating the structure to implement the project on a long-term basis was one of the major points of controversy. The project requires the consensus of the entire area. However, in Kinosaki, there were industry-classified associations only, and no adequate organization was found for the discussion of the OSF-POS system. The out-spa ticket issue was in the hands of the property ward assembly. The credit payment issue was in the hands of the commerce and industry association. The operational initiative of the project was separated. Then, Kinosaki set up a decision-making body consisting of representatives from all of the industry-classified associations in the area. This new organization functions as the center of discussions of business that affects the entire area, as well as as a responsible body for the continued operation of the OSF-POS system. It is essential to define the body responsible for guaranteed operation in the future.

6 Conclusion

In order to introduce the optimum design loop for service quality improvements in sightseeing areas, it is necessary

to conduct continuous surveys on consumers' behavior on a mid- and long-term basis. In this study, we have indicated that the proposed survey system, which includes incentives, has a beneficial effect. We have also considered the importance of collaborative activities between the local people involved and the engineers.

When the practical survey system was introduced, the main concern of the local entities involved was whether the utilization of data would be possible by local people only. This concern was solved by providing data frequently and in a friendly manner. The project demonstrated that beneficial ideas are generated by local hotel owners and shopkeepers.

For the promotion to be effective in attracting tourists, it is required that we give due consideration to next year's plans by stating a hypothesis. The decisions involved in the planning process may be affected by the presence or non-presence of subsidies or human relations. Therefore, operations in the future shall be carefully observed.

Acknowledgement

This study was conducted with the support of a project [a promotion to create a new market by integrating IT and service (service technology research and development project)] by The Ministry of Economy, Trade and Industry in 2010.

Notes

Note 1) Although a cash register and POS system are basically different (the purpose of a POS system is to analyze data), they are often used as synonyms.

Note 2) POS, as indicated in this study, refers to an ordinary POS (point of Sales) system. OSF-POS is the name of the proposed system, and here POS means Point of Service.

Note 3) Although this service was very popular, all restaurants did not always accept credit payments. The reason for this is that collecting money early in the morning or late at night places a heavy burden on them. Besides those restaurants, only a few souvenir shops accepted credit payments.

Note 4) In contrast to hotel spas, a public spa is called an out-spa. There are seven out-spas in Kinoshima.^[10]

Note 5) Hotels were required to visit the town office periodically and were obliged to stamp the hotel name on the back of the tickets. Hotels sometimes experienced a shortage of tickets because some guests took many tickets at one go. Hotels also experience cleaning difficulties because some guests left the unused tickets in the sleeve of the yukata. In

order to know the number of out-spa guests, the town office had to count the number of recollected tickets manually. Since this work is very time consuming, it was always three months behind. Nevertheless, details of the behaviors and activities of the guests could not be determined.

Note 6) These ideas were not yet implemented as of January 2012, mainly because of the shortage of human resources.

Note 7) In documents,^{[6][7]} adding to the ascertained claim-type service and the updating claim-type service, a stamp-type service for the guests who do not have IDs is also described. For example, sightseeing information (audio-visual information based on the guests' requests) is a stamp-type service. However, this type of service does not contribute to the accumulation of data. Hence, the service is to be divided into two types, as described in this study.

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Author

Yoshinobu YAMAMOTO

Engaged in the research of human interface and cognitive science. 2009 to date: Senior researcher, Center for Service Research, National Institute of Advanced Industrial Science and Technology, Japan. 2001 to 2008: Cyber Assist Research Center, AIST. 2006 to 2007: Technical Advisor, East Japan Marketing & Communications, Inc. 2005 to 2009: CTO, director, Synergy Media Co. Ltd. 2001 to 2003: Chief System Architect, Cyber Technologies Laboratory, SONY Electronics, Inc. 2000-2001: Visiting Scholar, Center for the Study of Language and Information, Stanford University. 1994-2000: Senior researcher, Information Science Division, Electrotechnical Laboratory, MITI, Japan. 1994: Ph.D. Member of Information Processing Society of Japan, The Japanese Psychological Association and Japanese Cognitive Science Society.



Discussions with Reviewers

1 Research paper in general

Question and Comment (Yasunori Baba, Research Center for Advanced Science and Technology, The University of Tokyo)

In this area, there is an important preceding study conducted by Susumu Ogawa presented in the book, “Emergence Logic of Innovation - surpassing manufacture-oriented research system” – Chikura Shobo (2000). I highly recommend reading through this book to upgrade the analysis as well as to gain a better understanding of the phenomena. This will make this paper more reader friendly.

Answer (Yoshinobu Yamamoto)

Since your recommendation, I have read the book. I feel that the concept presented in this book is quite important and useful. Before I read the book, I did not adopt the viewpoint of technology transfer or innovation. I strongly feel that further consideration from a new point of view will be possible by employing Ogawa’s concept of adherence of information. In order to make the modification as indicated, I have conducted a drastic review because minor changes and modifications were not enough.

2 Productivity of service

Question and Comment (Yasunori Baba)

This paper says that the introduction of the OSF-POS system that was developed by the author produced the improvements to service productivity and argues that this improvement contributed to the prevalence and continuous operation of the relevant system in the area. It is desirable to proceed with the analysis having

a clear concept of service productivity. From the viewpoint of who benefits from productivity improvement, it is also desirable to conduct an analysis and give it due consideration, though not quantitative, on the following: (1) What impact was observed in tourists’ movements (such as the number of tourists and the amount of consumption) when tourists were the beneficiaries? (2) With the introduction of the OSF-POS system, what impact was observed by local business operators of a different nature?

Answer (Yoshinobu Yamamoto)

The primary significance of service productivity improvement in this study is to conduct investment decisions on a mid- and long-term basis based on an objective assessment of the measures used to attract more tourists. I have tried to make this point clear in this paper.

3 System improvements by local business operators

Comment (Yasunori Baba)

In order for the introduced system to operate on a continuous basis, a key factor is to construct a social infrastructure wherein system improvement can be accomplished through the initiative of the local business community. Since this is very important, it is advisable to cut back other parts in an appropriate manner and enforce this point specifically. A proposition or suggestion for the future is expected such as the possibility of using technological support to exploit the potential of local business people’s ideas, or any unexpected functions to be added.

Answer (Yoshinobu Yamamoto)

I have reviewed subchapter 5.3, including the title. Overall, rearrangements were made. In order to support awareness, I have indicated (1) to review data frequently and (2) to provide data in an awareness-raising style. For reviewing data frequently, I indicated that data should be provided by e-mail and other communication outlets, as well as data should be interesting data that people want to see on a daily basis.

4 Meaning of POS

Comment (Koh Naito, Service Engineering Research Center, AIST)

POS is used as the abbreviation of both [point of service] and [point of sales]. POS is, in general, recognized as the abbreviation of the latter. Therefore, the former should be standardized by [OSF-POS]; otherwise, another abbreviation must be adopted. Since comprehending the service process, such as pedestrian movements, is a typical feature of this paper, I ask that you duly consider applying [Process] instead of [Point] for P in OSF-POS. Meanwhile, POS is not recognized as a survey system and does not represent the actual conditions. The reality is that this system is not used to a satisfactory extent as a survey system.

Answer (Yoshinobu Yamamoto)

Your suggestion to change Point to Process is greatly appreciated. I understand that by doing so, the word may include the meaning of service process. However, the word “POS” was initially introduced as an acronym for the Point of Sales system. Hence, it is somehow not the case that two completely different things coincidentally share the same acronym. Therefore, I believe further explanation will be required to delve deeper into its meaning. I have then standardized in this paper that POS is used as an acronym for Point of Sales, while Point of Service is represented as POS (Point of Service) or OSF-POS, as a name of the developed system. For further explanation, Note 2 was added.

In order to make it clearer, [is not recognized as a survey system] was modified to [This system is recognized, by sales people, not as a survey system but as a tool for the smooth operation of the daily sales task].

Development of basic tools for glycoscience and their application to cancer diagnosis

— A 10-year strategy of the Research Center for Medical Glycoscience of AIST —

Hisashi NARIMATSU

[Translation from *Synthesiology*, Vol.5, No.3, p.190-203 (2012)]

We proposed a 10-year strategy for the development of a new scientific field, glycoscience. Initially, we developed basic technological tools to help scientists and engineers entering this field. As the first project, we exhaustively discovered glyco-genes and carried out their functional analyses. The fruits of this work led to several follow-on projects: (1) technology for enzyme synthesis of glycans, (2) technology for structural analysis of glycans, and (3) analysis of biological functions of glycans. The basic tools, developed in the first 5 years of our 10-year strategy, were applied to the development of more useful products, e.g., disease biomarkers, particularly for cancer diagnosis. We are also close to achieving the practical use of a liver fibrosis marker and a cholangiocarcinoma marker for diagnosis. Moreover, we are pursuing development of biomarkers for diagnosis of other cancers. The successful research results for these 10 years have now been transferred to the world, in particular, Asian countries, and yielded collaborative research contracts with domestic and overseas research groups.

Keywords : Glycan, *N*-glycan, *O*-glycan, glycosyltransferase, glyco-gene, lectin, lectin array, mass-spectrometry, IGOT, biomarker, liver fibrosis, liver cancer, cholangiocarcinoma

1 Introduction

Glycans are often regarded as the third biological chains of fundamental biopolymers, following nucleic acids (first chain) and proteins (second chain). Proteins are easily understandable as they are the principal gene products (nucleic acids). The protein synthetic mechanism is similar among species, and thus the principles clarified in lower organisms are also applicable to humans. In contrast, glycans are synthesized sequentially by more than 180 kinds of enzymes called glycosyltransferases.

The substrate specificity of glycans amazingly changes along with the evolution of species, resulting in wide differences in monosaccharides which make up glycans and also in their structural sequences between the lower organisms and humans. This is interesting, as nucleotides and amino acids which make up nucleic acids and proteins have barely evolved. There are a few monosaccharides that are common between bacteria and humans, but the majority varies. Equally, with animals and plants, a large part of the monosaccharides are uncommon. Glycans also differ between anthropoids including humans and other mammals such as pigs, cattle and lower species.

In general, glycans are attached to proteins and phosphates forming glycoproteins and glycolipids, respectively. Most of the membrane proteins and serum proteins are glycoproteins,

and they become functionally-matured molecules after receiving proper glycan attachments (glycosylation). A group of glycoproteins consist of uniform protein moiety, but their glycan moieties are quite inhomogeneous. For example, immunoglobulin G (IgG) has double stranded, simple *N*-linked glycans (*N*-glycans), which have a wide variety of structures (36 types). However, it is very difficult to purify glycoproteins consisting of homogenous glycan structures. Moreover, it is almost impossible to synthesize glycoproteins consisting of homogenous glycan structures. For these reasons, the variety of glycan functions attributed to slight alteration of glycan structures is so far hardly analyzed.

Glycans binding to glycoproteins are roughly classified into *N*-glycans and *O*-linked glycans (*O*-glycans). *N*-glycans are attached to the asparagine-X-threonine or -serine (Asn-X-Thr/Ser) sequence, and this preference is relatively conserved among species. In contrast, *O*-glycans can be attached to any part of threonine or serine. In humans, there are about 20 members of ppGalNac-T, a glycotransferase family which initiates synthesis of *O*-glycans, and each of them exhibits various expression patterns along with differentiation or canceration of cells. This means binding sites of *O*-glycans are affected by differentiation or canceration of cells. Unfortunately, no technology to identify the binding site of *O*-glycan has been developed yet.

It is a natural habit of scientists to think that there should

Research Center for Medical Glycoscience (RCMG), AIST Tsukuba Central 2, 1-1-1 Umezono, Tsukuba 305-8568, Japan
E-mail : h.narimatsu@aist.go.jp

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be some important functions in the existence of glycan molecules. However, functional analysis of glycan-related proteins is often avoided by many scientists, as there is no appropriate basic technology for analysis.

The whole human genome sequencing was completed 11 years ago, and major attention was given to proteomics (comprehensive analysis of proteins) taking the resultant genome sequences as the templates. We were sure that this flow of scientific approach will be directed toward the comprehensive analysis of glycoproteins, the final form of functional molecules. It would require development of the basic technology tools for glycoscience. By means of such tools, analysis of glycan functions would be enhanced under the concept of glycoproteome. We were aiming for the goal of glycoproteomics as the biomedical application, in other words, diagnostic and therapeutic technologies.

2 About glycans

“Glycans are like clothing for cells and proteins” (Fig.1). Characteristics of glycans as summarized are expected to be applied in many fields.

(1) Sequential structures of glycans are dramatically altered along with differentiation, maturation, and activation of cells. If a normal cell becomes a cancerous cell, the cell will dedifferentiate and its glycan structures will be widely modified as well. Such alterations would make glycans the best prospective cancer markers and be applicable to regenerative medicine. Glycan structures change regularly along with the direction of differentiation, which supposed to be useful in the lineage determination of cultured cells. The germ cells mature and differentiate most rapidly among other cells. Glycans

of sperm and ova indicate fast and amazing changes, which suggest an important role of glycans in maturation.

Moreover, glycan structures also react and change quickly upon activation and inactivation of cells. Cells related to the immune system show alterations of glycan structures along with their activation and inactivation.

- (2) Glycan structures are varied by the derivate tissue of the carrier protein. As an example, transferrin is produced by both the liver cell and choroid plexus, but the glycan structures of transferrin derived from different origins are different but their carrier proteins are the same. Thus the origin of a protein can be detected based on its glycan structure. Moreover, expression levels of certain sialyltransferases and sulfotransferases often increase dramatically in cancerous cells, and as a result, many glycoproteins are sialylated or sulfated. The negative charge of the cancerous cell surface increases due to the increase of sialic acid and the sulfate group. This indicates that controlling only a few glycotransferases would affect functions of abundant glycoproteins. As a result, characteristics of cells are widely affected by glycotransferases.
- (3) Glycan structures in a variety of glycoproteins produced by one particular cell vary widely. Despite the fact that the glycoproteins derived from the same cell have the same expression pattern of glycosyltransferases, each kind of glycoproteins has a characteristic glycan structure, and the mechanism for this system has not yet been clarified.
- (4) Glycans have individual specificity. A representative example is the blood type. Not only the ABO blood group system, but also Lewis, P, and Ii systems are based on

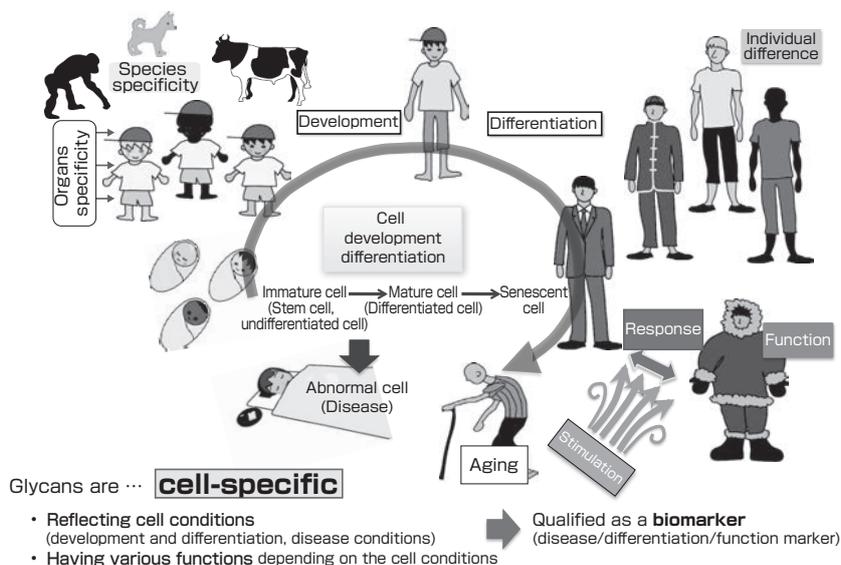


Fig. 1 Glycans are like clothing for cells and proteins

the individual differences of glycan structures. Mutation of the relevant glycotransferase genes induces loss of enzyme activity or alteration of substrate specificity, causing the differences in glycan structures. This mutation is inherited from parent to child. The largest obstacle of organ transplantation in humans is the difference of glycan structures concerned in the ABO blood group system.

- (5) Glycans have species specificity. Evolution of glycosyltransferase genes is the fastest among that of all genes. This is probably due to the fact that the glycans on the cell surface are most directly affected by the changes of the outer environment, and the glycan structures have long been selected in response to those changes. Erythropoietin being used as a pharmaceutical antibody and hematopoietics is produced by using hamster cells. Thus its glycan structures are the same as those of hamsters, not of humans. Erythropoietin could be used for doping by athletes. Therefore, testing for hamster-type glycans is applicable for doping inspections. Studies for transplantation of pig organs (xenotransplantation) have been ongoing, but acute rejection occurs due to different glycan structures, as pigs have specific glycan structures that are not found in humans.
- (6) In infectious disease, infection is initiated by binding of pathogenic microorganisms with specific glycans of the host cells. Many kinds of viruses including influenza virus bind to glycans. There are also opposite cases. Glycan structures of pathogenic microorganisms are recognized by and bound with lectins on the surface of the host cells, and thus the host cells become infected. The terminal end of glycans is most closely interacted with the outer environment. Infection of many pathogens begins by binding to glycans (or lectins) of cells, suggesting that the individual selection to avoid the infection from pathogens is one of the causes for the fast evolution of the glycan structures. To avoid infection genetically, alteration of glycan structures helps preserving the species. Influenza viruses bind to α 2,6 sialic acid, *Helicobacter pylori* to Lewis-type blood group glycans, and noroviruses to ABO and Lewis-type blood group glycans. Individuals which gained tolerance against infection through mutation of glycosyltransferases survive and procreate descendants. Such individual selection can be seen for more than ten-thousand years. The ABO blood group system can be found in species upper than anthropoid, but the Lewis blood group system is specific to humans. The mutation of glycosyltransferase that specifies the Lewis blood group antigens occurred 20 to 30 thousand years ago.

3 Scenario and strategy of glycoscience

As described above, glycan structures well reflect the

differentiation and dedifferentiation (canceration) of cells, as well as tissue specificities. These characteristics serve as the principle for development of glycan biomarkers. Glycan structures are determined mainly based on the expression patterns of glycosyltransferases, and thus are estimated to be controlled by the transcriptional regulatory mechanism or epigenetic mechanisms (control of expression patterns by post-translational modification not relying on the gene sequence). However, such basic research had hardly been conducted 10 years ago. Therefore, we had to start from the development of basic technologies required for the glycoscience by ourselves, which greatly contributed to the remarkable progress of the research field. It was the most desired and attractive task to be accomplished as a pioneer of a new science. If a scientist starts research using technologies developed by a foreign country, it cannot be denied that this scientist lags behind the foreign country. This can be applicable to any of the scientific fields.

In the glycoscience, likewise in the genetics and protein science, the firstly-required basic technologies are those for synthesis and structure (or sequence) analysis. These basic technologies must be easy to use for every researcher. Ten years ago, most of the available technologies for synthesis and structure analysis were immature and inappropriate for non-expertized users. Therefore, we set a 10-year perspective to pursue the sequential approach for glycoscience (Fig.2). We focused on the development of basic technologies during the first 5 years, and then application of the technologies during the latter 5 years. The process of research was as follows: (1) Human-derived glycogenes were comprehensively identified and analyzed. (2) Recombinant glycosyltransferases were expressed from the obtained glycogenes, and obtained enzymes were used in combination to synthesize glycans with a variety of structures to make a glycan library. (3) Obtained glycans with known structures were used as the standards for development of glycan analysis technologies. (4) *In vivo* functions of glycans were analyzed.

To elucidate the effects of alteration of glycan structures on the function of glycoproteins and cell phenotypes, the basic technologies for the following purposes are necessary.

(1) Glycogenes:

The human-derived glycogenes were comprehensively identified and analyzed in the project for establishment of a glycogene library, Glycogene (GG) Project. To synthesize a glycoprotein, the protein moiety is regulated by expression of one gene, but the glycan moiety is controlled by the coordinate expression of dozens of glycogenes. Therefore, if all the glycogenes are elucidated, the mechanisms for biological synthesis of glycoproteins and glycolipids should be clarified. To reach the final goal, that is, understanding of the glycan functions, elucidation of all glycogenes was necessary as

the first step.

(2) Synthesis:

Glycosyltransferases were expressed as recombinant enzymes based on the obtained glyco genes, and used in combination to synthesize glycans with a variety of structures to make a glycan library. Biochemical synthesis of glycans requires a huge amount of work and time. Moreover, an innovative organic chemical synthesis method for glycans has not yet been developed, and synthesis with organic solvents is environmentally offensive. Synthesis of complicated glycans with a variety of structures is impossible, and it takes considerable time to create even one kind of structure. The only advantage is that once an organic chemical synthesis method is established, mass production at an industrial level would become possible.

In contrast, the glyco genes that were comprehensively obtained at the previous step were expressed as recombinant enzymes for enzymological synthesis of glycans. Through the combination of a variety of enzymes, quite a lot of desired glycans in a variety of structures could be synthesized freely in a short time. Glycosyltransferases are highly substrate-specific, and thus one kind of enzyme can synthesize only one kind of structure. Therefore, certain glycan structures are synthesized easily and rapidly by the glycosyltransferases with known substrate-specificity. The reaction is hydrolytic and thus is eco-friendly. The disadvantage is that because the enzymes are derived

from human origins, they are extremely unstable and the production costs much. However, it is impossible to use glycosyltransferases obtained from lower organisms alternatively for synthesis of human glycan structures. Therefore, the enzyme method is very suitable for synthesis of a small amount of variable glycans, but not for mass production.

(3) Structures:

In the Structural Glycomics (SG) Project, the above-obtained glycans with elucidated structures were used as the standards and contributed to the development of glycan analysis technologies. This enzyme method is suitable to produce a few milligrams of many kinds of glycans required as the standard substances.

We thus established two structure elucidation methods using the standard glycans and glycoproteins: Tandem mass spectrometry (MSⁿ method) and lectin array method. Each of them has advantages and disadvantages, and is suitable for different purposes. The MSⁿ method is superior in the following: (1) The analysis is easy for everyone. (2) The glycan structure can be determined. It is inferior in the following: (1) The analysis requires relatively large amounts of glycans (about several micrograms). (2) The glycans must be purified prior to analysis. On the other hand, the lectin array is superior in the following: (1) The sensitivity is very high. (2) The antibody-overlay method does not require complete purification of the target glycoproteins. (3) Comparison of glycan profiling among multiple samples is possible.

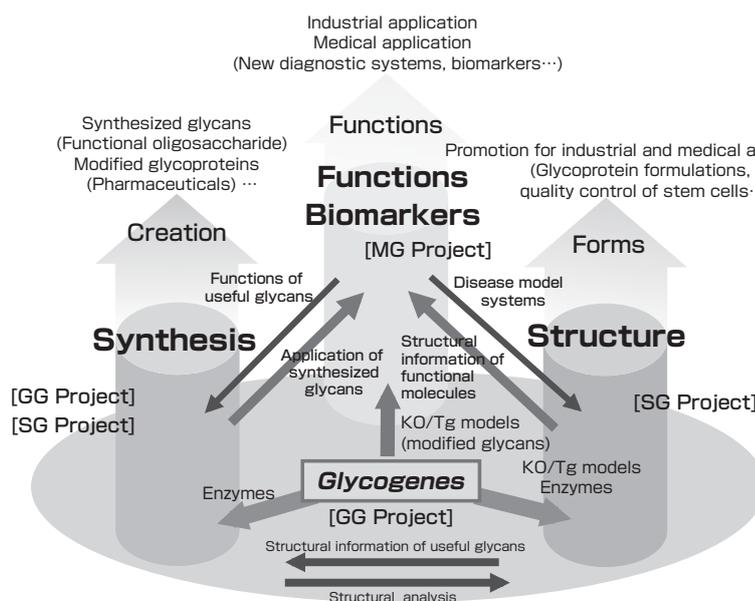


Fig. 2 The three main themes of glycoscience

Glyco gene (GG) Project: Establishment of glyco gene library, Structural Glycomics (SG) Project: Glycan engineering (structural analysis technologies), Medical Glycomics (MG) Project: Application of determined functions (functions and biomarkers)

It is inferior in the following: (1) Absolute structure determination is impossible. (2) Lectins may not always be readily available.

(4) Functions and biomarkers:

In the Medical Glycomics (MG) Project, effects of the change of glycan structure on the glycoprotein functions and cell phenotypes were determined *in vivo* using the above technologies (1-3). As we went through, “synthesis”, “structure”, and “functions and biomarkers” have been the three main themes and interactively developed. Their application can be seen as “synthesis” in the production of functional oligosaccharides and glycan-modified glycoproteins, “structure” in the quality management of glycoprotein pharmaceuticals and ES cells, and “functions and biomarkers” in the commercial and medical applications as shown in diagnosis technologies.

4 Development of elemental technologies for basic technology tools

Figure 3 shows a list of elemental technologies developed for glycoscience. The following is the summary of each element.

Elemental technology 1: Identification of glycosyltransferases in human genome databases by bioinformatics technology

We started from the comprehensive identification of candidate genes for glycosyltransferases by full application of the bioinformatics technology. Kikuchi, a member of our project team assigned from Mitsui Knowledge Industry

Co., Ltd., developed new software to identify the candidates from the available genome databases. This software is capable of searching not only amino acid homologues but also characteristic glycogenes such as (1) glycogenes possessing a membrane binding site to hydrophobic amino acids at proximal to the *N*-terminus, and their lengths being about 18 to 22 amino acid residues, slightly shorter than cell membrane binding proteins, (2) glycogenes with a subsequent main structure that is rich in proline and has many serine and threonine, (3) glycogenes subsequent to the enzyme activity domain, and have active domains consisting of 300-400 amino acids and containing several cysteine and 3-amino acids of the DXD motif binding to bivalent cations. About 100 glycogenes with such characteristics were identified and their cDNAs were generated mainly based on the RNA of human cultured cells. All the candidate genes coding the entire enzyme were cloned by PCR.

Elemental technology 2: Recombination of glycosyltransferases into expression vectors and substrate specificity analysis of recombinant enzymes

For the development of this technology, many original members of the Research Center for Glycobiotechnology (predecessor of Research Center for Medical Glycoscience [RCMG]) of AIST (Togayachi, Sato, Goto, Kudo, Tachibana, Cho, Kubota, Sawaki, and more) greatly contributed. Glycosyltransferases are membrane proteins binding to the Golgi membranes and endoplasmic reticulum membranes. To activate the glycosyltransferases as recombinant enzymes for *in vitro* synthesis of glycans, they have to be in the form of

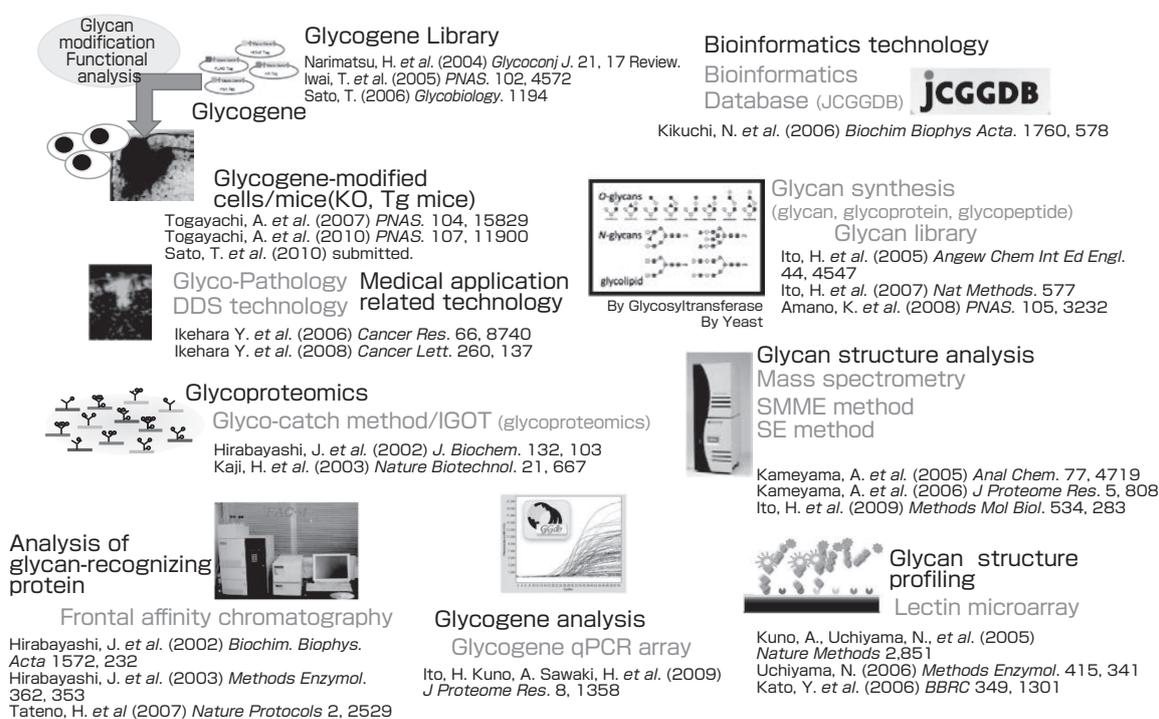


Fig. 3 Representative basic technology tools developed or utilized in RCMG

soluble enzymes. Therefore, the membrane binding moiety of the candidate genes was omitted and the area supposed to be the enzyme activity domain was incorporated into the gateway vector tagged with FLAG, and transfected into the human embryonic kidney blast cells (HEK293T cell). The obtained recombinant proteins secreted into the medium were partially purified from the supernatant. We concentrated on comprehensive, easy, and fast detection of activities in recombinant enzymes derived from many candidate glycosyltransferases. We purchased nine human-derived substrates labeled with radioisotope, and added into the culture media. Moreover, we added monosaccharides and oligosaccharides, as well as a mixture of glycolipid and a mixture of glycoproteins obtained from cultured cells as the acceptor substrates. The HEK293T cell was used for recombinant expression of glycosyltransferases, because it was already known that human derived glycosyltransferases are quite unstable and fragile proteins, and impossible to be expressed in active forms by *Escherichia coli* or yeast. The HEK293T cell is derived from humans and its glycoproteins are highly glycosylated. It is estimated that many glycosyltransferases are expressed endogenously in the HEK293T cell, which leads to a prediction that there are machineries required for expression of ectogenic human recombinant glycosyltransferases with their own activity. Even under the current knowledge, the human derived HEK293T cell is the most suitable for expression of human recombinant glycosyltransferases. The newly developed glycosyltransferase genes in this project were applied for the substance patents and most of them were published in major journals.^{[1]-[29]} However, in the future, the mass production of glycans will be required. For the mass production, an inexpensive bulk production method is necessary. Production by vertebrate-derived cultured cells costs much and is not suitable for mass production. From this point, Chiba and his group of RCMG are establishing a mass production system of human-derived glycosyltransferases in yeast.^[30]

These accomplishments are accumulated in the glycosyltransferase databases for open access at Japan Consortium for Glycobiology and Glycotechnology Database (<http://jcgdb.jp/>). This database is being expanded to contain not only the information about glycosyltransferases, but the wider range of contents to form an advanced database by Shikanai and other members of the RCMG.

Elemental technology 3: Quantitative assay method for 186 kinds of glycosyltransferase expressions

Glycosyltransferases, which synthesize the main structure of *N*-glycans, are expressed in every cell. The expression level of glycosyltransferases is large and not affected by the conditions of cells. The expression level of other glycosyltransferases is low; especially those synthesizing the terminal moiety of glycans are very slight compared with other genes. They are impossible to be detected by ordinary DNA

chips, and even if it could be detected, their modifications cannot be measured correctly. We developed a technology to measure the expression levels of all 186 glycosyltransferases accurately in a comprehensive, high throughput manner. The quantitative real-time PCR (qPCR) for comprehensive glycosyltransferase expression analysis is a matured experimental technique, which is the most reliable biological analysis method in terms of detection sensitivity and measurement accuracy. Glycosyltransferases are experimentally known as low in the expression levels in most of the cases, thus qPCR was considered to be suitable for the development of the expression analysis system.^[31] Specifically, customized qPCR arrays for the 186 glycosyltransferases encoding the glycosyltransferases and modification enzymes were established by the members of RCMG with Sawaki as the core member. The plasmid DNA pool of the glycosyltransferase clone library used as the calibrator enabled the system to indicate the amount of transcription products of all 186 glycosyltransferases based on their copy number at a one-time measurement. Classification of cells in terms of the expression profiling of glycosyltransferases is well correlated with the cell differentiation or canceration, and the expression of glycosyltransferases is known to be proportional to the expression of glycans.

Elemental technology 4: Establishment of *in vitro* synthesis method of glycans and glycopeptides by recombinant glycosyltransferase

As the recombinant glycosyltransferases are derived from humans, most of them can be purified as soluble recombinant enzymes without losing activity by means of human-derived HEK293T cells. Based on this principle, we established an *in vitro* synthesis method of glycans and glycopeptides. As an exception, the glycosyltransferases attributed to the main structure of *N*-glycans cannot be recombined as they are synthesized on the rough endoplasmic reticulum (ER) and they pass through the lipid membrane several times. As for the main structure of *N*-glycans, commercially available purified natural forms were used as the starting materials. As for the *O*-glycans, representative peptides possessing *O*-glycans, such as mucin were used as the starting materials and glycans were elongated by adding glycosyltransferases sequentially.^{[30][32][33]}

Synthesis methods were established for two objectives by Ito *et al.* of RCMG. The first objective is the mass production of one kind of glycans in the largest quantity. The conditions for enzyme reaction were set at a certain level, and the largest amount of enzymes was reacted for the longest time possible. The obtained products were separated and refined by liquid chromatography. The second objective was the simultaneous synthesis of multiple glycan structures at small quantities in one tube. Reaction of each enzyme was terminated by heat when the production reached about 50 % saturation. Then the next enzyme was added to the tube and similarly the reaction was terminated at the 50 % reaction point. Theoretically, 2ⁿ

kinds of glycans can be yielded in one tube by this method. As the molecular mass of produced glycans is preliminarily known, the desired mass can be measured in an aliquot of the final mixture by mass spectrometer. We named this method Mass-tagged synthesis.^{[34][35]}

Elemental technology 5: Large-scale identification technology of glycoproteins by LC/MS

Based on the newly developed LC/MS analysis method that can simultaneously identify more than 1,000 proteins in a peptide mixture sample at the same time, we established a large scale identification method for elucidation of binding sites of glycoproteins and glycan structures of glycopeptides isolated from protein digestion samples by affinity chromatography. As the peptide moiety of glycopeptides was not fragmented by MS/MS analysis with collision-induced dissociation due to the presence of large glycans, glycopeptides were not suitable for direct identification. Therefore, glycans were released from glycopeptides by glycopeptidases, and the obtained deglycosylated peptides were subjected to the large-scale identification. In this reaction, Asn in the glycosylation site was replaced by Asp, and the mass was increased by 1 Da, which indicated the glycosylation site. During this reaction, as non-glycopeptides receiving de-Asn reaction were also present in the mixture and thus the de-glycosylated peptides could not be distinguished, stable-isotope labeled water (H₂¹⁸O) was

added to the solvent for enzymes to incorporate the labeled oxygen. As a result, the glycosylation site was labeled, and thus the highly accurate glycoprotein identification method was actualized (IGOT method). Based on the integration of LC/MS and IGOT method, Kaji *et al.* of RCMG are actively pursuing the high-throughput mass identification of glycoproteins. The current high speed mass analysis system enables a series of identification processes for 500-1,000 kinds of glycoproteins in 1 mg of a tissue-originated protein sample in about 10 days.^{[36][37]}

Elementary technology 6: MSⁿ-based identification of glycan structures

In the tandem MSⁿ method, mass of the target glycan (mass of MS¹) is measured first. Then the glycan is dissociated by weak collision of a rare gas such as argon or helium (Collision Induced Dissociation: CID), and the mass of each derived fragment is measured (MS²). Each of these fragments is isolated and again fragmented by CID to obtain MS³. Theoretically, MSⁿ can be measured as long as a sufficient amount of the sample is available. In the actual measurements, even a slight difference of a glycan structure can be distinguished by MS⁴ based on the dissociation pattern obtained by CID (Fig.4).

Therefore, we obtained the data up to MS⁴ of as many standard glycans as possible, and compiled them into a

PA = pyridylamino

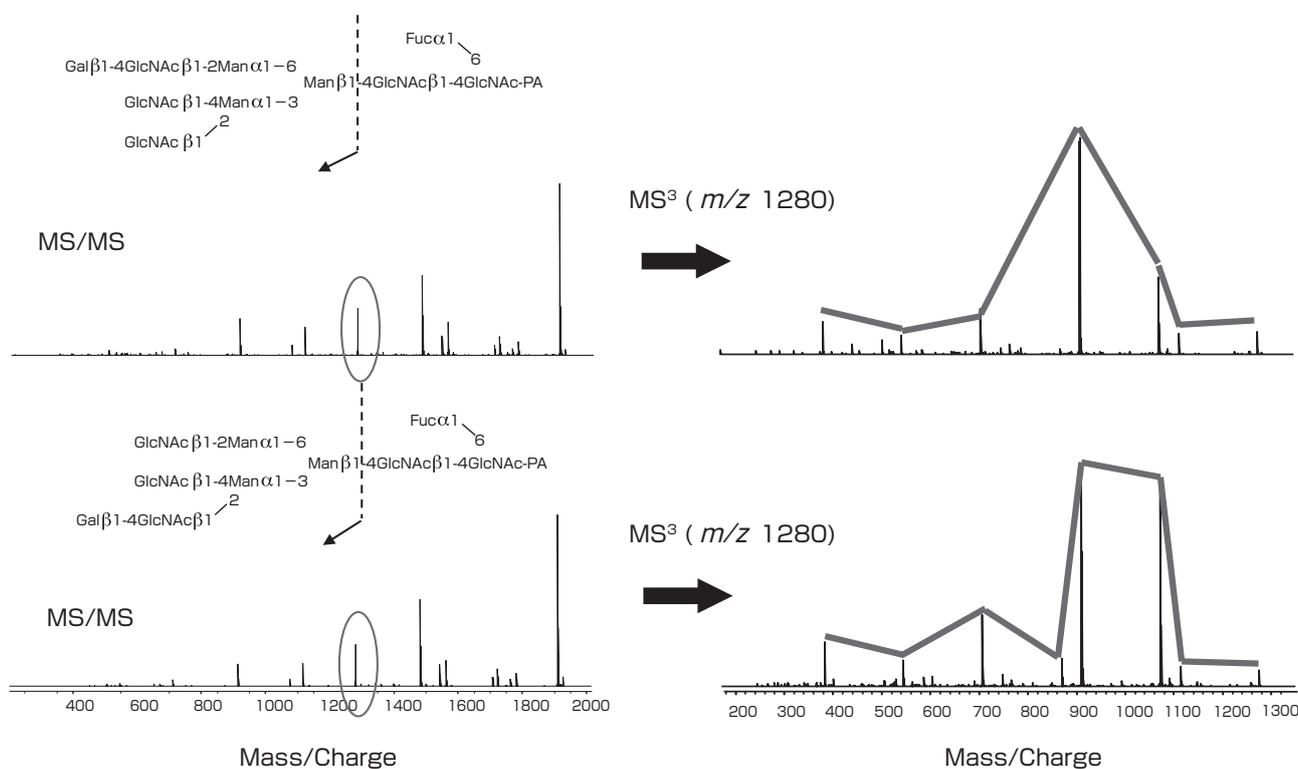


Fig. 4 Application of the tandem MSⁿ-based structure identification on isomeric glycans

database (DB). A researcher to identify an unknown glycan structure should analyze the target glycan up to MS² and refer to the DB. The DB will suggest to the researcher which fragment should be subjected to MS³. The researcher will refer to the DB with the obtained MS³. In most of the cases, the structure would be determined at this point, but sometimes the DB would direct the researcher to MS⁴.

This MSⁿ method for the glycan structure identification system was developed collaboratively by Kameyama, Narimatsu, and other members of AIST, Shimadzu Corporation, and Mitsui Knowledge Industry Co., Ltd., and marketed by Shimadzu Corporation.

Elementary technology 7: Antibody-overlay lectin microarray

To determine the alteration of glycan structures on glycoproteins along with disease development in biological samples, “high throughput, highly sensitive, highly reproducible, and rapid” comparative analytical technology is necessary. The most suitable system is the antibody-overlay lectin microarray developed by Kuno and Hirabayashi *et al.* of RCMG.^[38] The lectin microarray consists of 43 lectins with a variety of specificity solidified on a glass base plate, which can analyze several samples simultaneously by one plate. In the antibody overlay method, the glycoproteins as the objective samples are applied on the lectin micro array without labeling or any other preprocessing, and the reacted glycoproteins binding to the lectins on the plate are detected by the fluorescence labeled antibody recognizing core proteins.

By the excitation light radiated from the glass fragment and its total reflection, about 200- μm thick of evanescent wave is generated around the glass surface. We designated the system so that only the labeled substances within this layer are signaling. This system is highly sensitive and useful even for detection of only a slight amount of glycans (Fig.5). The preceding glycan analysis methods by liquid chromatography or mass chromatography require a considerable amount of preprocessing and time to release glycans from proteins and to label them. In comparison to these methods, this is a progressive method enabling easy detection. Although the sensitivity relies on the quality of antibodies, the amount of the target glycoprotein samples required for western blotting (a few nanograms) is sufficient for this method. Moreover, as the binding signal of the target glycoprotein is detected specifically by the antibody, the only sample preparation required is simple purification by immunoprecipitation or similar methods. In fact, we were successful in comparative analyses of more than 50 glycoproteins in about a 10-ng level of samples efficiently enriched from the serum or tissue samples and cell culture supernatants by the antibody overlay lectin micro array. This technology is applied for verification of candidate glycoproteins for biomarkers and contributed to establishing the development pipeline of useful glyco-biomarkers.^{[31][33][38][39]} The detail of this developmental scheme was published as literature.^[40] The lectin array glycan profiling system was developed by Kuno and Hirabayashi *et al.* of AIST and GP Bioscience, and made publically available by GP Bioscience.

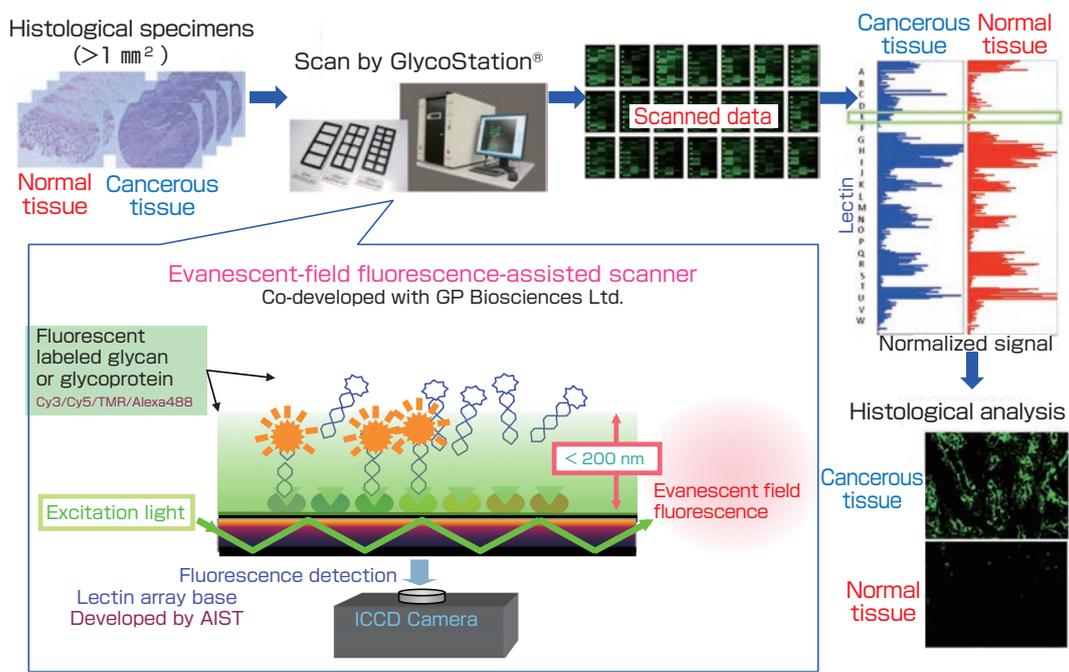


Fig. 5 Application example of lectin microarray
 Selection of useful lectins from enriched glycoproteins in slight pieces of histological samples by comparative analysis

5 Search and practical application of disease biomarkers by accumulated base technologies for glycoscience

5.1 Strategy of the disease glycobiomarker search

The search for disease biomarkers by application of proteomics technology is largely pursued. In proteomics, the concept of biomarkers is based on the quantitative difference of proteins. However, our principle is totally different. In our glycoproteomics approach for development of biomarkers, we are targeting on finding qualitatively changed glycoproteins based on the fact that the glycan structure of the disease-derived glycoproteins is altered from that derived from normal cells. Such glycoproteins can be called post-translationally modified isomers.

The amount of *in vivo* glycobiomarkers (isomers) is considered to be very slight. Especially in the search for the early stage cancer markers, the amount is sparse as earlier the stage is. Therefore, it is impossible to find such a molecule in a serum. We fully utilized the preliminarily developed technologies and established a developmental scheme for cancer markers as shown in Figure 6.

1. The RNA is extracted from both cancerous and normal tissues, and expression patterns of their glycozymes are comprehensively analyzed by the real-time PCR. As a result, the glycan structures receiving modification by canceration are determined.
2. Glycan profiles in the total glycoproteins obtained from cancerous tissue and cultured cancer cells are comparatively analyzed by lectin microarray. Characteristic lectin is selected as the probe.

3. The candidate marker glycoproteins are comprehensively identified with the selected lectin by the LC/MS/IGOT method. The number of candidate glycoprotein is narrowed to about a few hundred at this point.
4. To detect a marker in serum, glycoproteins that are abundantly present in serum even in a normal state are advantageous. We utilized bioinformatics to do the following: (i) Estimation of the serum concentration of candidate glycoproteins, and select candidates with sufficient amounts. (ii) Confirmation of the origin of the candidate is the target tissue. If the candidate has multiple origins, it is avoided due to dilution of the target molecule. (iii) Selection of the molecules with many *N*- or *O*-glycan binding sites, as more binding sites induce higher affinity to the probes. We prioritized the candidate molecules based on these parameters.
5. The candidate molecules are analyzed by western blotting with purchased antibodies according to the priority, and the serum concentrations are estimated.
6. We further narrow down the promising candidates, and immunoprecipitate for rough purification. These concentrated molecules are again analyzed by lectin microarray, and the lectin indicated the most different profiles between cancerous patients and healthy controls (lectin A) is selected.
7. In general, most of commercial antibodies are weak in affinity. In such cases, suitable antibody is also originally developed for the protein moiety of the candidate glycoprotein.
8. With the developed antibody possessing high affinity

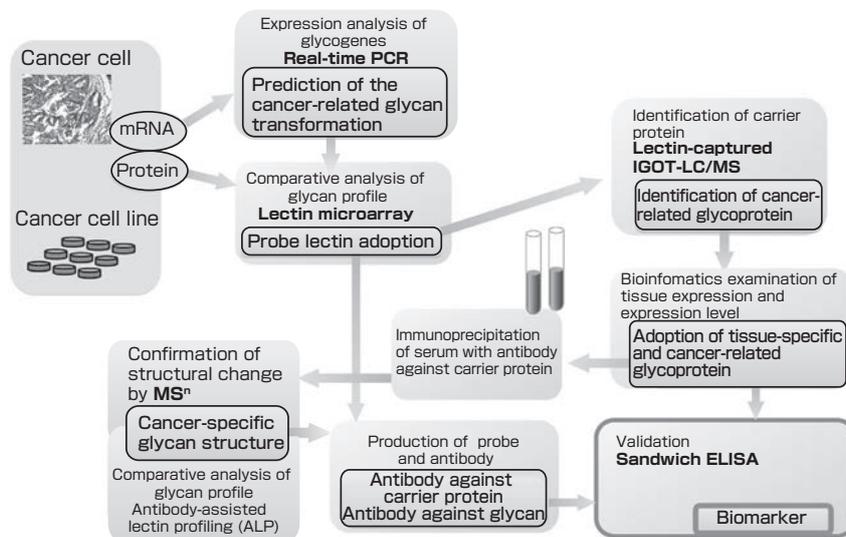


Fig. 6 Strategy for development of disease glycobiomarkers

and specificity and the suitable probe (e.g., lectin A), an antibody-probe sandwich detection kit is established and verified with more than 100 samples.

9. If the advantage over current markers is statistically confirmed, verification of the kit is further conducted with more than 1,000 samples.
10. Furthermore, the modification of glycan structure is determined by MSⁿ. As the available samples obtained from patients are generally limited, it is difficult to identify the glycan structure of the samples by MSⁿ. In such cases, we first confirm that cultured cancerous cells indicate the same lectin reactivity, and then the target glycoproteins are purified in large amounts from supernatant of the cultured cells, and are determined for the glycan structure by MSⁿ.
11. At this point, we ask for cooperation of domestic clinical doctors. With the objective data presented under the cooperation of many doctors, the kit is evaluated comparatively with the current biomarkers, and applied for production and health insurance approval by the collaborative public company for the final production.

We have targeted many diseases. The followings are successful examples in development of the liver fibrosis marker and cholangiocarcinoma marker.

5.2 Development of liver fibrosis marker

We have developed a liver fibrosis marker, which is almost ready to be applied for production approval by the collaborative company.

Infection with hepatitis B virus (HBV) and C virus (HCV) progresses to acute hepatitis, chronic hepatitis, cirrhosis, and finally hepatocarcinoma in 20-30 years after infection. The patients infected with HBV and HCV are estimated to be several hundred million worldwide, 7 % of the Japanese population (about 8 million) and 10 % of the Chinese population (about 150 million). In the course of fibrosis, hepatocytes are disrupted after infection and replaced with fibrin molecules, and the stiffness of the liver increases. Currently the definitive diagnosis is made by needle biopsy; however, this is an invasive and burdening method for patients, requiring 2-3 days of hospitalization. The level of fibrosis (liver stiffness) is classified into F0 (fibrosis 0) to F4. The incidence of hepatocarcinoma increases along with the progression of fibrosis. At F3, the fibrosis level is considerably progressed as a result of chronic hepatitis, and F4 is the state of cirrhosis. Medication with interferon and ribavirin is mostly effective at F3, but cannot be expected at F4. Development of the biomarker for simple blood tests to evaluate the fibrosis level is keenly awaited for the evaluation of therapeutic effect and prediction of the risk of hepatocarcinoma.

According to the above-described developmental scheme, alpha-1 acid glycoprotein (AGP) was selected as the first candidate for the fibrosis marker. AGP is a glycoprotein abundantly present in blood, and mainly secreted from the liver. We premised that AGP would well reflect the status of liver fibrosis, and its lectin avidity would be strong as it has five *N*-glycans. Moreover, it has been long known that the glycan structure of AGP is altered along with liver fibrosis. We could use the serum samples provided from clinical doctors, available with the data of fibrosis levels diagnosed by biopsy. The most suitable lectin for distinguishing F4 and F3 was selected via immunoprecipitation of AGP followed by lectin array. Three lectins, AOL, MAL, and DSA were able to evaluate the fibrosis level quite accurately.^{[41][42]} We established the sandwich detection system consisting of the anti-AGP antibody and three lectins in collaboration with Sysmex Corporation, and optimized the system for an automatic clinical chemistry analyzer, HISCL produced by Sysmex. This system can measure one sample in 17 minutes. However, AGP was not suitable enough for clinical diagnosis, as AGP must be immunoprecipitated from serum before analysis, which requires 2 hours of processing. We further searched for an appropriate glycoprotein for direct measurement of serum by HISCL, and found "molecule X" (the name cannot be disclosed as it is before publication). Glycans on molecule X detected by lectin Y well reflect the status of fibrosis. We prepared a monoclonal antibody against molecule X and established a sandwich assay system with this antibody and lectin Y. This system enabled evaluation of fibrosis within 17 minutes by HISCL without preprocessing of serum. In the future, a patient visiting a clinical doctor would receive the serum test before seeing the doctor, and the doctor would be able to have the fibrosis level of the patient on the same day before consultation.

5.3 Development of cholangiocarcinoma marker

When a hepatic mass is found by an imaging diagnosis method, intrahepatic cholangiocarcinoma derived from bile duct epithelial cells and hepatocarcinoma derived from hepatic cells must be clearly distinguished. Prognosis of intrahepatic cholangiocarcinoma is bad, and its therapeutic strategy is totally different from that of hepatocarcinoma.

In accordance with the developmental strategy of the cancer marker mentioned above, we incised small tissue specimens of 1-mm diameter from the cholangiocarcinoma tissue and the normal region by microdissection. As a result of the lectin array of the fluorescence labeled glycoprotein extract, the WFA lectin signal was remarkably different between the cancer tissue and the normal tissue. We identified many candidate molecules (230 glycoproteins) of the cholangiocarcinoma marker that bind to WFA by the IGOT method. These molecules were prioritized based on the estimated blood concentrations by bioinformatics. The antibodies were purchased for the 10 glycoproteins of

higher priority and the bile and serum concentrations of the candidate molecules in the patients of cholangiocarcinoma were estimated by western blotting and immunoprecipitation. We confirmed that the candidate molecules were actually produced by the cancer cells based on the immunostaining of the cancer tissues obtained from the patients. Currently, two assay systems, anti-MUC1 antibody/WFA and anti-protein Y/WFA, have been established, and the marker concentration of each system in the bile of patients was quantified. The detection rate of cancer cells in the most widely used diagnosis system is low at about 20-30 %, but our system indicates 85-90 % of high diagnostic accuracy.^[43] This methodology is proved to be effective for the assays with patient serum as well as bile.

6 Conclusion

We are applying the same strategy aiming successful development of truly useful clinical diagnosis markers for other cancers, such as lung cancer, ovary cancer, pancreas cancer, prostate cancer.

The most important thing for development of disease markers is the tight relationship with reliable clinical doctors for collaborative research. The research and development should be pursued in careful consideration of the following points: (1) What is the really desired marker? (2) What kind of phenomena or indices should be compared to achieve the goal? Can the collaborative doctors offer the samples for comparison? (3) Are there suitable samples of patients with clear disease history retained at the clinical site? (4) Presence of long-time chronological samples of the same patients is very important if possible. (5) Presence of samples of the same patients before and after treatment is also very important.

There is a bad example of the cancer biomarker search. In the serum of the terminal cancer patients, there are abundant abnormal molecules due to cachexy caused by the state of cancer. Although more than several hundred kinds of abnormal molecules can be identified immediately in comparison of sera from the terminal cancer patients and healthy controls, these are clinically useless. Truly helpful biomarkers for judgment of disease progression cannot be found by the comparison between the terminal cancer patients and healthy controls.

More than 10 years of the scientific activity in the field of glycoscience at AIST is the most substantial scientific experiment for me because of the following: (1) We were able to receive enough grant through NEDO for our research. (2) We were able to invite excellent researchers from outside sources. (3) We were able to have researchers from various scientific backgrounds such as medical science, agriculture, physical science, and engineering. (4) We started the

glycoscience with about 30 members, but now we have about 100 members aiming toward the same goal.

In addition, I would like to enhance the collaboration in the Asian region for glycoscience. When I started the glycogene project 11 years ago, I imagined the great development of science in China 10 years later. Therefore, I hired about 10 Chinese post-doctoral researchers and educated them in glycoscience from the beginning. They accomplished their research in 2 to 3 years and returned to China, and now they are holding professorships and important roles for development of Chinese glycoscience. Last year, we established a branch office of RCMG of AIST within the Shanghai Jiao Tong University to facilitate the collaborative research, and the common scientific themes are pursued through frequent interaction of researchers. I am expecting further cooperation with many organizations through acceptance and education at AIST of post-doctoral researchers and doctoral students from domestic and international universities. I am sure that the 21st century will be the era of Asia. To emphasize the cooperation in Asia in the field of glycoscience, we founded Asian Consortium of Glycoscience and Glycotechnology (ACGG) and hosted the first ACGG symposium in Tsukuba 3 years ago. The second symposium was held in Taipei and the third in Shanghai, and its participants are increasing rapidly.

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Author

Hisashi NARIMATSU

Graduated the Keio University School of Medicine and received M.D. in 1974. Completed the Keio University Graduate School of Medicine and received Ph.D. in 1979. Became an associate professor at the Keio University School of Medicine and a professor at the Institute of Life Science, Soka University in 1991. Joined the Institute of Molecular and Cell Biology, AIST as a principal research scientist in 2001 and became the director of RCMG since 2006. Currently, also serves as a professor of the Graduate School of Comprehensive Human Sciences, Tsukuba University, a visiting professor of the School of Medicine, Keio University, and the advisory professor for the Shanghai Jiao Tong University. Specialties are glycobiology, biochemistry, immunology, microbiology, and tumor biology. Received the Nikkei BP Technological Award in 2007, Chemistry-Bio Tsukuba Award in 2010, Tsukuba Award in 2011. Affiliations: councilor, The Japanese Society of Carbohydrate Research General; council member, Japan Consortium for Glycobiology and Glycotechnology; council member, Human Proteome Organization (HUPO); council member, Japan Human Proteome Organization (JHUPO); councilor, the Japanese Biochemical Society; councilor, Japan Society for Molecular Marker Research; cooperation member, Science Council of Japan; member of Japan Cancer Association.



Discussions with Reviewers

1 Overall evaluation

Comment (Akira Ono, AIST)

The author clearly describes a developmental strategy (scenario) for the research in a new scientific field as a pioneer of glycoscience. The author has appropriately selected necessary elemental technologies and successfully achieved the development. Moreover, the processes followed by the author in which the elemental technologies are integrated and applied to

the establishment of cancer diagnosis systems are remarkably described.

It is noteworthy that the author regarded the development of basic technology tools, which are accessible for use by many scientists and engineers, as the first target aiming for the future enhancement of a new scientific field, glycoscience. Scientists are apt to gather under a fully developed fruitful tree and wish to become an end-user of fashionable sciences, but often avoid seeding or growing young trees of basic science. In contrast, this approach by the author and his team is worth praise as leading a new scientific field for other researchers.

Moreover, I think that the establishment of the three main themes, “synthesis”, “structure”, and “functions and biomarkers” at the initial phase as shown in Figure 2 was the key to the steady growth of the following research activities. I am sure that, to successfully lead the big project under a solid scenario, intensive and concerted efforts by a large group such as a research center of AIST for a long period as 10 years were necessary, as the author describes in “6. Conclusion.”

Comment (Noboru Yumoto, AIST)

The development of the elemental technologies for analysis of glycan structures by a multi-disciplinary approach and the integration of the elemental technologies in accordance with the scenario of developing the disease biomarker is a great example of “Type 2 Basic Research.”

2 Domestic and international application of the basic tools

Question (Akira Ono)

I assume that the basic tools developed in this research are broadly utilized in Japan and overseas to enhance glycoscience. Please introduce some of the examples for current application of these developmental achievements by other research groups of other institutes and companies. Are there any collaborative researches with domestic or international organizations? If so, please let us know as much as possible.

Answer (Hisashi Narimatsu)

Here is a list for some of the applications that I know of for our-developed basic tools used by other organizations

Glycogenes

- We hold the patent for about 30 glycogenes, and granted the licenses of 13 genes to GlycoGeneInc.
- We provide unpatented glycogenes for about 20 domestic and overseas research organizations. Moreover, we deposited these glycogenes to the National Institute of Technology and Evaluation (NITE) for wider distribution.
- Our developed glycogene database, GGDB had 172,570 access/year (2011fy).
- We developed 13 strains of glycogene knock-out mice. Collaborative studies with 5 domestic institutes and 3 overseas institutes are ongoing using them as disease models.
- Collaborative studies of glycan synthesis by glycosyltransferases aiming at applications such as to glycan arrays are ongoing with domestic and overseas institutes.
- A collaborative study for glycoprotein synthesis using inexpensively expressed glycosyltransferases by yeast is ongoing with a private company.
- Many research articles have been published as achievements of collaborative studies.

Lectin microarray

- GP Biosciences Ltd. commercialized the lectin microarray
- More than a few tens of related reports are published from external organizations. I picked three important reports that

have a strong impact. The first report is the utilization of lectin microarray for evaluation of iPS cells by Dr. Yamanaka of Kyoto University:

YC. Wang *et al.*: Specific lectin biomarkers for isolation of human pluripotent stem cells identified through array-based glycomic analysis, *Cell Res.*, 21(11), 155-1563 (2011).

EL. Bird-Lieberman *et al.*: Molecular imaging using fluorescent lectins permits rapid endoscopic identification of dysplasia in Barrett’s esophagus, *Nature Medicine*, 18(2), 315-321 (2012).

SA. Fry *et al.*: Lectin microarray profiling of metastatic breast cancers, *Glycobiology*, 21(8), 1060-1070 (2011).

- The Lectin Frontier Database, LfDB, had 23,605 accesses in 2011.
- We have already applied for seven patents concerning glycan biomarkers based on the lectin array.

Glycan structure analysis based on the mass spectrometry

- The system has been marketed from Shimadzu Corporation/Mitsui Knowledge Industry Co., Ltd. They sold one system each to Qatar, Beijing, Shanghai, and the United States, and three in Japan (one each for National Cancer Center, Gifu University, and Japan Anti-Doping Agency).
- The access counts to the two databases were 18,256 for GMDB and 36,729 for GPDB in 2011.
- We have many accomplishments of collaborative studies in glycan structure analyses. These are some of the representative articles.

T. Fukuda *et al.*: α 1,6-fucosyltransferase-deficient mice exhibit multiple behavioral abnormalities associated with a schizophrenia-like phenotype: importance of the balance between the dopamine and serotonin systems, *J. Biol. Chem.*, 286(21), 18434-18443 (2011).

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Creation of values and synthesis

[Translation from *Synthesiology*, Vol.5, No.3, p.204-210 (2012)]

Professor Masatoshi Ishikawa of the University of Tokyo stated that the creation of new social value is necessary in addition to the analytical pursuit of truth. As the Executive Vice President of the University of Tokyo from April 2004 to March 2006, he worked to develop a system for transferring highly original research results from academia to society. Professor Ishikawa, who practices such transfer that is also the aim of *Synthesiology*, discusses value creation and society with the former Editor-in-Chief Ono and Executive Editor Akamatsu.

Synthesiology Editorial Board



Participants of the round-table Talk

Masatoshi ISHIKAWA Professor, Graduate School of Information Science and Technology, the University of Tokyo

Akira ONO AIST [Editor, *Synthesiology* (former Editor-in-Chief)]

Motoyuki AKAMATSU AIST (Executive Editor, *Synthesiology*)

Akamatsu

Dr. Ishikawa states that in the intellectual production structure of the 21st century, there are the analytical method where “theory = truth” is established by the accumulation of experiments and logical evidences, and the synthetic method where highly original hypothesis is raised and the social value is created by verifying this hypothesis. Dr. Ishikawa also states that these two methods are not in contradiction but comprise a dual structure.

I feel his statement matches the objectives of *Synthesiology*. Dr. Ono, can you give us an introduction to this journal?

Ono

It is fully four years since the launch of *Synthesiology*. The journal is becoming recognized outside of AIST as well as within. Paper contributions from outside have been increasing.

The necessity of “synthetic” and “integrating” method, not only analytical and reductionist method, is well recognized when conducting scientific and technological researches. However, I don’t think there have been systematic investigations on the particulars of how to conduct synthetic and integrated researches.

AIST has emphasized the industry-academia-government collaboration since its days as the former Agency of Industrial Science and Technology. In the eyes of academically minded

researchers, however, such collaboration may have seemed to be mere side jobs. I think Dr. Hiroyuki Yoshikawa thought that was not right. There must be solid soul and logic in the so-called applied research and it is an endeavor worth doing the best for researchers. This can be highlighted so that such researchers contribute more to society at the greatest levels. That was the passion poured into this journal.

In the guidelines for submitting research papers to this journal, we ask the authors: to clearly set a research goal; to rationalize the relationship between the research goal and society or to state the social value of the research; to present a scenario to obtain the goal; to describe selected elemental technologies; to describe the relationships among the elemental technologies and the process by which they were integrated; and to self-evaluate the results and to discuss the future prospects. When tackling a complex issue that characterizes the present day, it is difficult to seek solutions within one technological discipline, and it is inevitable that technologies in diverse disciplines must become incorporated into the research. The motivation of research is realization of social value rather than academic curiosity. The solution obtained as a result of research is not necessarily unique, and there may be multiple equivalent solutions. Although some solutions might be better than others, that is not a matter of right or wrong.

Our next issue is value evaluation of synthetic researches. How do we evaluate whether a certain synthetic research

result is right or wrong? Based on what criterion should synthetic researches be evaluated? From what perspective should the reviewer evaluate it? Although these are difficult issues, we take a certain direction in doing the reviews. The value of conventional academic papers is evaluated by peer reviews. Researchers whose discipline is closest to the author's one are selected as peer reviewers. This is because a close researcher is the only one who can see whether the claim of the author is truly novel and logically sound. However, there is a limit to the peer review system. Peer reviewers often are unable to see society as a whole. They are able to see only the workings of a small community around them. I think this is one of the reasons that separate the academia from society.

We of *Synthesiology* call our review "merit review" because we think the people who receive merit by using research results claimed in the paper should review the paper according to the scale of the merit received. Specialists of the close fields are usually eliminated in our review system. Two reviewers, one from a related field and another from a different field, are selected as merit reviewers. We are quite surprised that such a review system can actually function properly. The names of the reviewers are publicized, and dialogues between the author and reviewers are placed at the end of the paper to help the readers' understanding. This has been very positively accepted by the readers.

Akamatsu

In the *Synthesiology* paper, we have people write a scenario of why the topic was selected and why the methodology was used to solve the selected issue. It is important to tell the whole story which is one fact of research, and the purpose of this journal is to accumulate such facts. I think it may help determine how research should be carried out.

The whole picture may be lost if the subject is segmented and studied in the analytically and reductionist manner. We are aware of what we should do to prevent ourselves from getting stuck in the foxhole.

True originality in value creation



Dr. Masatoshi Ishikawa

Ishikawa

What is lacking in science today is the world of "value creation." The organization theories and research methodologies are processes, and these are not enough. It is necessary to think about the values that can be created beyond them.

In this case, there are two issues: who will evaluate the "value" and how do we evaluate "creation." Aside from subjective evaluation, the researcher as an individual cannot evaluate the value objectively, and he/she is not in the position to do so. It is also, in principle, difficult for the organization to evaluate the value. Therefore, I strongly state, "It is society that evaluates the value."

Considering the above, it is necessary to have the perspective of what is research that generates an outcome of which society will accept its value. It is also necessary to reconsider what is creation in a true sense, not merely as a means of catching up. Because society evaluates the value of research results, research organization must publicize to society the value in the manner that can be evaluated by society. At the same time, the organization must be able to accept the value that society recognizes, and there must be a mechanism to receive the social evaluation within the organization, but that is the difficult part. Many researchers think that if the research results are published at academic societies, they are evaluated as being valuable, but that is not necessarily true.

For example, even Nobel Prizes are sometimes given to synthetic accomplishments. I think the synthetic works include the X-ray CT of Godfrey Hounsfield and Allan Cormack, and IC of Jack Kilby. I think there will be more prizes given to such works. Though there may be objections to my statement, their research did not start from a given topic, but started from "I wish I can do this" fantasy. In addition to their accomplishment of realization, we should focus on their greatness as researchers who said, "This result can be achieved. The value lies there." This is something that must be done by any researcher, whether large or small in scale, and the "social evaluation" lies ahead. If the result is not employed despite the researcher's defense, as long as society does the evaluation and the researcher is not allowed to evaluate, I think it is a "justifiable failure." If it is justifiable to the point of stating something that is logically and technologically correct, and there is a potential for value creation, then the research should be done. Whether it actually has value will be judged by society, and the processes of writing the paper or filing a patent are intermediate steps. If it is transmitted to society and becomes valuable in society, it will receive some kind of acclaim, perhaps even a Nobel Prize. The researcher must understand this mechanism.

Concerning "creation," catching up is not creation. In ordinary academic papers, it will become highly acceptable for publication if one writes in the introduction, "This is what

society deems necessary. The other researchers did these researches but they are flawed. To cover the flaws, I used this new method to solve them, and achieved better performance.” However, it is apparent that this is nothing more than solving a given topic and it is “catching up” from the perspective of new value creation, and there is no originality in such papers. I think a truly original paper, for example, says, “I think this is valuable but society does not recognize it yet. There is no other paper to make a comparison. But I think this can be accomplished, and I’ve already done part of it.” The researcher should write such a paper. In reality, an excellent paper may fall somewhere in between, but the perspective of how to evaluate the ability to pioneer the future demand and market is a major issue that faces future science and technology. The presentation of a result in the form of a paper is, as mentioned before, only midway in the process of being evaluated. Therefore, if there is a justifiable and original statement at that point, it should be given full score of 100 points, but if society does not evaluate it positively after some years have passed, the full score should be retracted to 50 points. However, the activity of the researcher is justified. This is justifiable failure. Of course, if society recognizes the value, it should be given full score or even 200 points.

I think Japan must shift to a process where society properly recognizes “creation.” This is easily said than done. To aim for “innovation” is a mere copy of the American innovation policy, and it is rather paradoxical to place this in the center of “original” science and technology policy. Creation is to go left when others say they’ll go right. Originality stands only a step away from fantasy, and the point is how the organization or society recognizes this. *Synthesiology* says, “There is a theory and it is not just fantasy,” and I think it is an interesting attempt. However, it is not about seeking quick answers, and it is necessary to have an attitude that how a research result will be evaluated by society is unknown. If it is known, it is just a catch-up research.

Evaluating “justifiable failure”

Ono

As time changes, a certain technology may come into spotlight, and we do not know which technology will become the best as society changes. Therefore, I think we should accept all of them although this might be very generous.

Ishikawa

If you accept that there are many justifiable failures and the future path will be determined by society, Dr. Ono’s argument is great. However, if you assume that something that is not accepted in society is nothing but failure, then that argument is not right.

Ono

I see. It is not necessarily true that the research projects

of AIST or the Ministry of Economy, Trade and Industry (METI) were all successful. Because we cannot talk about our failures to others and try to clean them up within our tiny logic, we lose our ability to step up to the next stage. There is the danger that people will shuffle around only in their small worlds.

Akamatsu

I think the idea of “justifiable failure” is good, but I think there is the problem of how to judge whether something is a failure. Positive or constructive things do not come out from analyzing failures, and I think there is a danger that people may offer justifications with small arguments that “ultimately the product could not be made because this and that went wrong.” How can we overcome this?

Ishikawa

“Justifiable failure” here applies only to research that is original in its claim and has undergone a proper research process. The failure in the research process is nothing else but lack of ability. People with ability can always produce some kind of outcome if they engage in research. Until now, all research that produced outcomes was successful, but that is no longer true. When the outcome is presented to society and if there is a mismatch with the social evaluation that is yet to come, it is a “justifiable failure.” Here, originality must be maintained, and justifiable failure has the potential of generating value with accumulation. After some years, it may be revived. Therefore, we must spend effort to make sure that the accumulated results may someday become valuable in the ever-changing society. On mismatch with society, coincidence or trend of the time may be influential, and the mismatch in this situation must be tolerated because it is a world where originality and fantasy are separated by a thin line.

How to link research to society

Akamatsu

What do you think about the extent to which the researcher should be involved in the process where a research result which is successful is accepted into society? I feel that there are many researchers who take the stance, “I did good research and produced good results, and the rest should be done by others.”

Ishikawa

I work on high-speed image processing, and I create systems that can be understood by society, not just the device and theory. In addition to nurturing the elemental technology, for example, I make a batting robot using this high-speed image processing. The majority of the researchers think that once a paper is written, someone will pick it up, and once the patent application is filed, someone will understand it and buy it. As long as the researchers think so, no new field will emerge.

The reason is simple. It is because the person who has the most knowledge of the result is the person who produced that result. There is no other person who understands the results better and who is capable of linking the results to social value than the researcher. Since there is no infrastructure that allows the research results to be linked to social value, to simply present the research result and say, “The rest is up to you,” is like throwing your own efforts in a trash can. At the present state, the choices are to wait until the infrastructure is built or to do it yourself, and in the absence of the infrastructure, the researcher must do things on his own to some extent.

In fact, the researchers should raise their voices against the lack of infrastructure. Some things need not be done by a researcher, and if the infrastructure becomes available, the researcher may offer ideas only. However, such infrastructure is very difficult with the current lack of understanding by organizations, and even at the University of Tokyo, it took five years to organize the supporting organization for intellectual property, collaborative research, and start up ventures. There are still lots left to be done, and time is also required to shift consciousness. In the current situation, the researchers must do a lot. I think this is a sad thing about Japan for the development of science and technology.

Ono

It’s the valley of death indeed.

For the researcher to write the scenario

Akamatsu

You need a refined sense or intuition in the process by which the researcher presents the results to the world. Although it is not known whether it will be a good seller, one needs a degree of refined intuition to specifically show society that something is valuable. I think the researcher must cultivate this refined intuition in the future. If one becomes dependent on other people, I feel there is less opportunity to cultivate this refined intuition.

Ishikawa

There are variations. For this kind of “sense” or refined



Dr. Akira Ono

intuition, I think the word “art” fits well. Referring to Donald Knuth’s “The Art of Computer Programming,” art, originality, and intuition (or sense) are needed in science and technology. Since my field is sensing, I use this word and say “The Art of Sensing.” I want to say I dig deep, I do synthetic research, and I draw the whole picture. Perhaps this is a bit exaggerated.

Akamatsu

I’d like to say that *Synthesiology* is the art of research. Drawing from what you said, I hope people with refined artistic sense will present their research, and people without it would experience it through some sort of education. I hope the percentage of such refined people will increase.

Ono

Talking very optimistically, I want to think that people who produced socially valuable research results had some sort of scenario. I don’t think social value can be generated without a scenario. I feel that there are many researchers who realize that they had a scenario on retrospect but were never aware of it during the research processes. We’ve been surprised to find there were many cases where the authors became aware of scenarios when writing up the *Synthesiology* papers. If that is the case, it would be much better that those researchers create their scenarios from the beginning of the project and engage in the research as they mature the scenario.

Ishikawa

In this age, it is reckless to do research without a scenario. To have an original “scenario” that leads to social value is an absolute requirement, but there are many ways of writing this scenario, and the variations should be allowed. For example, one method is to do a thought experiment, where one assumes that a venture is built based on a research result, or a technological transfer is done to some company, and then write a scenario on how one’s technology will be returned to society and how it will be evaluated. I think the things that are lacking or points that the researchers are unaware of will become visible.

Akamatsu

By trying to write the scenario, the scenario that existed in the mind becomes clear. By repeating this exercise, one becomes capable of writing a scenario for the future. I think one can develop such skills.

Ono

Making scenarios is the first step, and then there must be the process of showing it to someone else, being criticized, revising it, and prioritizing it. Currently, however, it seems to me that the quality of scenario writing is poor at the beginning.

Ishikawa

I think AIST carries the mission. Since the companies aim to maximize profit, they do not present the scenario. There are probably few people at the universities who have got a scenario. I want AIST to actively make presentations to society in the form of scenarios, as well as to do R&Ds.

Ono

Yes. I think that is the industry-academia-government collaboration.

Ishikawa

AIST should present several major scenarios. There should be a variety of patterns of scenarios such as ones that include the research results, market, or technological prediction. There should also be scenarios that will be rejected, or ones agreed by 80 % but rejected by 20 % of the people. Such scenarios are much more original than the ones that receive unanimous approval.

Evaluation of human resource for value creation

Akamatsu

Now we shift to evaluation. It is, of course, difficult to do evaluation where one has to accept failure. Don't you think evaluation itself is impossible in some cases?

Ishikawa

This is a matter of "do or don't." It is necessary for both the evaluator and the evaluated to accept that randomness functions in adopting a socially accepted value. At times, the evaluation may not be technologically correct, but the evaluation is about whether it generates value. Going a bit further, there are many technologies that generated new markets and values in the world today because "they had well-crafted scenarios." In this way of thinking, evaluation is a matter of do or not do rather than possible and impossible.

Ono

You mean, to evaluate is to take risks?

Ishikawa

Yes. As an assumption, it is necessary to lower the evaluation



Dr. Motoyuki Akamatsu

of the person with "unjustifiable failure." The person with justifiable failure should be evaluated as zero or something extra, and the person with success should be rewarded, for example, by increasing his salary. Since the Japanese culture tends to emphasize equality and merit of accumulation, this may raise opposition. However, if there is a common understanding or that if everyone understands that some degree of randomness exists, there will be an acceptance that "someone wins the lottery." By raising the evaluation of the person who generated value, the whole may start moving in that direction.

Akamatsu

In an evaluation, the evaluators tend to get into negative evaluation. I think it is a major issue of how to cultivate the habit of rewarding.

Ishikawa

Things should shift to a point-addition system. This is the attitude of saying, "Hey, this is great." The rest should follow. The point-addition system can be in the form of salary or awards.

Ono

Awards have the effect of clearly indicating what society and organizations demand now. I believe that the awards exist not only for the persons who receive them, but also for the persons who do not receive them.

Akamatsu

Since evaluation is a culture, it is necessary to build the culture. To do so, one must continue raising one's voice.

Ishikawa

If the culture is set, it will be easier to evaluate. It's a matter of solving the problem of chicken or the egg.

Akamatsu

It also affects the organizational management.

Ishikawa

In terms of research organizations, I think there are pull type and push type organizations. The push type is a management style that starts from the groundwork such as organizational design and consciousness building, the momentum for the entire organization is then generated, and the researchers are told, "Let's all go there," from behind. The pull type is a management style where outstanding activities are accepted and people are told, "Follow me." Both have their good and bad points. Since with the push type, the groundwork is done and then the research takes off, the force is great but the movement is slow because everyone moves in unison. In contrast, the pull type is fast, but only few sharp ones do well, and the movement does not involve the whole. In reality, both types are necessary in the management of

the research organization depending on time and content. Therefore, push-pull management is necessary. In nurturing the culture and developing the policy-driven evaluation, the organizational management style that alternates between push and pull is necessary.

Companies, universities, and AIST must team up for human resource training

Ono

The human resource training is one of the missions of AIST. However, I hear that few students continue on to the doctorate course.

Ishikawa

It may be helpful if the universities and AIST form a team and set a certain career path. We'll be scolded if we say there is a highway directly from the University of Tokyo to AIST, but perhaps a country road will be okay.

The reason the excellent master's course students of the University of Tokyo do not go on to the doctorate course is because there are many places that provide high salaries and good jobs to people with masters only, like foreign companies, for example. The activities of the foreign countries are extremely aggressive and they are quick to evaluate. When our research result appears in the newspaper, the first to contact us are the foreign companies. Before, the calls came from Koreans, but the other day, a Japanese who transferred from a Japanese company showed up. I think the outflow of excellent, experienced engineers and researchers who have supported Japan, as well as young people, is a serious problem. We must see that here also lies a problem of evaluation. Even the large Japanese companies started as ventures. I think we are at a stage where we should not regard Apple, Google, and Facebook as the rich on the other shore. I hope there will be more people who will think hard about how to create values that can face up to such companies.

Government's organization design for value creation

Akamatsu

Is the national policy changing?

Ishikawa

The Project for Creating Start-ups from Advanced Research and Technology (START) started from FY2012 by the Ministry of Education, Culture, Sports, Science and Technology (MEXT). This is a project where the government offers a place to bring in risk money and allow active challenges, so the research results of the universities can be linked to social values. As a policy, success is the goal, but as it can be seen from bringing in risk money, the risk of "justifiable failure" will be absorbed within the mechanism. The MEXT personnel says, "This is a challenge for MEXT."

It is very fresh to hear the MEXT personnel use these words, and I think it is innovative.

Considering the interface with industry, I think we are taking in too much demand of industry. The demand of industry is the demand of now. As soon as the demands of industry are gathered and declaration is made that the important policy for Japan is to incorporate such demands, Japan will be trying to catch up, and we will dive right into researches that merely improve the current situation. Of course, improvements are necessary, but for policies to create the future, the government must take risks. How the government can manage the risks is in question. Here, you can replace the word "government" with METI or AIST. I think building the structure that allows the government to take risks is a matter of ideas. It is a matter of design as stated by Dr. Yoshikawa. Unless this structure is included, the research organization in the future will be working only on improvement research.

Ono

Certainly, a new technology may be the technology that may crush the current companies. The difference is whether such a technology emerges from one's own company or somebody else's. Ideally, the technology must come out of your own company, but because self-destruction is scary, one falls into the way of thinking that there is no demand. When the company loses its vitality, it starts accepting the current situation, and the power to change weakens.

Changing the subject a little I work in the field of standardization. There I am often asked "to develop international standards that back up the current Japanese technology." That is not quite right. We should develop standards needed by the world in the future, and Japanese industries must quickly adapt to that. However, there are still many people with attitudes that accept the status quo, and I think this is a problem to be addressed.

Ishikawa

For standard, I think you need the courage "to change." Occasionally, the organization must also have the courage "not to change." Various forms of courage are necessary to change a culture. In the atmosphere of no change, one needs the courage to change, and in the atmosphere of change, one needs the courage not to change. I think the point is to appropriately select and develop what are necessary and unnecessary for the creative culture, by capturing the social demand.

Akamatsu

I wish our journal will contribute to building this culture. By combining the system building, I hope we can build something for Japan as a whole.

Ishikawa

This kind of activity should be done actively in the spirit of challenge, and I am for it. I am also for the synthetic approach that considers the total system, and I think we need the schemes for the direction of organizations and the ideas about how to realize the policies. From my experience in designing the organizations and systems at the University of Tokyo and MEXT, I think AIST has an important role to create new social values, and it is expected to take on new challenges to generate such values. I pray for your future successes.

Akamatsu

Since there are differences in organizational format between the universities and research institutes, I hope we can work as a team by practicing the ways suitable for each of us. Thank you very much.

This roundtable talk was held at AIST in Tsukuba, Ibaraki on February 24, 2012.

Profile

Masatoshi ISHIKAWA

Graduated from the Department of Mathematical Engineering and Information Physics, School of Engineering, the University of Tokyo in 1977. Completed the courses at the Department of Mathematical Engineering and Information Physics, Graduate School of Engineering, the University of Tokyo in 1979. Joined the Industrial Products Research Institute, Agency of Industrial Science and Technology, Ministry of International Trade and Industry in 1979. Assistant Professor, Department of Mathematical Engineering and Information Physics, School of Engineering, the University of Tokyo in 1989, and Professor in 1999. Appointed as Special Adviser to the President, the University of Tokyo in FY2002 and FY2003; Vice President in 2004; Executive Vice President in 2005. Worked on the design and management of the organization of the industry-academia collaboration for the University of Tokyo. Doctor of Engineering. Received the Medal with Purple Ribbon in 2011. Currently, Professor, Department of Creative Informatics, Graduate School of Information Science and Technology, the University of Tokyo; and Research Advisor, AIST.

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*

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.

3.3.2 The text should be in formal style. 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:

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 Tsukuba Central 2 , 1-1-1 Umezono, Tsukuba 305-8568
 E-mail: synthesiology@m.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:

Synthesiology Editorial Board
 c/o Website and Publication Office, Public Relations
 Department, National Institute of Advanced Industrial
 Science and Technology(AIST)
 Tel: +81-29-862-6217 Fax: +81-29-862-6212
 E-mail: synthesiology-ml@aist.go.jp

Letter from the editor

We deliver *Synthesiology* Volume 5, Issue 3. In this issue, in addition to the five research papers, there is a roundtable talk with Prof. Masatoshi Ishikawa of the Graduate School of Information Science and Technology, the University of Tokyo and the editors of *Synthesiology*, including former Editor-in-Chief Akira Ono and Executive Editor Motoyuki Akamatsu. The topic of the roundtable talk is “Creation of values and synthesis.” As stated in the declaration of the International Council for Science (Budapest) in 1999, one of the key phrases that characterizes science and technology of the 21st century is “science in society, science for society.” The point of view of Prof. Ishikawa, who asserts the necessity of “creation of new social value,” becomes clear through the exchanges with the *Synthesiology* editors. The new concept “justifiable failure” was explained in the roundtable talk, and this is an attractive concept that encourages the researchers who must accept the social scrutiny of their research outcomes after intrepidly engaging in research at a higher level from the perspective of value creation. As a reader, I read the article with great enthusiasm, as the approach method, where the research is developed under a scenario in which the value creation is thoroughly contemplated and established, is highly compatible with the research papers of this journal that aims for scenario building from a synthetic standpoint.

I succeeded the position of Dr. Ono, the former Editor-in-Chief, from April, and became the second editor-in-chief of *Synthesiology*. I had no previous experience in editing *Synthesiology*, and this is a start from zero, but I am able to face the research papers of each issue with a fresh attitude. The five papers published herein can be categorized by the subjects of research. They include the information technology field pertaining to database search, the materials science and metrology fields that aim for the discovery and utilization of new functions, the service engineering field for open field research, and the life science field that investigates sugar chains. Diverse fields are covered. The greatest characteristic of *Synthesiology* is the review of the papers of such wide-ranging fields from the perspective of “merit review rather than peer review” (as described by former Editor-in-Chief Ono in the roundtable talk) and to publish them as papers that stand on a common ground. I would like to continue in this footstep, and accept submissions from wider ranging groups and transmit this information. I am grateful to the great efforts of Dr. Ono to *Synthesiology*.

Editor-in-Chief
Shingo ICHIMURA

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c/o Website and Publication Office, Public Relations Department, AIST

Tsukuba Central 2, Umezono 1-1-1, Tsukuba 305-8568, Japan

Tel: +81-29-862-6217 Fax: +81-29-862-6212

E-mail: synthesiology-ml@aist.go.jp

URL: http://www.aist.go.jp/aist_e/research_results/publications/synthesiology_e

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Messages from the editorial board

Research papers

Developing an evaluation system of visually induced motion sickness for safe usage of moving images

-Fermentation of a social understanding to supply secure and comfortable images through integration of researches on human characteristics, image analysis technique and image production technique-

H.UJIKE

Spinning process using robot technology

-Field-based bricolage of manufacturing technology-

H.ARAI

International cooperation for the utilization of earth observational data in an integrated manner

-Development of de jure standardization of the common infrastructure for the global earth observation system of systems-

K.IWAO

Development of a pressure sensor using a piezoelectric material thin film

-Application to a combustion pressure sensor for mass-produced cars-

M.AKIYAMA, T.TABARU and K.KISHI

Novel functional gels and their commercial distribution as chemical reagents

-New development of functional soft-materials-

M.YOSHIDA

Evaluating the effects of actions taken to attract visitors to sightseeing areas

-An Open Service Field behavior survey technology-

Y.YAMAMOTO

Development of basic tools for glycoscience and their application to cancer diagnosis

-A 10-year strategy of the Research Center for Medical Glycoscience of AIST-

H.NARIMATSU

Round-table talks

Creation of values and synthesis

Editorial policy

Instructions for authors

"Synthesiology-English edition" is a translated version of "Synthesiology," which is published quarterly, ISSN 1882-6229, by AIST. Papers or articles published in "Synthesiology-English edition" appear approximately four months after the publication of the original "Synthesiology."