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Synthesiology

English edition

Demonstration test of energy conservation of central air conditioning system at the Sapporo City Office Building

Designing products and services based on understanding human cognitive behavior

A novel technology for production of drinking water in emergencies

Integrated development of automotive navigation and route guidance system

Innovative electron microscope for light-element atom visualization

2011

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MESSAGES FROM THE EDITORIAL BOARD

There has been a wide gap between science and society. The last three hundred years of the history of modern science indicates to us that many research results disappeared or took a long time to become useful to society. Due to the difficulties of bridging this gap, it 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 be active.

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 Researc*h

This is an analytical research type where unknown phenomena are analyzed, by observation, experimentation, and theoretical calculation, to establish universal principles and theories.

Note 5 : *Product Realization Research*

This is a research where the results and knowledge from *Type 1 Basic Research* and *Type 2 Basic Research* are applied to embody use of a new technology in the society.

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Contents

Demonstration test of energy conservation of central air conditioning system at the Sapporo City Office Building

— Reduction of pump power by flow drag reduction using surfactant —

Hiromi TAKEUCHI

[Translation from *Synthesiology*, Vol.4, No.3, p.132-139 (2011)]

In recent years, the amount of carbon dioxide emission in the civilian sector has been increasing. In this experiment, the so-called Toms effect, i.e. the effect of flow drag reduction when surfactant is injected to circulating water, has been verified to reduce the transfer power of circulating water for air conditioning systems of buildings. Concerning this effect, much basic research and a few applications to buildings have been reported. There is no clear report, however, on how to add the surfactant to the circulating water in buildings constructed with complicated pipework, how the flow and heat transfer performance change after the injection of the surfactant, and how to maintain the effect for a long time. Consequently, the technology using this effect has not yet been put to practical use. This paper presents the findings of the demonstration test using the air conditioning system at the Sapporo City Office Building. Generalization of the results will hopefully lead to the spread of this technology.

Keywords : Surfactant, drag reduction, central heating/cooling system, energy conservation, demonstration test

1 Research objective

The amount of energy consumption is gradually increasing in the civilian sector. That is, while the energy conservation efforts are conducted in the individual devices through the introduction of the top-runner method in the private sector, the energy consumption continues to increase due to the pursuit of convenience and comfort in daily living, as well as the increased number of households. Particularly, in the business sector, energy consumption is on the rise due to the increased use of office appliances. Table 1 is the result of a statistical survey of the energy consumption structure in a business building[1]. According to this survey, the consumption is highest for lighting and power outlet at 42.4 %, followed by heating at 31.2 %. For the former, energy conservation measures are taken for the office appliances and by using LED lighting. For the latter, improvements are in progress as the inefficient refrigerators and boilers installed over 20 years ago are replaced by equipment with high coefficient of performance (COP) through the Energy Service Company (ESCO) program. While energy conservation through such replacement of hardware is effective, large initial investment is necessary. In this research, we focused on the heat transport essential in air conditioning of buildings, particularly on reducing the power needed for cold/heated water transport using circulating water.

In table 1, the percentage of power dominated by primary and secondary pumps for cold/heated water is estimated to be 2.6 % or more, and the absolute value of energy consumption is small. However, by introducing the flow drag reduction technology using surfactants, it is possible to reduce the power consumption without altering the current heat transport system. This technology is based on the phenomenon which Toms indicated in 1949 that the flow drag could be reduced by tens of percent in the presence of surfactants[2], and the basic researches and installations to air conditioning systems of buildings have been done in Japan. However, there is hardly any publication of the data. The method of injecting the surfactant, the phenomena that occur, the daily maintenance, as well as how much energy savings was achieved and the lifespan of the surfactant have not been disclosed, and this method is not widely used.

The objective of this research is to measure the energy conservation effect of the flow drag reduction technology,

Table 1. Energy consumption structure in a business building[1]

Category of energy use			Main energy consuming device
Item	Sub-item	Percentage (%)	
Heat source	Heat source itself	26.0	Refrigerator, water cooler/heater, boiler, etc.
	Supplementary motor	5.2	Cooling water pump, cooling tower, cold/heated water primary pump, etc.
Heat transport	Water transport	2.6	Cold/heated water secondary pump
	Air transport	9.4	Air conditioner, fan coil unit, etc.
Hot water supply	Heat source itself	0.8	Boiler, circulation pump, electric water heater, etc.
Lighting, power outlet	Lighting	21.3	Lighting equipment
	Power outlet	21.1	Office appliance, etc.
Motor	Ventilation	5.0	Garage fan, etc.
	Water supply and drainage	0.8	Pumping-up pump, etc.
	Elevator	2.8	Elevator, escalator, etc.
Others	Others	5.1	Transformer loss, store motor, etc.

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and to consider how much it can contribute to the energy conservation in air conditioning systems of buildings. Therefore, we collaborated with the City of Sapporo and applied this technology to the cooling/heating water circulation system of the office building, conducted a demonstration test for energy savings, and attempted to diffuse this technology further by publishing the results.

In this paper, we look at the technology that was introduced in only a limited number of facilities because the research stopped at the basic phase or because the data was not disclosed even though the effectiveness was demonstrated. We gathered specialists of the component fields of the technology, and these specialists assumed their respective roles according to the technology integration scenario. The demonstration test was conducted in the Sapporo City Office Building that was in full operation. The results will be discussed here.

2 Scenario

First, the Toms effect will be briefly explained. In 1949, Toms showed that it was possible to reduce the pressure loss of the turbulent flow in a pipe by adding a small amount, about 5 to 10 ppm, of long-chained polymer to the water flowing inside the pipe[2]. The effect is temporary since the polymer structure is destroyed by the shear force of the flow and the structure is not reconstructed. On the other hand, when a surfactant is used instead of the polymer, the micellar structure formed is repeatedly reconstructed and the effect is sustained. As shown in Fig. 1, with the increased concentration of the surfactant, the monomers aggregate to form a spherical and then rod-like micelle. When these rod-shaped micelles form a three-dimensional micelle network structure, the turbulence of the flow is inhibited and the flow drag is reduced. Fig. 2 shows the velocity vector distribution of the channel flow[3]. Fig. 2a shows the case of water only, and Fig. 2b shows the case when the surfactant is added. By adding the surfactant, the irregular eddies in the flow disappear, and regular flow is achieved. This structure is broken in areas such as pumps, valves, elbows, or any parts where the flow path is greatly disturbed, but is reconstructed in relatively straight sections of the pipe, and contributes to the reduction of flow drag. When cooling and heating large buildings by circulating cold or hot water, large amount of electric power must be used to operate the water circulation pump. To drastically reduce this energy, it is effective to apply the Toms effect where the flow drag is decreased by injecting the surfactant in the circulating water. The principle of energy conservation using this method is as follows: the circulating water that surpasses the rated flow can flow through when the flow drag is reduced by adding the surfactant; the revolution of the circulation pump is lowered using the inverter to regain the rated flow; and the power consumption of the pump decreases, thus achieving energy conservations.

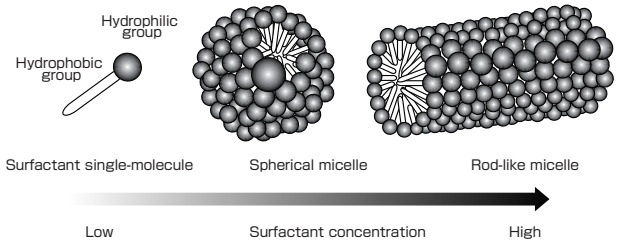

Fig.1 Changes in micelle formation due to concentration change

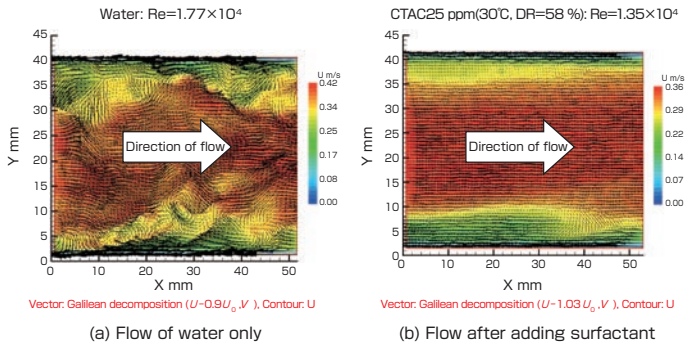

Fig. 2 Changes in flow due to micelle network

As shown in Fig. 3, one of the elemental technologies is to design and create an agent to see which type of surfactant matches this purpose. Another element is to clarify what kind of fluid dynamics and heat transfer occur in the water with added agent in the circulation channel and make explicit the energy conservation effect. Also, it is necessary to study the long-term stability of the added surfactant, the duration of the energy saving effect, and the maintenance procedure to operate and sustain this energy conservation technology.

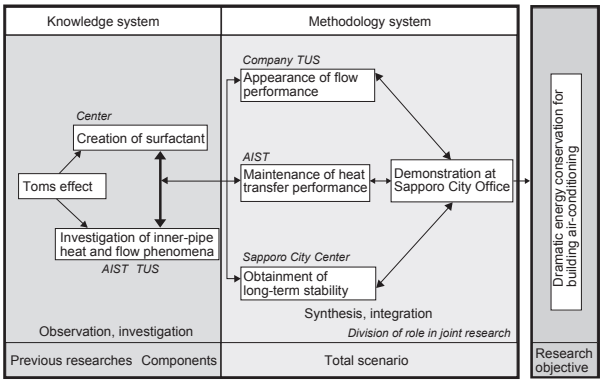

Fig. 3 Scenario for energy savings using surfactant in air conditioning of buildings

In Japan, several basic researches have been conducted for the flow drag reduction technology, various agents were developed, and their fluid dynamic properties were studied. There were over 120 cases of use of agents in building circulation water. However, since they were conducted by private companies, the technical information is undisclosed, the accumulation of technology pertaining to flow, heat transfer, and long-term stability as well as energy conservation effects are lacking, and this technology has not spread widely. In this research, specialists took the role to integrate the elemental technologies for studying the occurrence of flow performance by agent addition, evaluation of the energy conservation effect, maintenance of heat transfer property, and long-term stability of the agent. Then, a demonstration test was conducted at a public facility to generalize the results, and attempts were made to enhance energy conservations in air conditioning of buildings.

3 Development of the elemental technologies

The development of the flow drag reducing agent was conducted by the Yamaguchi University, the Shunan Regional Industry Promotion Center, and four companies in 1992, as part of an industry-academia-government collaboration, and a product was realized in 1995. The main components were: oleyl bis-hydroxyethyl methyl ammonium chloride, a surfactant; sodium salicylate, a counterion agent that promotes the formation of three-dimensional micelle network; rust inhibitor; and others[4] (hereinafter, this will be called the agent). In the Eco Energy Urban Project of the Ministry of Economy, Trade and Industry, the research mainly on the development of surfactant was conducted as an industry-academia-government collaboration for three years starting in 1997, and two research institutes under the Agency of Advanced Industrial Science and Technology also participated. For one year and a half from 1998, the project for the use of the agent in regional cooling/heating system was conducted as a NEDO project. Through these activities, detailed experiments were conducted at research institutes, and trials were done in actual buildings mainly by private companies.

The installation of the agent commercialized by the Yamaguchi Prefecture to the air conditioning of buildings had been done to some extent, but it was far from becoming wide spread. In 2002, the research group for the realization of “smooth water” was established. Specialists of industry-academia-government of this technology convened to discuss how to grow this technology into a practical product, and the need for demonstration tests was indicated[5].

The factors that affect the flow performance include the diameter of the pipes, length of the straight sections of the pipes, flow rate, water temperature, agent concentration, water quality and so on. In general, the pipes on site are very complicated, and it is not rare that the pipe arrangements are quite different from the initial plumbing diagram due to several repairs and renovations that have been done. Also, older sites tend to be without flow meters or thermometers, and this is a major inhibition in energy conservation management, let alone conducting tests. In many cases, it is difficult to utilize on site the flow performance data that was obtained at research institutes. For the maintenance of heat transfer performance, while it is reported that the agent reduces the heat transfer as well as flow drag in laboratory scale tests[6], such phenomenon has not been reported in the actual installation, and this difference must be solved. In addition, there is no disclosed data on the long-term stability or lifespan of the agent, and this is one of the priority issues for the on-site concentration management.

4 Air conditioning system of the Sapporo City Office Building

Based on this scenario, it was necessary to conduct a demonstration of the integrated elemental technologies by actually injecting the agent to the water circulation system to see how much reduction of flow drag will be obtained, whether there will be any reduction in heat transfer performance, and whether long-term stable effect can be sustained. Since the data publication after the test was necessary, we decided to conduct the demonstration test in the cooling/heating water circulation system of the Sapporo City Office Building, a public facility, rather than a private one. This was possible as AIST and the City of Sapporo had signed a basic agreement and memorandum for the efficient use of energy. It was stated therein that: the City of Sapporo would provide test sites free of charge to AIST; AIST could install test equipment in such sites to conduct experiments; and the results obtained would be shared. Figure 4 shows the exterior photograph of the office building. The building was

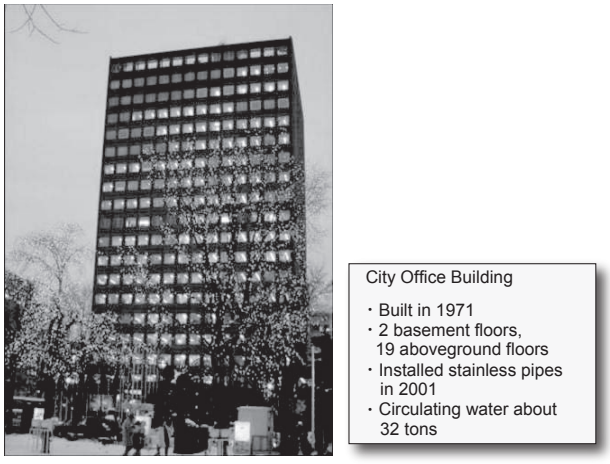

Fig. 4 Exterior of the Sapporo City Office Building

completed in 1971. It has two-tier basement, 19 aboveground floors, and a total floor area of 42,000 m^2. It is designated as a "type 2 designated energy management factory"[Note] .Figure 5 shows the cooling/heating water circulation system of the building. The circulating water is ejected from the 37 kW circulating pumps installed in the machine room on the 2nd basement for summer and winter. The water is sent to the expansion tank on the 19th floor via four 5.5 kW and one 3.7 kW or a total of five booster pumps located in the air conditioning equipment room on the 8th floor, and it is returned to the 2nd basement. The water circulated is 32 tons.

Individual air conditioning is not installed in each room. Since the test involved using the system common to the office building that would be used for daily work, it was impossible to operate or shutdown the system for the purpose of this test. Due to this situation, unlike the test in the lab, it was difficult to freely change the parameters, and the experiment had to stop immediately in times of emergency and the original condition restored. Therefore, five parties became in charge of their respective roles: Shunan Regional Industry Promotion Center, which had been involved in the development of the agent and therefore had full knowledge of the agent property, had experience in various cases as it was involved in the injection at several facilities; AIST and Tokyo University of Science (TUS) which had the abilities to conduct basic research as well as to project or clarify the transitional changes of flow and heat transfer phenomena of the circulating water after agent injection; Fujiwara Environmental Sciences Institute Ltd. which had expertise in measurements of flow rate, temperature and electric energy in a cooling/heating system composed of complex pipes; and Sapporo City Office which had mechanical and electrical engineers who were knowledgeable of the entire system and would engage in maintenance and management after the injection.

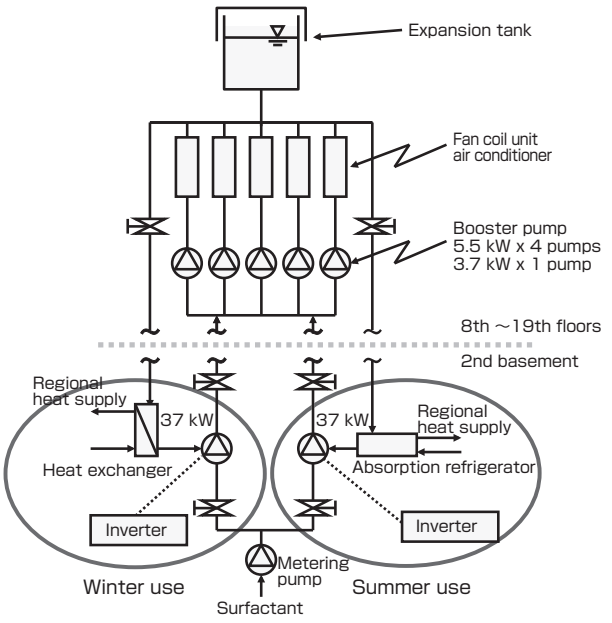

Fig. 5 Diagram of the cooling/heating system water circulation of the Sapporo City Office

5 Preparation of the demonstration test

5.1 Basic understanding of the flow property

The agent showed flow drag reduction effect at 5~65 °C, so it could be used continuously throughout the summer period when cold water was circulated and in the winter period when heated water was used. However, there was a temperature dependency of the flow drag reduction effect, and it was necessary to study the values from 7 °C to 45 °C that was the actual usage range. It was also useful to understand the effect of the rust inhibitor used concurrently on the reduction effect. These were measured using the water circulation experiment apparatus of the Tokyo University of Science. The test section had channel length of 1 m and internal diameter of 10.7 mm. The agent concentration was varied between 3000~6000 ppm, to measure the flow rate dependency of the flow drag reduction effect[7].

In using the surfactant on site, there were cases when it could not be used due to bubbling. For example, the expansion tank might be open to the atmosphere and air might be regularly introduced in some areas. For the identification of complexities in the channel, the staff of the control room of the City Office in charge of the daily system maintenance did a preliminary check of the problem areas.

The power consumption of the pump and the flow rate in each pump channel were measured before the agent injection. Portable transit time ultrasound flow meter was used for flow rate measurement, and the feeder power recorder was used to measure the power.

5.2 Inverter installation

As the flow drag decreased by agent injection, the amount of circulating water would surpass the rated flow. By decreasing the revolution of the circulation pump using the inverter, this would be brought back to the rated flow. As a result, the power consumption of the pump would decrease, and energy savings would become possible. Therefore, the installation of an inverter was necessary for this technology. From the results of the preliminary flow property tests and flow rate measurement, it could be determined that sufficient circulation would be obtained after the agent injection even when the operation of the five booster pumps on the 8th floor is stopped. The inverters were installed in each of the 37 kW winter and summer circulation pumps. The harmonics outflow current that might affect other devices was measured, but it was found that countermeasures were unnecessary.

5.3 Water quality adjustment

When 1000 ppm of the agent was added and stirred with the sampled circulating water, cotton-like precipitate was formed. This was thought to be a hydrate formed by the reaction between the anionic rust inhibitor in the circulating water and the cationic one that was used. Therefore, if this agent were injected in the circulating water directly, the hydrate would form and clog the narrow parts of the pipes. To prevent this, the cationic rust inhibitor was used. The circulating water was replaced the total of four times using the off-days to reduce the concentration of the anionic rust inhibitor to several tens of ppm, and the set volume of cationic rust inhibitor was added. The hydrate did not form when the readjusted circulating water and the agent were mixed.

The injection of the agent was done near the ejection point of the circulating pump on the 2nd basement. The plunger pump was used to pressure inject a certain amount of agent placed in the agent tank into the circulating water.

For the sampled circulating water, the calibration curve of the agent concentration and electric conductivity was obtained beforehand to calculate the agent concentration of the circulating water after injection. During the demonstration test, the circulating water was sampled from the 2nd basement, air conditioning equipment room on the 8th floor, and expansion tank on the 19th floor. The mixing state of the agent for the whole building was estimated from the distribution of the agent concentration.

6 Demonstration test

6.1 Appearance of the flow performance

The demonstration test for winter was conducted in November 2006. The details are described in reference[8]. The heating system of the office building started operating in early morning and was stopped at 17:30. Therefore, the actual circulating water was sampled at 9:00 when the entire circulating water system became thermally steady. The calibration curve for the electric conductivity and agent concentration was obtained from the samples. Since the agent had high viscosity, unevenness in concentration occurred in the system when it was bolus injected, and in extreme cases, the high concentration of the agent might cause clogging in the narrow channels. Therefore, the agent was initially injected at a slow speed of 10 kg/h. Then circulating water was sampled, concentration measured, and abnormalities were checked at the 8th and 19th floors. Slight bubbling was observed in the expansion tank on the 19th floor, but the amount was not problematic, and there was no further increase of the bubbles. A total of 100 kg of the agent was injected over three days. The estimated agent concentration at this point was 3000 ppm.

Table 2. Demonstrated operation condition and energy saving rate for summer and winter periods

Air conditioning mode	Agent concentration (ppm)	Set frequency (Hz)	Rated flow (L/min)	Energy conservation rate (%)
Cooling	about 3500	40	6600	47
Heating	about 5000	35	6600	65

To even out the agent concentration further throughout the system, the second injection was conducted after one week. Two days were taken to inject 80 kg of the agent, and the injection was completed when the estimated agent concentration reached 5400 ppm, which was sufficient to generate the flow drag reduction.

In the series of maneuvers described above, the inverter frequency was changed at the agent concentrations of 0 ppm, 3000 ppm, and 5000 ppm, and the values for the flow rate and power consumption of the pump were measured. It was found that 65 % of energy conservation could be achieved by setting the agent concentration to 5000 ppm and the inverter to 35 Hz to match the rated flow during the winter period.

The flow drag reduction was studied for the period of cooler use (summer period). It was found that 47 % of energy conservation could be achieved by agent concentration of 3500 ppm and inverter frequency of 40 Hz. The results of the demonstration test for the cooling and heating periods are shown in table 2. The calculated amount of saved energy for the cooling and heating periods in a year was 52,000 kWh, and this amounted to conservation of over 1 % of power usage for the entire city office building.

6.2 Maintenance of the heat transfer property

As shown in Fig. 5, for the reduction of the heat transfer performance in the heat exchanger used in the winter period, it was thought that the reduction of both the flow drag and heat transfer performance would not occur due to the great turbulence in the flow due to the complex channel of circulating water, because the high temperature steam supplied by the regional heat travelled through the heat exchanger tube while the circulating water flowed inside the shell-side separated by the segmental baffle plate.

The heat exchanger of the evaporation unit of the absorption refrigerator used during the summer period is composed of 414 U-shaped copper tubes of the length of 6 m and an inner diameter of 16 mm. The circulating water flows inside this hairpin tube, and flow drag reduction is expected to occur in the straight section. If the reduction of heat transfer performance is also occurring, the circulating water will circulate the building with insufficient cooling, and the cooling capacity of the entire building will be compromised. For the heat transfer coefficient of the tubes of the heat exchanger, the value obtained from the empirical equation[9]

and the value obtained from the temperature difference measured at the inlet and outlet of the heat exchanger were compared, and the measurement value was about 13 % lower. In general, it is said that the reduction of heat transfer performance is greater than the flow drag reduction. In the test, the flow drag reduction for the entire building was 47 %, and about 13 % reduction in the heat transfer coefficient indicated that the heat transfer performance reduction in the heat exchanger tube was not that great. Also, the outlet temperature of the refrigerator remained at 11 °C, the set value for operation during summer, and it became clear that the energy conservation by flow drag reduction did not cause any problems for operation of the air conditioner.

6.3 Maintenance of long-term stability

After the injection of the agent, it is necessary to maintain the appropriate agent concentration. The primary reason why the concentration decreases is the leakage of the circulating water containing the agent. If there is small but regular leakage from the joints such as from the packing, relatively large amount of water may escape during the channel switching from summer to winter. The accumulation of air in the channel is prevented by adding freshwater, but the agent concentration may decrease and the flow drag reduction effect may be reduced in this maneuver. The total amount of freshwater added must be measured, and extra injection of the agent is necessary if significant reduction in agent concentration occurs. In case of the Sapporo City Office, there was no leakage from the joints, but there were several tons of outflow when switching the channel from the summer absorption refrigerator to winter heat exchanger. Therefore, after switching, the surfactant concentration was measured, and additional injection was done based on the measurements. With accumulated experience, measures could be taken in the switching maneuver, and the work could be accomplished with very little outflow. As a result, currently extra addition of the agent may or may not be needed. The measurement of the surfactant concentration is done twice a year after switching the cooling/heating. Although the concentration can be estimated indirectly on site from the electric conductivity of the sampled water using the calibration curve, the concentration of the agent is measured directly along with the concentrations of the iron, copper, and other substances by subcontracted analysis.

The pipes were replaced from iron to stainless in 2001 due to rusting caused by aging. However, the heat exchanger is iron and the fan coil in each room is copper, and electric corrosion may occur. About 1600 days have passed since the agent had been introduced, but the concentration of iron and copper in the circulating water is stable, and it is determined that there is no corrosion in the pipe system.

The long-term stability of the agent is expected to be affected by the interaction of the agent and the substances that were already present in the circulating water, the expiration of effectiveness due to the temperature history, and the lifespan of the agent itself. Although the instability that may occur in a short time can be seen before injection, the long-term effect must be determined from the past case studies. However, the follow-up surveys of past injections have not been disclosed. Therefore, this case in which the effect has been sustained for over 1600 days is a valuable demonstration.

For the toxicity of the agent, material safety data sheet (MSDS) has been created, and there is no problem as long as the agent is processed through the wastewater processing plant, without direct release to the rivers.

7 Effect of technology diffusion promotion

Figure 6 shows the changes in the number of inquiries to Company L, the developer of the flow drag reduction agent, after the three press releases.

The number of inquiries increased after AIST conducted a press release[10] in May for the heating period test results in February 2007. Also, the test results for the cooling period for 2008 were announced at the Sapporo City Office, but there were no significant increase in inquiries, perhaps because the releases were mainly in local newspapers. The inquiries increased dramatically when Japan Broadcasting Corporation (NHK) aired the news in January 2009[11].

The places where the surfactant was actually installed in two years are shown in Fig. 6. There were 18 cases, including 9 cases, the highest number, in private company factories, 4 airport facilities, 3 public facilities, and 2 private buildings. According to Company L, the number of installations increased clearly after the public announcement of the demonstration test by AIST. Until then, even if Company L installed the agent to a private facility and publicized the energy saving effect, it was mostly seen as an advertisement of the technology by a private company. However, the news coverage of a public research institute such as AIST demonstrating

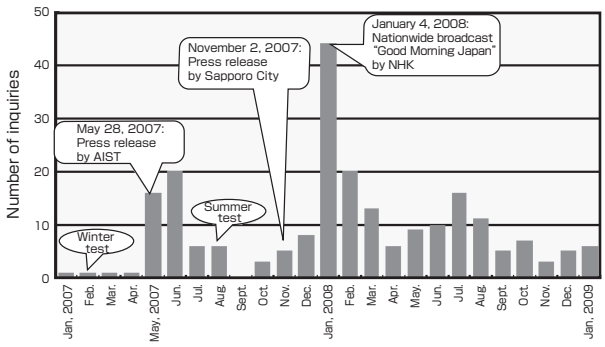

Fig. 6 Changes in the number of inquiries to Company L

Table 3. Examples of inquiries to AIST and responses

Inquirer	Question	Answer
Central government ministry	Can it be installed in the government buildings?	Since the aging of the pipes has progressed, the rust inside the pipes may be a problem. The surfactant and the rust may bond, and may inhibit the effect.
Local government	The person in charge of the facilities brought diagrams, and mentioned they wanted to do tests for the new government building that was being constructed.	Since the cooling tower is open to the atmosphere, bubbling occurs at this section, and therefore the surfactant cannot be used.
Major beverage company	We want to save energy because we need large amount of energy for cold water circulation at our plant. Also, is there any surfactant that is approved as food additive and also has flow drag reduction effect?	The person in charge visited the Sapporo City Office, and we explained the principles and MSDS. We have not done basic experiment for the flow drag reduction using food additives.
Individual home	We installed a heat exchanger in the attic 15 years ago, and get hot water from spring to autumn. Can the same effect be obtained for small pumps? Also, the heating medium has antifreeze to prevent freezing. Does the water containing surfactant have antifreeze function?	The effect can be seen even in small pumps. For example, the portable experiment apparatus used for the demonstration of Toms effect is a channel where the 18 m vinyl tube with inner diameter of 12 mm is coiled up into rings of diameter of about 30 cm, and about 30 % energy saving effect can be obtained. The pump is 150 W. The decrease of freezing point cannot be expected with 5000 ppm of this surfactant. It is necessary to check the flow drag reduction in the presence of antifreeze using the small experimental apparatus.

the efficacy of the technology was considered objective, provided practical information to offices that wished to quickly deploy energy-saving practices, and led to the increase in inquiries, and some places did actually install the technology. The nature of the inquiries was distinctly different from the usual ones that simply asked for the outline of the technology. Many of the inquirers presented the outline of the facilities in their buildings and asked about the cost, assuming actual installation.

Table 3 shows the typical questions among the 150 inquiries to AIST after the press release, and the answers. In the inquiries, there were several questions about the flow drag reduction in low temperature, including the combined use with antifreeze and ice thermal storage. Feedback from basic research such as the development of a new agent for low temperature is necessary. There were also several inquiries about the cooling system for plants that handle foods and beverages, but in most cases installation was not done since there was a possibility of circulating water leakage that might contaminate the foods. There was an inquiry from a Japanese company that had plants in Southeast Asia for use in the cooling system, but this was not done due to the problem of local concentration management.

8 Future development

Up to present, the consideration of installation to the building, the injection work, and the maintenance and inspection, as well as the manufacture and sales were done entirely by the company that developed the agent. In the future, we believe this technology will quickly diffuse if the building maintenance companies, building management companies, or design offices will conduct the preliminary check of the water quality and pipe system and the maintenance including agent injection and concentration management. From this perspective, it is probably effective to organize an annual technical experience seminar by expert lecturers to the engineers of maintenance companies.

Although the application to the regional cooling/heating system will greatly promote energy conservation, there is no clear conclusion on the issue of heat transfer performance. This is an issue that must be solved quickly through demonstration tests by the experts of the elemental technologies that comprise the system.

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Notes

Note) Type 2 designated energy management factory: This is a facility in which the standard value for energy use per fiscal year is 1,500 kL to less than 3,000 kL by crude oil equivalent for fuel (heat), and 600 kWh to less than 1,200 kWh for electricity. Such facilities are required to reduce the specific energy consumption by annual average of 1 % or more.

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Discussions with Reviewers

1 Overall

Comment (Akira Ono, AIST)

I think this study is a good example of a joint study with a local government, which is an entity with which the researchers do not regularly have contact, to diffuse the research result of the basic research to society. I also think it was difficult to conduct an experiment in an actual working building. I hope this will be referenced by many readers as a good case study of a methodology for *Type 2 Basic Research* or *Product Realization Research*.

2 Significance of the demonstration research conducted by a public research institute

Comment (Yasuo Hasegawa, Energy Technology Research Institute, AIST)

In the process of introduction and diffusion of a new energy conversion technology, there are several factors that inhibit the process, and a long time is required. This paper describes the installation procedure and energy conversion effect conducted by a public research institute for a public facility, and it is particularly valuable because it contributes to further diffusion and promotion.

I think you should present cases where the result of this demonstration led to the increase in the number of installations, and provide deeper consideration on the meaning of demonstrations conducted by a public research institute.

Answer (Hiromi Takeuchi)

The number of inquiries increased after the press release introducing the result of this demonstration, and this led to increased installations. I described the outline in chapter 7, and added considerations for the significance of the demonstration research by a public research institute.

3 Joint research with a local government

Comment (Akira Ono)

I think you should address the various factors unique to having the local government as a joint researcher, and how you solved the difficulty of conducting an experiment in a working building.

Answer (Hiromi Takeuchi)

Since any failure originating from the test was not allowed in the working building, we carefully studied the entire water circulation system and the location and performance of the component machinery. We also utilized the off-days of the office.

I did not describe some factors directly in the text since many of them do not pertain to technology, but the most difficult points were to get the people of the local government to understand the importance of this demonstration test and to obtain approval for conducting the test in the building where these people work everyday.

Designing products and services based on understanding human cognitive behavior

— Development of cognitive chrono-ethnography for synthesiological research —

Motoyuki AKAMATSU[1] * and Muneo KITAJIMA[2]

[Translation from *Synthesiology*, Vol.4, No.3, p.140-150 (2011)]

When technology development is conducted based only on a developer's idea, we face difficulties in realizing products and services that will be well accepted by people. This is because it is difficult for a developer to know precisely how various users think and feel while using products or receiving services under real life situations. In order to overcome these difficulties, we have developed cognitive chrono-ethnography (CCE) which is a new method to understand cognitive behavior under various situations. This method clarifies the cognitive behavior process by selecting "elite monitors" taking characteristics of target users into consideration, identifying "critical parameters" utilized in designing the products or services, recording the human behavior in real life situations under the control of the parameters, and retrospectively interviewing the participants. This method is applied in the early stages of synthesiological R&D processes oriented toward designing target products and services acceptable by people.

Keywords : Behavioral experiment, verbal protocol, daily life, retrospective interview, subject selection, car navigation system, baseball game watching

1 Introduction

The research outcomes of science and technology are ultimately used by people in the form of products, systems, or services. Of course, there are R&Ds for some elements of a system as well as R&Ds for the materials used as parts, but eventually all of them will be used by people. Therefore, as synthesiology for utilizing the results of science and technology in society, it is necessary to have a research methodology to design the product or service that people perceive as being beneficial in their daily lives.

Ever since the Industrial Revolution, various industrial products entered the people's lives through mass production technology. However, as the living standards increased, people are no longer satisfied with the current mass produced products, and there are demands for products custom fit for the individual. It is the age of different strokes for different people. The traditional mass production is limited in responding to the people's diversified tastes, and the research is done for minimal manufacturing[1] and on-demand manufacturing technology[2] that can respond to low-volume high-mix production and built-to-order (BTO). In the service industry, it is recognized that a person may want something different according to the time and occasion, and the age of different strokes for a single person has arrived[3]. For example, in the information service, providing information that pleases the user at a certain moment is expected to be realized based on the location information through GPS and optical communication[4]. The industrial technology is expected to develop the products and services that can fulfill various demands for various people, but the methodology for providing the policy for realizing what function and which service has not been established.

If the product or service is already accepted in society, the improvement of the function of that technology will be the objective of the R&D, and the researcher can set the R&D scenario by applying the knowledge of natural sciences involved. However, this will not generate a novel product. When conducting the technological development of a novel product, the developer comes up with an idea, the idea is reviewed, and the research is conducted under the decision that it may be accepted by the users. However, that does not necessarily result in a hit product. This is not only because the individuality of the developer and the user is different, but it is also because it is impossible to switch the viewpoint completely to the user's side when one is on the developer's side. The reason why it is difficult to imagine the actual usage situations from the developer's viewpoint is because the product and service are used in various situations, including the user him/herself, that changes in various ways. Therefore, there must be a process early in the stage of R&D to understand the actual usage situations of the person with certain personality traits, and obtain hints needed for designing the product and service for such a person.

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2 Why cognitive behavior in actual daily scenes?

In ergonomics, a discipline to realize the product and system compatible with humans, the first thing to do is to correctly understand the characteristics of human users. Therefore, the human characteristics are studied by using the knowledge and methodology of psychology, physiology, medicine, and engineering, such as mechanical and information engineering. These methods attempt to understand humans in the framework of natural sciences. In the natural science approach, factors that are irrelevant to the essence of the phenomena under investigation are considered as disturbances, and it is very important to control such disturbances. If the researcher sets up a laboratory experiment that reconstructs the environment in which the product is used by appropriately controlling the disturbances, it is possible to create the product and environment that is compatible with the sensory function of, for example, elderly people[5]. This approach is effective in cases where the research subject is the interface between the person and the product or system, such as the design for display or shape of the product. However, there is a limit to studying the function and contents of the product, system, or service. That is because the user perceives the value by using the product or system or receiving the service in the context of daily life, and not in the laboratory[Note 1)].

As a person lives in the daily life, the environment constantly changes and the individual recieves various stimuli and information. The brain and the body change to adapt to them, and behavior occurs. People interact continuously with the ever-changing environment, and the individual also changes continuously[Note 2)]. When we use some device in our daily life, we behave not only according to the device, but also according to the situation in which the device is placed. For example, when one is using a copy machine, one's behavior is affected by the way the paper is being discharged, the placement of the lid of the device, and the operations one had been doing, and not just according to what is displayed on the copy machine display. This is called the situated action[6]. Therefore, unless the person is using the product or receiving the service in the actual situation, it is difficult to correctly know how the person uses the product or receives the service.

What is frequently done to obtain the evaluation of usage is to make a prototype, have some assumed user try out the product in a trade show or an exhibition, obtain the comments on it, and find points that must be improved[4][7]. However, against our intentions, it is difficult to reproduce the usage in actual daily life with this approach. Also, since the starting point is the realization of the requirement imagined by the developer side, the true requirement of the user may not be met even if improvements are made. The developer must start by understanding the user's situation of use and then make a product that is highly likely to satisfy the user. Therefore, a research method that clarifies what is needed by the person, what the person wants, and what pleases the person is necessary, to discern the user's true requirement that may not have been imagined by the developer. This method is not a pure cognitive science method to merely understand the cognitive behavior of the person, but the content obtained from the research must lead to designing the functions of the product or service.

Most of the human behavior is carried out unconsciously, and a research method that allows analysis of how the person felt and how he/she made decisions done on-site is necessary, rather than a post-event method like a questionnaire survey. In this paper, we explain the cognitive chrono-ethnography (CCE) that was developed to understand humans by incorporating the chronological changes of the humans and environment based on the cognitive science method. The research scenario for this method is comprised of the following processes: first, the critical parameters that lead to the design of the product or service are reviewed to construct a hypothesis; the experiment is conducted in actual daily conditions that is controlled based on the critical parameters; then the adequacy of the hypothesis on the human behavior is verified from the analysis; and the function that should be realized in the product or service is proposed.

3 Development of the cognitive chrono-ethnography method

3.1 Retrospective interview

In the 1970s, the verbal protocol method was proposed for analyzing the cognitive process in the field of cognitive science[8]. This is a method where a person is asked to verbalize and express whatever comes to mind on site. As mentioned earlier, humans select their actions continuously based on the limited cues obtained in certain situations, even if the selection is not necessarily optimal for achieving the goal. However, when explaining one's actions to another after the event, one gives explanations as if there is total rationality in the series of actions that are remembered in fragments, to make one's actions meaningful. Therefore, the verbal expression of past events is considered to be unreliable. In the case of the verbal protocol method, the advantage is that the subject cannot reconstruct and offer rationalizing explanation since the verbalization is done in real time. This method is used often in the usability testing of information device, but the subject may be too focused on verbalizing whatever comes to mind at each action and this may interfere with the operation of the device. Although this may not be a problem when the device is operated in the laboratory, it is not readily applicable when studying the cognitive behavior in daily life.

In the case where the verbalization of the cognitive content cannot be done in real time, the only method is to look back afterwards, but this cannot be done by relying solely on

the subject's memory. Therefore, we proposed a method of recording the video images of the environment in which the behavior took place and the behavior itself, and then have the subject report what triggered the action while viewing the video replay[9]. In the study of learning and memory in psychology, it is known that the memory of the event at the time (episode memory) can be recalled when the subject visits the place or sees the object that was there. This is called the context-dependent memory[10]. Showing the image from the subject's viewpoint that changes from moment to moment along with the behavior provides hints for recalling the environmental situation. It is considered useful for reporting the cognition and decision recalled by the subject in the situation.

In the case where the subject is asked to verbalize the cognitive process at the time as the past behavior is re-experienced through recorded images, the method can be considered as the retrospective verbal protocol method. On the other hand, in the case where the subject is asked to describe the cognition and decision processes of only the behavior that the experimenter wishes to focus upon, the method is an interview, and this is called the retrospective interview method. Since it is not necessary to verbalize all of the daily actions if the aim is for designing the product or service, a retrospective interview method will be used where the interviewer picks up the action that may be related to designing and asks question[Note 3)].

3.2 Chrono-ethnography

Ethnography is the sociological methodology to understand the people's activities in society[11]. The word means a research method to describe (graph) the people (ethno) by entering the social group to observe the behavior of the constituents of society, conducting interviews to the people, and then describing the activities of the people in that society through language[Note 4)]. In the sense that the method involves recording and analysis of the people's activities by focusing on the cognitive behavior in real life situations, it can be said that the retrospective verbal protocol and retrospective interview methods are the combination of cognitive science and ethnographical methods[Note 5)]. While the original objective of ethnography is to understand the social activities as they are, the combined method that controls the experimental conditions as explained in the following chapter is effective for designing the product or service. This is because it is difficult to obtain findings that can be utilized for product or service design from the research that attempts to merely understand and recognize human beings.

Since whether the person perceives the product or service as pleasing depends on the chronological history such as what cognitive features the person has, what history, and under what circumstances this person grew up, we decided to treat the chronological history explicity. Therefore, since the emphasis will be on the person who changes over time and the detailed description of the cognitive process of the person placed under a situation, we call this method the cognitive chrono-ethnography (CCE) by adding chrono- (for time) and cognitive to ethnography.

3.3 Elite monitor and critical parameters

Through joint researches with companies that wanted to investigate the human cognitive behavior for constructing a product or service, we have developed the cognitive chrono-ethnography method, as we applied the retrospective interview method as a practical method using the recorded images of the behavior scenes using a small camera attached to the head. This was used for studying the daily scenes such as the behavior of elderly people in train stations or driving automobiles. While the details cannot be described fully due to the limitation of space of the paper, it was found that the behavioral characteristics for individuals could be clarified by selecting certain types of subjects based on preliminary hypothesis, and using them as the participants of the experiment. In the case of the behavior of elderly people in train stations, we set the hypothesis that there were differences in the cognitive functions of the elderly and these cause differences in the behavior. We hypothesized that there were people with impaired attentive functions, working memory functions, and planning functions. The hypothesis was investigated by creating an experimental procedure that may reveal these differences[12]. Starting with the hypothesis, the method for selecting a typical person based on the hypothesis is considered (in the above example, the AIST cognitive function test was developed), the actions of the different types of selected people are compared, and the difference in the behavioral characteristics of individuals is clarified to verify the hypothesis. The experimental participant with typical characteristics is called the elite monitor. By using the elite monitor, it is possible to obtain hints for the product or service design for a certain characteristic[Note 6)]. By integrating the abductive research method for hypothesizing the difference in characteristics and the retrospective interview method, we constructed the cognitive chrono-ethnography method that will provide useful findings for the product or service design.

While the ethnography research places importance on describing everything as they are, in the approach of synthesiological method for designing the product or service, it is important to seek the critical parameters that can be used for design. The critical parameters include, for example, the parameter to determine whether the experiment participant is a target user, or the timing of information presentation that gives the impression that the provided information is useful. Therefore, if the candidates for the critical parameters are found through preliminary observation study, the experiment using the actual scenes is conducted by controlling and recording the critical parameters. When the elite monitors

with typical target user characteristics or the person with typical characteristics for the subjects under investigation (for example, skilled service provider) are selected and used as the experiment participant, it is possible to clarify the product or service that may please that person.

3.4 Research process

Through the research projects described above, the CCE research method was established. However, as a research method, it must be used widely rather than be used by only certain researchers. Therefore, research experiences were reviewed, and the whole process was clarified so it could be used as a universal research method. Since there were some parts where the optimal method was not taken when we reviewed individual research projects, the research process was established incorporating the revisions.

The main process is shown as follows. Before the experimental investigation process, the hypothesis is formed by observing the relationship between people and an object (or among people) in the daily situation under investigation, and the elite monitor is selected by some appropriate method. The participants are asked to behave under control of the critical parameters in a daily situation, and the video image from the point of view of the participant is recorded along with other related events including the uncontrolled parameters. A retrospective interview is done for the recorded actions and the cognitive behavior process is described. After the investigation, the findings for the product or service design are extracted and the hypothesis is verified.

The details of the process are described in references [13] and [14]. The CCE can be organized into the following six steps to be followed by the researcher:

(1) The basic survey method such as ethnography and observation study is used to see the rough structure of the action selection process of a person in the situation under investigation.
(2) Based on the behavioral and cognitive characteristics of the person that have been clarified under current knowledge, what kind of characteristics, knowledge, or environmental factors are involved in the action selection of a person is considered based on the result in (1). The critical parameters are identified and the hypothesis for the cause-effect structure is formed.
(3) Based on this hypothesis, the person with typical behavior characteristics is selected among various people that comprise the group under investigation, and the selection criteria and recruiting method for the elite monitors are created.
(4) The elite monitors are selected. They are asked to behave in the situation under investigation, and their behaviors are recorded.
(5) Using the recorded behavior, the action selection process is analyzed, compared with the hypothesis established in (2), and the adequacy of the hypothesis is discussed.
(6) If the result is unsatisfying, the investigation is repeated by reconsidering the method by returning to (2). If it produces satisfying results, the findings that may aid the product or service design are organized from the results.

This was the process of development of the cognitive chrono-ethnography research method and its concepts. We present specific examples in chapter 4.

4 Application of CCE

4.1 Providing of smart information in driving

To realize a car navigation that provides useful information to assist driving, we conducted a joint research with an automobile manufacturer using the CCE. While useful information can be defined as the information that pleases the driver, we started by investigating whether there is information that people actually find pleasing. People may think that a human passenger will be capable of providing pleasing information compared to a car navigation that is a machine, but that is not always true. Therefore, the creation of a passenger who can provide information that the driver finds pleasing was conducted as part of the research process. Since the same information may or may not please the driver, the requirement was that the passenger knew the driver well. Therefore, it was not just a driver and a passenger, but the relationship between the driver and the passenger who could provide smart information was identified as the critical parameter to determine the elite monitor.

To obtain the passenger who knew the driver well, pairs such as married couples and friends who went driving together frequently were gathered through an Internet questionnaire. Among the 1,600 people gathered, 10 driver-passenger pairs were selected as elite monitors based on the questions on whether the partner was “officious”, “attentive” ,“considerate”, and others. Interviews were done to confirm both of them were considerate. The destination that one of the pair knew but the other didn’t was selected, and the advice points for the route were described by the one who knew. The results were carefully examined, and four pairs who were expected to provide much thoughtful information were selected as the elite monitors of the experiment.

Even if the monitors were selected through this process, it was uncertain that the information that the person considered thoughtful was truly pleasing and useful for the driver, and it might be that the person simply believed so. To solve this problem, three experimental driving trips were conducted. In the first driving trip, the information was provided according to the information that the passenger thought would be

thoughtful. After the drive, the pair was shown the video image of the conversation recorded along with the road scenes (Fig. 1), and the driver was asked to evaluate whether the provided information was thoughtful. Also, what points were useful and if not where lay the problem were extracted through the retrospective interview. The passenger learned what the driver considered useful, and the second driving trip was conducted. The same process was done after the second trip. The findings obtained from other pairs were shared to see the points that were perceived as being thoughtful, and the third driving trip was done. The driver and the passenger changed places and the same procedure was applied. They could learn what was the thoughtful information from both standpoints. By using the elite monitor who knew the route, knew each other well, and knew what information pleased the driver, we were able to clarify the information provision for somewhat ideal driving assistance[15].

The dialog contents extracted in this process were categorized into ones for road guidance such as need of right or left turns, safe and smooth driving, information about the facilities and sightseeing points to enjoy the area, and others. For each information provided, the content, the provision method of timing and ways of instruction, the situation of the road such as the width, and whether the driver's workload was high or not were described (Table 1). These were the critical parameters since they influenced whether the provided information was perceived as thoughtful or not. Of the extracted information, the information that was perceived as thoughtful was categorized into those that corrected the driving action, those that assisted or enhanced the driving action, and others (Table 2). For example, the correction of driving action is information provided when the passenger thinks that a certain driving action is necessary for the driver in the current situation (for example, early lane change or something that will make driving easier later), but the driver may not take that action. If the information is provided at an appropriate timing such as after passing through the intersection and the traffic flow becomes smooth, it is perceived to be thoughtful advice. Through this study we were able to clarify the structure of the provision of thoughtful information.

Table 1. Attributes to describe the provided information

Attribute	Explanation	Value
Provided content	Information provided by verbalization	Specific content
Provision method	Information communication method	Timing, instruction method
Road situation	Road situation during verbalization	Road width, speed, etc.
Driver' s condition	Driver' s condition during verbalization	Driving workload, assumed knowledge

Table 2. Motivation for information provision by the passenger

Correction of driving action	The passenger thinks that a certain driving action is necessary for the driver to drive in the current situation, but thinks that the driver is not likely to take the action.
Assistance of driving action	The passenger thinks that a certain driving action is necessary for the driver to drive in the current situation, and thinks that the driver is likely to take the action, and the driving action will be encouraged if the information is given.
Addition of supplementary information	The passenger thinks that the driving satisfaction will increase if the driver is given some information in the current situation.

4.2 Growth stage of a baseball fan

The method to study the thoughtful information provision in driving involves setting the scenario of taking a trip to an unknown destination and training (or nurturing) the elite monitor. This is called the scenario-oriented CCE. In contrast, the approach involving the observation of people in their daily situations without a scenario is called the non-scenario oriented CCE. As an example, we describe the application to the study of spectator behavior at a baseball game.

Fig. 1 Monitors during the driving trip

In the service that provides sports entertainment, it is important first to get people to the ballpark or the soccer stadium, and the next issue is what kind of experience can be given there. People who come to watch sports include those who come to the stadium for the first time and those who attend frequently or the repeaters. Even a repeater had the first time when he/she attended the game. Before that, the person most likely watched sports on television, and turned into a repeated game goer through various information and experiences. The objective of the research was to clarify the structure of the shift or how a sports watcher turned into a repeater.

We investigated the critical parameters that determined how the repeater of baseball game watching enjoyed the baseball game. First was the objective and enjoyment of going to the stadium, second was the degree of information exchange about the baseball team with the surrounding people, third was the strong feeling of support as a team fan at the games, and fourth was the personality (behavioral characteristics) of the person. From this perspective, 30 elite monitor candidates were selected based on the response to the Internet questionnaire survey of about 1,000 members of the baseball team fan club. Five males and five females were selected from the three enjoyment types including "sports watching is my personal enjoyment", "it is enjoyment for the entire family", and "it is enjoyable but I don't really want to become a hardcore fan". These three types were found from the cluster analysis of the questionnaire survey. Each group contained differing critical parameters. Group interview was held with 30 people, and they were mapped on the two-dimensional graph composed of the axis for how they enjoy the game (from people who enjoy the game itself to those who enjoy cheering for the team) and the axis of fan maturity (from hardcore who goes to fan service events as well as the games, to those who love baseball but have no time to watch the games). Then, nine people were selected as elite monitors, making sure there were no biases. The elite monitors were asked to watch the games at the stadium, and the behavior of the monitors, the progress of the game, and the atmosphere of the spectators' stands were recorded on the video. Heart rate of the monitor was also recorded as the physiological measure to see the state of physical excitement during the game. Retrospective interview was done, and the feelings they had during the games were extracted as the monitor watched the video (Fig. 2). Also, other sports watching behavior the elite monitors engaged in the past were surveyed through the interview.

From this survey, the stages of the fan were categorized into the following three: pre-fan who "knows/doesn't know baseball but is not interested in professional baseball games", fan who "has become fond of the team and goes to watch the game at the stadium", and the repeater who "goes to the games enthusiastically, has his/her own watching style, and consciously makes time to go to the games" (Fig. 3). The motives that were given for shifting from pre-fan to fan included the introduction of a star player, the expectation for league victory, and the amazement at the cheering fans at the game that one happened to attend. The motives for shifting from fan to repeater were the sense of unity with the other spectators at the stadium that does not get communicated through TV, the accumulation of detailed knowledge about the players, and the aquisition of companions such as family or friends with whom one can watch the games together. There were several paths for the shifts, and there were cases whereby "the person who did not know anything

Fig. 2 Interview to baseball fans after game watching at the stadium

about baseball" became a fan because he/she was amazed by the excitement at the stadium, voluntarily participated in cheering, and became adherent to the total experience of cheering and the game. Another case was that "the person who knew baseball and was interested in professional baseball" became emotionally involved in the players and the team through the real game, and became a person who enjoyed the game, or enjoyed both the game and cheering (Fig. 4). By using the CCE, we were able to clarify the structure of fan growth, or how a person who was not really interested in baseball became a repeater and how they enjoyed the game.

5 Application to product or service design

After obtaining the clues for identifying the function and service that the target user wants by the CCE method, we move into the R&D process for concretizing the product or service. For example, if we know that well-timed, useful information from a considerate passenger is given when and about what, we can set the development goal of providing such information from the car navigation system. Since good timing by which the information is provided is the critical parameter of whether the person perceives the information as being thoughtful, the technological issue will be whether the system can determine the timing. Therefore, we conducted an experiment where the content and the timing decision for providing the information were defined as clearly written rules, and the information provision was done according to the rule. Although the information provision is done by a human operator, rather than changing the information provision flexibly, a manual is followed to simulate the information provision by a system using this rule. Moreover, to investigate whether it is possible to determine the timing according to the traffic condition and the driver condition without the passenger, we investigate whether an information provider (an operator) on a separate vehicle can provide the information at appropriate timing based on the image and sound information from the cameras in the subject vehicle via radio communication. This research is still in progress, but by providing the information via radio communication from a separate vehicle, the cues for timing decision is becoming clear, and the system may be able to determine the timing using sensors[16]. In case of information provision by a device, the function of the product will become clear through these research processes, and the function to be realized will become concretized.

In the case of service, if, for example, the motive for a baseball fan to rise from an "occasional game watcher" to a "repeater" becomes clear, the baseball team owners can plan the actions to be taken. They can determine how they can reach out to the target subjects, how they can provide the motives, and how to set the incentives. Of course, several, and not just one plan, can be considered.

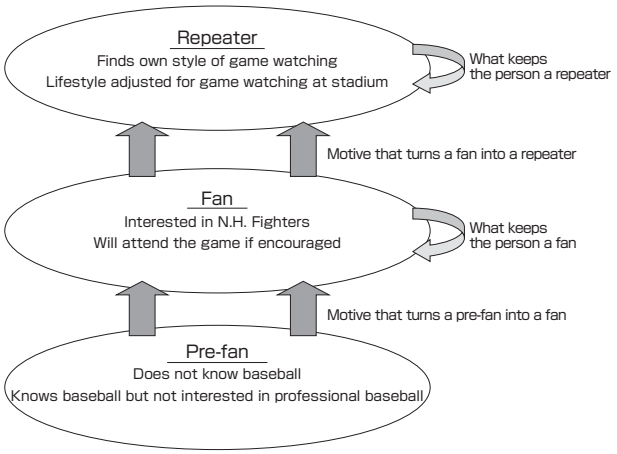

Fig. 3 Three stages of fan maturity

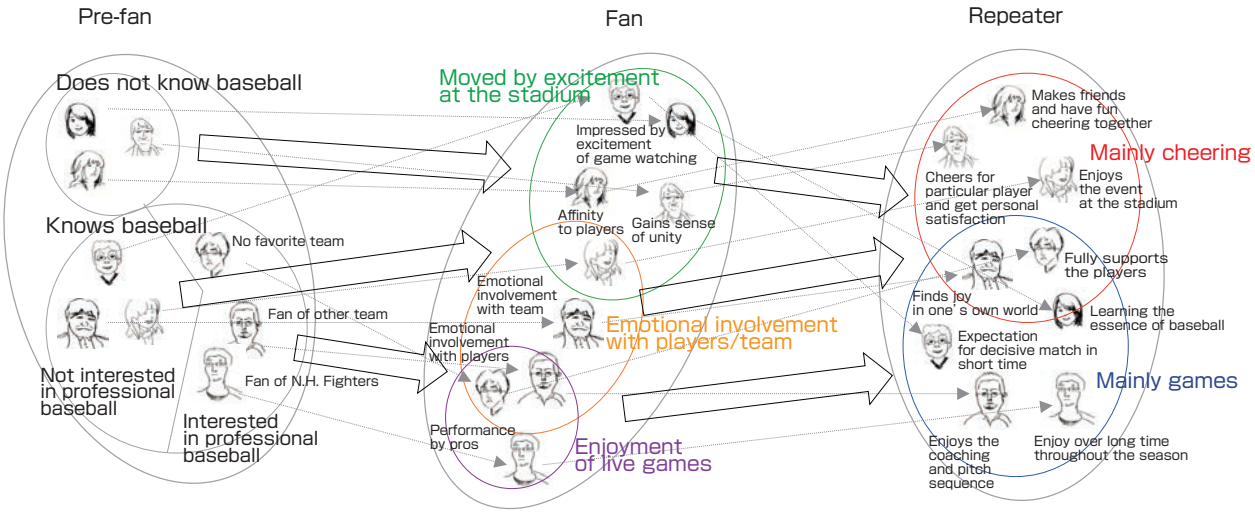

Fig. 4 Path of fan stage

Whether they are products or service, the design is constructed based on the findings obtained by the CCE method, and the specific requirements of the plan and the prototypes with functions to be realized are created. The ways to realize them are reviewed, and realistic specifications are created, considering the current technology level and the service provision environment. In some cases, the decision may be that the product cannot be realized with the current technology level, and the plan must be terminated. The prototype is built based on the specification, the trials are done using the expected target user under the target situation, and the evaluation is obtained. In case of a product, since development cost and time are needed, it is necessary to conduct the experimental evaluations at various stages of the development process to make sure the project does not wander in the wrong direction. However, in case of service, the service can be implemented more easily compared to products, and the new service can be incorporated into the actual service provision process. The survey is done by executing the service, seeing that the service expected by the service designer is provided to the target user, observing whether the service is effective, and improving the plan by understanding where the problem lies if the service does not seem effective. By turning this cycle of the hypothesis testing, the service provided is made compatible with the user[17].

6 Discussion

From the analysis of the *Synthesiology* papers, Kobayashi *et al.* indicate that the way of synthesis when realizing the product to be used in society by integrating the elemental technologies differs according to the technological field[18]. For example, in the research fields that handle the materials themselves such as nanotechnology, and device technology, the researcher can utilize the knowledge of natural sciences, clarify the elemental technologies and the factors that affect the subjects, and select what must be done for synthesis. On the other hand, in the research fields that handle daily living and in some life sciences, the researcher may take the spiral approach where the product or service is introduced to society and advances are made as evaluations are obtained, because not only are there multiple factors, but also because there are many unknown factors. However, unless the product or service that is being introduced initially has high prospect for acceptance in society, it will not diffuse in society even in the spiral approach. To prevent such failure, it is necessary to have a method that allows the factors and elemental technologies for the acceptance of the product or service to be clarified as much as possible and to be examined beforehand. The CCE method extracts and structurizes the variables for the target user in the actual usage situations, and aims to take a similar approach as the synthetic research in the field of material science, in the sense that the factors that affect the cognitive behavior under investigation are clarified and what must be selected for synthesis is determined.

Although it is similar to the research approach for materials, it does not have the same level of preciseness of natural science. Although hypothetical field experiments are done for the selection of the elite monitor and the critical parameter, it is difficult to show the validity of the hypothesis through statistical testing of the results. In CCE, there are only a few participants of the experiment as elite monitors. There may be only a few chances once or twice a day to make a certain situation constant when conducting the field experiment. For example, if the research involves railway use, the time zone when the experiment can be conducted is limited if the researcher wishes to avoid the effect of crowding. Also, there is no exactly-the-same action taken in the actual daily scene, and the analysis may remain qualitative. For example, if the majority of a certain category of experimental participants takes the same behavior and the behavior is not seen in other categories, it can be concluded that the categorization hypothesis was not wrong. Therefore, it is not hypothesis testing in the natural scientific sense. The natural scientific hypothesis testing may be possible if the scale of experiment is expanded, but considering that the same situation is not repeated in actual daily situations, the testing by reproducibility would be essentially impossible. The everyday situation in which we use the product or service changes continuously and we are never subject to the same situation. Therefore, we must be aware that there is a limit on depending on the natural scientific methodology. However, if we abandon the natural scientific research approach for understanding the factors that affect the phenomenon, we cannot reduce the gap to obtain acceptance of the product or service in society.

In the sense that research subjects are daily situations, the CCE is similar to the sociological method. Ethnography as a sociological method aims to understand society, or to seek the behavioral principles common to human groups or society by describing the behavior of humans in society just as they are[11] Note 7). In contrast, the CCE clarifies the differences in individual characteristics and adds experimental control such as setting the situation. This is a synthetic research approach for the purpose of constructing the product or service, and the insight for designing the product or service can be obtained by introducing the elite monitor and the critical parameter. If the product or service is constructed based on the findings of CCE, and the product or service becomes more acceptable to the user by turning the cycle of evaluation, then the validity of the findings obtained can be investigated, and the product or service acceptable to society can be realized.

It is not easy to realize a good product or service by thinking inside the developer's mind only. By using CCE, the product or service can be designed effectively. In the evaluation for the usage, the cycle of improvement and optimization can work efficiently by clarifying the viewpoints of function of the product or service.

Notes

Note 1) Experimental psychology to investigate the human sensory functions by controlling the stimuli in a laboratory setting was started by Wilhelm Wundt of the Universität Leipzig in 1879. However, Wundt indicated the necessity of psychology in the actual evironment, since it was impossible to discern the higher-level cognitive functions such as thought and problem solving by laboratory research.

Note 2) MHP/RT is the computational model for the action selection process taking in consideration this brain mechanism. It provides the logical framework of the CCE method, but the explanation was omitted here due to space limitation[13].

Note 3) The retrospective interview is conducted to have the subject report the contents of memory that was activated during the action selection. The memory that was activated during the action selection is encoded and stored in conjunction to the situation or the context. It is known that the reproducibility is good if the context when the memory is recalled is similar to the context when it is memorized (context dependency of memory). It is also known that the subject's report is affected by the way the interviewer asks the questions. There is a phenomenon called the "post-event information effect" in which the subject tends to report the information given after the event or the mixture of the original and post-event information if the subject is given information related to the event after he/she experiences the event. The action selection of the subject is done under bounded rationality (where the decision is based on limited views and limited cues, rather than making a rational decision that directs the goal and the totality of the situation) that is a human characteristic of decision-making. The retrospective interview, which is an important process of CCE, is designed to extract the cognitive behavior process according to bounded rationality, without the influence of post-event effect.

Note 4) The efficacy of the sociological method as a method of technology transfer, whereby the problem is solved by entering the organization under investigation is addressed by Kinoshita *et al.*[19]

Note 5) An example of the famous ethnographical research in the field of cognitive science is the study of cognitive process of the crew in a cockpit of an aircraft, conducted by E. Hutchins *et al.* Here, the researchers entered the cockpit to observe the behavior of the crew and then conducted interviews.

Note 6) The person who is expected to use a certain product is called the target user. The persona method is widely used for product development assessing highly individualistic target users. However, this method is used to clarify the target user in the development process, and the evaluation for how the expected user actually uses the product or service remains within the realm of the developer's imagination.

Note 7) Among the ethnographic research methods in sociology, the action research method aims to find the problem in society or organization and to seek the solution to that problem.

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Completed the doctorate course at the Department of Administration Engineering, Graduate School of Engineering, Keio University in 1983. Doctor of Engineering. Joined the Industrial Product Research Institute, Agency of Industrial Science and Technology in April 1986. Engaged in the researches for tactile perception, brain mechanism for sensory-motor integration, computer input device, ITS human interface, and car driving behavior. Currently, director of the Human Technology Research Institute, AIST. Professor of the Cooperative Graduate School, Tsukuba University. In this paper, reviewed the comparison and relevance to other researches to position this research in the field of synthesiology, and constructed the whole structure of the paper.

Muneo KITAJIMA

Completed the master's course at the Department of Physics, Graduate School of Engineering, Tokyo Institute of Technology in 1980. Doctor of Engineering (Waseda University, 1986). Joined the Industrial Product Research Institute, Agency of Industrial Science and Technology in April 1980. Engaged in the researches for reading device for vision-impaired people, cognitive modeling in human-computer interaction, usability for hearing-impaired people, and action selection in everyday life. Currently, principal researcher, Center for Service Engineering, AIST. In this paper, was in charge of the development and application of the cognitive chrono-ethnography method.

Discussions with Reviewers

1 Emphasis of the authors' thoughts and actions

Comment (Akira Ono, AIST)

This is an extremely interesting research, and it seems that the authors are creating a new discipline in synthesiology. On the other hand, I feel that the descriptions in this paper are rather explanatory and plain. I think the reader can better understand the significance of the research in terms of synthesiology if you emphasize your thoughts and actions, like what intentions the authors had, what they selected, and what they determined.

Answer (Motoyuki Akamatsu)

This paper not only recapitulates the research that we have been doing as synthesiology, but was written with an objective of positioning this research, while trying to define the overall picture of synthesiology. We tried to position our research by reviewing researches aiming to connect products to human users, and therefore, it has become rather explanatory. We revised some of the expressions to clarify our statements.

2 Verification of the cognitive chrono-ethnography method

Question (Akira Ono)

There are two interesting case studies of the cognitive chrono-ethnography (CCE) method, and the results are steadily being accumulated. On the other hand, I understand that you have not yet gotten to the point where you have done verification by obtaining user evaluation after applying the results to the design of car navigation and baseball game programming. Am I correct? Also, how do you test and evaluate the research results of whether the past CCE research method was adequate or inadequate?

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

I found that the method of this research has analogy to the idea of process standard in the sense that the quantitative verification is not discussed. In process standard, the procedure and the method to check the procedure are standardized, and that whether the procedure is carried out properly can be confirmed. Moreover, a person other than the one who created the process can execute it. Analogically concern, can this CCE method be replicated by anyone if the procedure is followed?

Answer (Motoyuki Akamatsu)

We need more time for product development based on the result of this research. Thus, as you indicated, we have not reached the state of evaluation by actual users. From the standpoint of the verification being the acceptance of technology and service by society, I must say that it has not been verified yet.

Before launching a product or service to society, a rationale will be needed for determining whether to give the go-ahead to the design of the product or service based on the findings of the CCE. Our current thinking is that the convincibility of the results obtained and the adequacy of the process are to be evaluated. The adequacy of the process is, for example, whether the procedure can extract the characteristics of target users of the product or service that one wishes to realize. However, we do not think that we will automatically reach the correct results as long as the process is carried out properly. Some sort of evaluation of the process or results is necessary. This evaluation may be difficult unless it is done by a person who has thorough understanding of the product or service under investigation, and it may be something like a peer review. In this type of research, I think it is important to do joint research with the people who have thorough understanding of the product or service, namely the people of the company that are providing the product or service and those who are capable of making evaluation.

3 Reference to other *Synthesiology* papers

Comment (Akira Ono)

In this paper, the discussion is developed by citing the papers published in *Synthesiology*. The reviewer thinks that the synthesiology researches should be mutually contributing even though the contents are diverse. Please express, from the standpoint of the author who cited the references, how these affected this research.

Answer (Motoyuki Akamatsu)

The research described in this paper was started over 10 years ago, and I was aware that we were engaging in *Type 2 Basic Research* from the beginning. However, this research is an analytic research in the sense that it attempts to clarify the human behavioral characteristics, and I wasn't quite sure what points ought to be emphasized as a *Synthesiology* paper that focuses on synthetic research in which the elemental technologies are integrated and synthesized to realize some object to be used in society. I found a way during the workshop that I cited as reference [18] where I discussed the different approaches to synthesiology in different fields. I sought the characteristics of the different approaches by breaking them down into categories: the researches governed by principles of the nature as exemplified by physics; the engineering researches that assemble the elemental technologies; and the researches that involve people using the results in the form of products. I was able to see the similarities between our research and the material research approach where one understands what can be realized by pursuing the properties of materials. If the human cognitive behavior can be clarified through analysis, we can understand what kind of product or service can be realized. I think there is a common ground that knowing well will guide toward realizing a product. Our research is to have people use the product, but even in the same human technologies, we can now compare the engineering research that first focuses on manufacturing the product and the research that first focuses on understanding human behavior, like the ones we are doing. That allowed us to write a *Synthesiology* paper.

4 Theoretical background of cognitive chrono-ethnography method

Comment (Masaaki Mochimaru)

The characteristic of the CCE that is the core technology in this paper is organized well in relation to the other previous methods. Reading the cited references, I can understand the theoretical background that the CCE was created based on cognitive science. In this paper, I think you should briefly explain the theoretical background so the readers can understand just by reading this paper.

Answer (Motoyuki Akamatsu)

The background of developing the CCE was because of our awareness of the need to understand the action selection process after an event, using limited cues under certain situations. We tried to solve this problem by reproducing the condition when the action selection was done, and then by expressing the cognitive process using the working memory at that moment, to prevent describing the action as being selected based on total rationality, even though it was actually action selected from limited cues. The conventional method in coginitive science for not falling into explanation by total rationality is the verbal protocol method. Since retrospective interview and CCE are essentially based on that method, I added some description in the beginning of subchapter 3.1. For the researchers interested in the theoretical background, I added Note 4).

5 Initial hypothesis

Question1 (Masaaki Mochimaru)

For the behavior observation, some degree of initial hypothesis (identifying the critical parameter and the selection of elite monitor by survey and observation) is needed, and the results obtained are applicable only in the set context and place based on the initial hypothesis. In that sense, isn't the framework of "findings that may be found" by the CCE is already determined at the point the initial hypothesis is set? Do you have the process of constructing the initial hypothesis properly as much as possible?

Answer1 (Motoyuki Akamatsu)

As you indicated, the identification of the critical parameter and the selection of elite monitor are very important, and they will determine the framework of the conclusion obtained. However, the CCE is not a method for hypothesis testing research whose objective is to verify the initial hypothesis. That is because the hypothesis is tested to determine the framework of the product and service (car navigation or sports game attendance) such as the critical parameter and elite monitor, and it does not directly determine the framework of the contents or functions provided by the product or service. The process of CCE is designed to readily obtain the insights for designing the product or service, and by setting the initial hypothesis, I think it avoids doing research without a hypothesis and missing out the useful conclusion.

At any rate, although the initial hypothesis is extremely important, our thinking at this point is that when one constructs the initial hypothesis, one must look at the objective by eliminating any assumptions as much as possible while utilizing the researcher's perspicuity as much as possible. Speaking from our experiences, to construct a hypothesis by eliminating assumptions, it is important to have plentiful knowledge of the target characteristics as well as deep understanding of the property of the product or service that one expects to create. These are completely the same as the initial insight when the researcher takes on the studies in various scientific disciplines, and the depth of the initial insight will affect the quality of the research results.

Question2 (Masaaki Mochimaru)

The expression in your answer, "The process of CCE is designed to readily obtain the insights for designing the product or service, and by setting the initial hypothesis, I think it avoids doing research without a hypothesis and missing out the useful conclusion" is the essence of this paper, and I understand that the way to conduct the research is "one must look at the objective by eliminating any assumptions as much as possible while utilizing the researcher's perspicuity as much as possible". However,

isn't the "way of doing the research" using the CCE by building the initial hypothesis, hypothesis testing research? Although verification is difficult, for example, if the framework of the product and service are synthesized appropriately, the product or service unseen before is accepted by society or users, and this leads to the change in society, wouldn't this fact be verification that the construction of the framework according to the initial hypothesis and the CCE process was appropriate?

Answer2 (Motoyuki Akamatsu)

I said this was not a hypothesis testing research because the research scenario followed is to conduct the research to the stage of designing the function of the product or service based on the hypothesis (or to determine that it cannot be realized with the current technology), as long as the hypothesis is not wrong without carrying out the strict "verification". Of course, the hypothesis will be proven correct if the functions of the product and service are compatible with the user and as a result, it is accepted by the user or society. However, I would like to state that the objective of the research scenario in the paper is to synthesize (it is "synthesiology") and is not to recognize by hypothesis testing (it is not "epistemology").

In a specific example, in the research of the behavior of the elderly people in train stations, the hypothesis was "there are several different types of impairment of cognitive function in the elderly, and they are impairments of attention or executive functions". When the CCE experiment was planned and conducted based on this hypothesis, it was found that the behaviors in the train station were different according to the types of cognitive function impairment. It can be said that the different types of functional impairment existed, but the objective of the research was not to test the hypothesis that "there are different types of functional impairments", but to propose ways to provide assistance according to functional impairment. (This does not mean that positive proposals could be made. For the group with attention function impairment, the subject could not pay attention no matter how many signs were placed in the station, and it was found that signs were not good ways of assistance.) The research scenario may include the hypothesis testing process, although it is not the objective of the research.

6 Intervention during behavioral observation and experimental setting

Question (Masaaki Mochimaru)

I think some kind of intervention may be involved in behavioral observation. Unless the intervention is in line with the product or service that will be created, it will not lead to good synthesis even with deep understanding of the behavioral observation with intervention. For example, in the case of service that displays heavily processed, real-time information or service that returns some information by integrating remote information, IT must be used for the intervention, and I think the performance of the experimental IT itself will affect the behavior observation. How should such cases be considered?

Answer (Motoyuki Akamatsu)

One approach is to create the experiment setting with technological limitations such as remote information as the given condition. For example, if there is a delay in communication, the experiment can be conducted by simulating the delay, if one wants to understand what kind of information provision is pleasing under this condition. How such technological limitation is set as the given condition will differ, for example, depending on whether the researcher wants to use the device or the system as is but wants to improve the contents, or whether he/she can change the performance of the entire device or the system.

In the CCE as a method of synthesiology, I think it is important to set the limiting condition for intervention according to the structure of the product and service to be realized. However, I think we can obtain an innovative product or service that never existed before, if we select the critical parameter for the CCE under no limitations or assumptions as much as possible, rather than setting the structure of the product or service at an early stage and setting them as given.

7 Quantitative data for product design

Comment (Masaaki Mochimaru)

I think the typical procedure to create a product is to convert the qualitative hypothesis or model obtained by CCE into some sort of quantitative data, and utilizing them in the design of the product or service. Do you have thoughts on how to convert the qualitative model into quantitative data or design?

Answer (Motoyuki Akamatsu)

The quantitative data needed for product design can be determined by conventional human factor experiments at the stage when the provided contents are determined to some extent by CCE. I think the CCE method will function effectively to discern the preliminary stage for determining the quantitative specification of the product or the requirements of the product and the system.

A novel technology for production of drinking water in emergencies

— Specific material for selective nitrate adsorption —

Akinari SONODA

[Translation from *Synthesiology*, Vol.4, No.3, p.151-156 (2011)]

Underground water has been used as a suitable drinking water source for a long time. In recent years, however, not a small number of wells have become out of use as a drinking water source owing to pollution with nitrate or nitrite. A mobile water purification system has been developed with advantages in portability and cost to utilize the polluted wells in emergencies. The system has been achieved by the combination of nitrate ion selective adsorbent developed in our group and contactless supporting and shaping technology developed by a company which enables formation of a material into easy-to-handle shapes without decreasing the performance of the functional material. This paper mainly describes the development of the nitrate ion selective adsorbent material, which is the important elemental technology in the mobile water purification system.

Keywords : Nitrate ion, ion specific adsorbent, distributed without any contact, drinking water, water purification

1 Background of research: Current situation of the underground water pollution[1]

The quality of underground water is published in the "Result of the Underground Water Quality Measurement" by the Ministry of the Environment. According to the Outline Survey for FY 2009[Note 1)], the percentage of wells that exceeded the environmental standard was about 6 %. By items, the environmental standard exceedance (3.8 %) of "nitrate-nitrogen and nitrite-nitrogen" was the highest. This was followed by arsenic (1.0 %), fluoride (0.5 %), lead (0.3 %), and boron (0.2 %). The top three items have not changed in ranking since the environmental standard items were added in 1999 (Fig. 1). Since 2003, there is a decrease tendency of "nitrate-nitrogen and nitrite-nitrogen" as seen in Fig. 1. It is assumed that the wells that were found to have underground water pollution would be excluded from the Outline Survey, and therefore, in turn the number of wells for continuous monitoring in Fig. 2 is increasing.

The wells that were found to be polluted in the Outline Survey becomes the subject of the Continuous Monitoring Survey[Note 2)]. Since the wells will be removed from the monitoring list if the pollution improves, the overall trend of pollution can be seen from the Continuous Monitoring Survey results. After the FY 2004, the number of wells with standard exceedance of "nitrate-nitrogen and nitrite-nitrogen" has been high and continues to increase (Fig. 2).

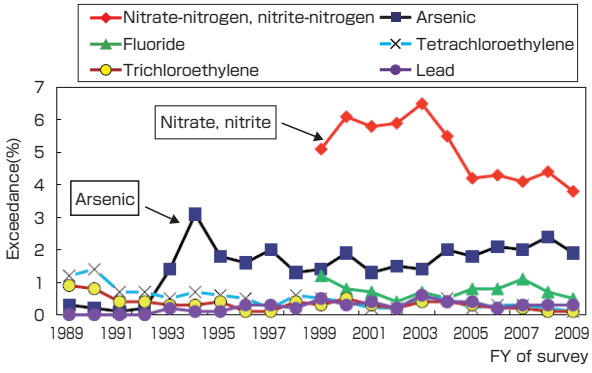

Fig. 1 Transition of the exceedance of environmental standard in the Groundwater Outline Survey (major items)

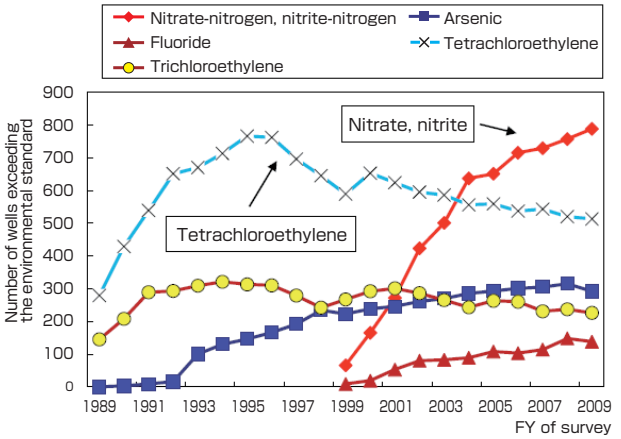

Fig. 2 Transition of the number of wells exceeding the environmental standard in Groundwater Continuous Monitoring Survey (major items)

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In the past five years, there were 530 cities, towns, and villages with wells that exceeded the environmental standard, and that dominates 31 % of all cities, towns, and villages. The cause of "nitrate-nitrogen and nitrite-nitrogen" pollution is mainly due to the nitrogen from fertilizer application, farm animal excrements, and sewage. In many cases there are multiple causes of pollution, and the range of pollution covers a large area.

When the water containing "nitrate-nitrogen and nitrite-nitrogen" over a certain concentration is consumed, it is known to cause methemoglobinemia, a disease where the oxygen deficiency occurs due to the loss of oxygen carrying capacity of the blood, mainly in infants. The environmental standard value for contamination of underground water for "nitrate-nitrogen and nitrite-nitrogen" is 10 mg/L or less, which is the sum of the concentrations of the "nitrate ion" and "nitrite ion" converted into "nitrogen".

In a case where the pollution that exceeds the environmental standard is found in the groundwater, according to the Water Quality Pollution Control Act, the prefectures and ordinance-designated cities must take the following measures: 1) take measures such as installing drinking regulations, such as designating as undrinkable, from the perspective of protecting health, 2) conduct surveys to determine the range of pollution and to identify the source of pollution, and 3) promote measures such as purification considering the usage of the groundwater.

Attempts to remove the nitrate ion using the anion exchanger have been done, but the effect was limited in the presence of coexisting anions. Therefore we developed a novel adsorbent reagent[Note 3)] that was selective for nitrate ion (Figs. 3, 4, and 5).The adsorbent reagent selective to nitrate ion is a layered double hydroxide (LDH) of aluminum and magnesium. It is an inorganic ion exchanger ($Mg_{0.80}Al_{0.20}(OH)_2Cl_{0.20}$) with anions with different Mg/Al ratios and ion exchangeability from the mineral called the hydrotalcite ($Mg_{0.75}Al_{0.25}(OH)_2(CO_3)_{0.125}$). The studies to increase the ion exchanging volume were done by increasing the aluminum content in the LDH, but it was found that the selectivity against nitrate ion appeared by decreasing the aluminum content. Also, since it was a chloride ion type, the nitrate ion could be adsorbed in water such as seawater that contains vast amounts of chloride ions.

The awareness of disaster prevention increased since the Great Hanshin Awaji Earthquake, and many local governments prepared the water purification system for emergency. However, the reverse osmosis (RO) system that can produce pure water from seawater requires power and cannot be operated readily by an untrained person, and therefore, a simple water purification system was in demand. In this R&D, we aimed at a product different from the RO system, and at a market of "simple device that can be operated manually without exterior power source", and created a prototype. The water qualities were measured for raw water from rivers, wells, and pools. The river water did not contain harmful ion, and sufficient drinkability could be obtained with the combination of simple filtering and sterilization. Some well water exceeded the tap water standard value for nitrate ion in some regions, and selective adsorbent material for nitrate ion would be effective. For pool water, the bromate ion, an impurity of the chloride disinfectant, was detected in some cases, and it was necessary to use a removing reagent for bromate ion.

2 Objective of the R&D

In the Consortium R&D Project for Regional Revitalization of FY 2006, a joint research unit was organized centered around AIST and Teijin Engineering Ltd., with universities, public research institutions, and local small/medium companies such as Kyowa Chemical Industry Co., Ltd. The unit worked on the topic "Development of mobile water purification system by the contactless compositing of nano-particles with separating functions".

AIST developed a nitrate ion removal system using a selective adsorbent reagent to make groundwater, which

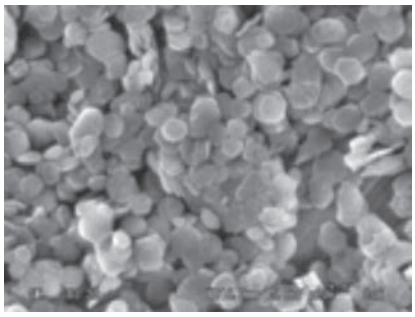

Fig. 3 SEM photograph of powder adsorbent reagent
Size of plate-like particle: width about 500 nm and thickness about 20 nm

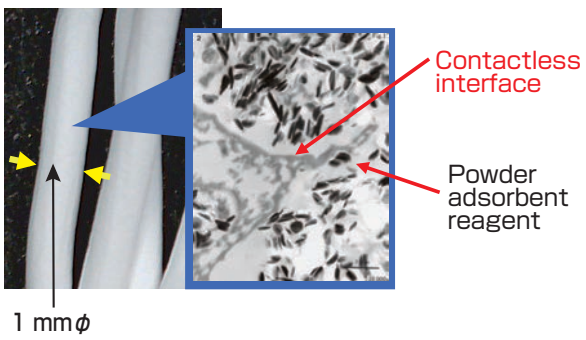

Fig. 4 SEM and TEM photographs of the fibrous adsorbent material
Diameter of the fiber is about 1 mm. The interior structure consists of powder adsorbent reagent sealed inside the porous polymer without contact.

is polluted by nitrate ions and is normally undrinkable, drinkable at times of emergency[2].

For the product to be realized, the following goals were set to fulfill the social demand (Fig. 6):

1) Price: 2 million yen per system; lower than existing product
2) Production capacity: 20 ton drinkable water per system per day; at 3 L per person, for about 6,000 people
3) Water quality: comparable level to tap water; clear the 50 items of tap water standard

To achieve these goals, the following targets were set, to be achieved by the end of the project:

1) Prototype: production capacity at 1/10 of the production model; 2 ton/day/system
2) High-speed processing of over 83 L/hour/system: 20 times or more of the column volume (about 4 L) per hour
3) Mobility
   - Downsizing to suitcase size: can be transported by one person
   - Combination of 1 μm particulate removal filter to counter cryptosporidium, organic material removal column for odor causing substance, etc., and nitrate ion removal column
   - Energy saving: manually powered, requires no power source such as electricity or engine, low noise
   - Operability: easy maintenance by simple principle and unitization
4) Nitrate ion removal: technological development to achieve drinking water standard (<10 mg/L)

The R&D scenario was as follows: AIST would reproduce the adsorption volume and selectivity functions of the "nitrate ion selective adsorbent reagent", for which the AIST owns the patent, as the elemental technology (Fig. 3); Kyowa Chemical Industry Co., Ltd. would establish the mass production technology; and Teijin Engineering Ltd. would deploy the contactless supporting and shaping technology (Figs. 4 and 5) to manufacture the adsorbent material that will remove the nitrate ion while maintaining the function.

Teijin Engineering Ltd. was also looking at the greater market of functional material for water treatment, as in the powder activated carbon, by using the contactless supporting and shaping technology.

The emergency water purification system with the two functions, organic substance and nitrate ion removal, and the suitcase size prototype with no power source, manual pump, and unitization became the clear goals under the leadership of Teijin Engineering Ltd. (Fig. 7).

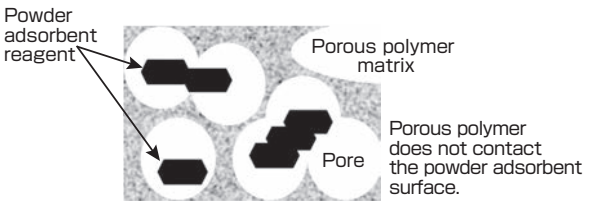

Fig. 5 Schematic diagram of contactless supporting and shaping

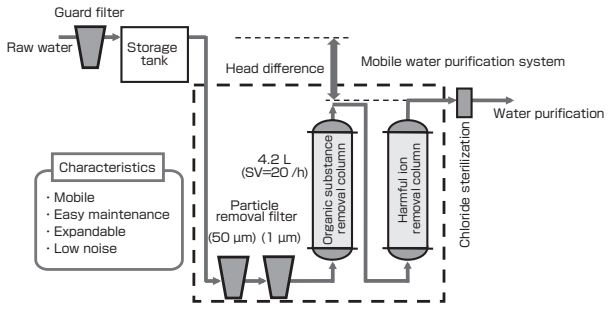

Fig. 7 Characteristic of the mobile water purification system and flow diagram

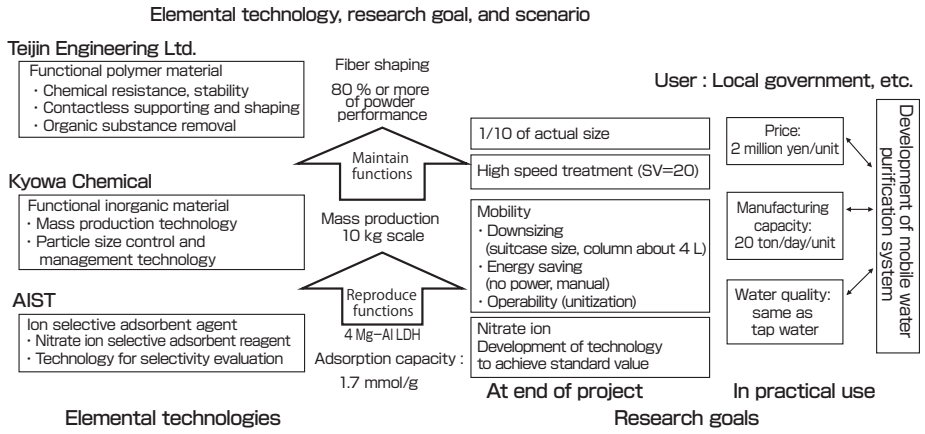

Fig. 6 Overview of the elemental technologies and research goals

3 Nitrate ion selective adsorbent "material" (topic for elemental technology needed for outcome realization)

3.1 Mass production technology (reproducibility of function)

Utilizing the experience of mass-producing similar compounds, Kyowa Chemical succeeded in the mass production of nitrate ion selective adsorbent by incorporating the AIST synthesis method into the industrial method. Although, by experience, Kyowa Chemical was aware of the positive correlation of the nitrate ion selectivity and crystalline property that were determined from the peak strength and half-value width of XRD, it was able to find the optimal synthesis condition when AIST evaluated the nitrate ion selectivity that Kyowa Chemical was unable to evaluate. To avoid clogging the nozzle when shaping, Kyowa's know-how was used for the pulverization and sifting of the adsorbent reagent, and the specification of particle diameter 45 μm or less, which was required by Teijin Engineering Ltd., was achieved.

The stance of conducting the R&D without leaking the corporate know-how to others by clearly setting the product specification, or adsorbent volume of nitrate ion > 1.7 mmol/g – powder adsorbent reagent, distribution coefficient ≒ 3000, is important in working with companies that have the technological capability.

3.2 Shaping technology (maintaining the function)

When shaping the powder adsorbent reagent, the binder ingredient covers the surface of the adsorbent and its performance decreases dramatically in the ordinary method where the adsorbent reagent and the binder are simply mixed. We conducted the shaping by using the liquid curing method for collecting lithium ion from seawater, but only about 60 % of the adsorbent performance could be obtained[3]. Treatment of large amount was difficult by the contactless supporting method[4] developed by Teijin Engineering Ltd., even when the researcher was resident at AIST Shikoku to conduct joint research over several years, and this was one of the issues.

The adsorbent material that could be produced at laboratory scale would not remove the nitrate ions when used in the large equipment at the plant. When this was carefully investigated at AIST, we reached the conclusion that the water, which in this plant was well water used directly, was suspect. We saw improvement by using the pure water line. Because the nitrate ion adsorbent material had high carbonate ion selectivity, the ion exchanging sites on the adsorbent material were all substituted when the adsorbent was washed with well water containing the carbonate ion, and the adsorbent became inactive against the nitrate ion.

We considered reviving the adsorbent material that failed to remove the nitrate ion with high concentration of saltwater, and found that it could be revived. That the spent nitrate ion adsorbent material could be used repeatedly was one of the unexpected results. However, it was also found that more pure water was required to produce the drinking water that could be manufactured by the water purification system. Therefore, the use of this system would be limited in times of normalcy. It was also projected that the nitrate ion removal performance would decrease if the carbonate ion was present in the polluted water.

4 Merit of the consortium and the remaining issues for commercialization (synthesis method for outcome realization)

Product realization was difficult with joint research with companies only. Therefore, we developed the nitrate ion adsorbent "material" by establishing a consortium and jointly setting the R&D objective. As a merit, the participating industry, government, and academia obtained the research funds as the joiners of the collaboration, and were able to focus on the product realization. By conducting the research using public funds, the private companies were given time limits and obligations, and this allowed them to achieve numerical objectives that they wrote in the proposals and were able to create a basic prototype (Fig. 8).

The follow-up research was continued for three years toward product realization. What remained were the developments of the system that instantly determines whether this water purification system can be used effectively, and the system for real time monitoring of the purification capacity. Teijin Engineering, the main body of the commercialization effort, terminated the development of this product in FY 2010.

5 Conclusion (evaluation of the results and future development)

Concerning the self-evaluation of achievements, we reached the fourth stage out of ten. It should be reemphasized that the issues that must be solved before commercialization are

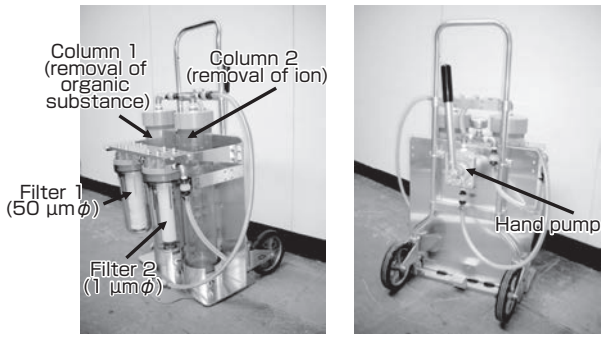

Fig. 8 Prototype of the mobile water purification system (exhibited at Hannover Messe 2008)

the function to instantly determine whether this purification system can be used effectively and the function to monitor the purification capacity in real time. We shall continue the R&D to solve these issues.

What I felt most strongly in this research is that the technology resides in people, and the continuation of technology is the responsibility of the organization. Among the people who cooperated in the joint research, there were the so-called baby boomers who were no longer in the forefront but had top-notch skills. Many things could be accomplished only because of their expert craftsman skills, and I fear that the technology may disappear if the organization is unable to pass on this technology.

The situation is similar at AIST, as the contract employees who accumulate the know-how by getting their hands directly on the project become distant from the work when a project finishes. When a foreign student learns the skills and returns to his/her home country, he/she can work as an expert of that research. However, an organization that fails to pass on the technology to the next generation because of some reorganization will cease to exist when the people with skills leave.

As the next development, we shall spend effort on the development of the sensor that can detect the nitrate ion in real time. The realization research of the ion selective adsorbent reagent will be done by applying the technology for selective adsorbents that was accumulated so far. This will be applied to resource, energy, environment, and health fields, and we hope this will produce some sort of product.

Acknowledgements

This technology was developed under the leadership of Takahiro Hirotsu, who was the Deputy Director of the Health Research Institute, AIST and the representative of "Development of mobile water purification system by the contactless compositing of nano-particles with separating functions", Consortium R&D Project for Regional Revitalization (FY 2006~2007). I express my thanks to: the engineers and researchers who participated in the project, including the people of AIST Shikoku, Teijin Engineering Ltd., and Kyowa Chemical Industry Co., Ltd.; the people of Awa Paper Mfg. Co., Ltd., Kagawa Prefectural Industrial Technology Center, Tokushima Prefectural Industrial Technology Center, Faculty of Engineering of the Kagawa University, and Naruto University of Education; and late Kyoya Tamura and Ryoichi Nishimura of the Shikoku Industry and Technology Promotion Center (STEP) who provided support as the managing entity.

Notes

Note 1) Survey conducted to understand the overall situation of the regional groundwater quality.

Note 2) Survey conducted for the continuous monitoring of the region in which pollution was detected.

Note 3) Here, the terms adsorbent "reagent" (Fig. 3) and adsorbent "material" (Figs. 4 and 5) are distinguished as follows.
Adsorbent reagent: a compound substance that can be expressed as one chemical equation. In the case of the inorganic ion exchanger, it is powder. In many cases, phase separation may be difficult if it is used directly for water treatment.
Adsorbent material: a material made by shaping the powder adsorbent reagent with binders, to make the phase separation easy when it is used in water treatment. Since it contains substances other than the active ingredient, performance per volume decreases compared to the powder adsorbent reagent.

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Author

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Completed the doctorate course at the Department of Molecular Science and Technology, Graduate School of Engineering Sciences, Kyushu University in 1993. Joined the Shikoku National Industrial Research Institute, Agency of Industrial Science and Technology in 1993. Worked as the planning officer of the Tsukuba Planning Headquarter, AIST. Also worked at the Research Institute for Environmental Management Technology and Health Technology Research Center. Currently, leader of the Health Hazard Reduction Technology Research Group, Health Research Institute. Participated in research on boron isotopes. Currently does research in the development of adsorbent reagent that is selective to harmful anions and the technology to reduce health hazard substances.

Discussions with Reviewers

1 Setting of the product specs

Question (Norimitsu Murayama, Advanced Manufacturing Research Institute, AIST)

Your indication of the product specs is very instructive: "The stance of conducting the R&D without leaking the corporate know-how to others by clearly setting the product specification is important in working with companies that have the technological capability". In this R&D, please tell us which organization took the leadership in setting the product specifications. Also, can you talk about your efforts on the breakdown from product spec setting to goal setting of the elemental technologies?

Answer (Akinari Sonoda)

As written in the Acknowledgement, the product specs were set under the leadership of Principal Researcher Hirotsu (currently Deputy Director) who was the research representative. As written in "2. Objective of the R&D", in setting the product specs, we set the goal that would allow us to win the competition against the current product, and the breakdown into elemental technologies started from there. Particularly, the aim at SV=20 was set for the flow rate, and we jumped into the experiment without certainties. As a result, although the treatment volume per column volume decreased, we were able to produce drinking water that fulfilled the tap water standards.

2 Reason the product was not realized

Question (Akira Kageyama, Innovation Promotion Headquarter, AIST)

This paper presents the development of the nitrate ion selective adsorbent "material" to supply drinking water in times of emergency, conducted jointly with private companies, and it achieves the technological objective through integrated R&D. On the other hand, the company made the final decision of halting the product realization of the water purification system. The reasons include the cost compared to the competing technology and the market size estimation (or projection) as well as the technological objective. Does that mean that the goal setting was too loose?

Answer (Akinari Sonoda)

One of the reasons was, as mentioned in "4. Merit of the consortium and the remaining issues for commercialization", we did not do the simultaneous development of real time monitoring technology, and the user could not determine the pros and cons of using this system.

In the initial goal setting, we conducted the R&D and prototype fabrication by setting our objective as creating a product that was distinctly different from the current RO system. However, looking back at the end of R&D, not only were the objective values insufficient, but also 1) market size projection, 2) cost setting, and 3) consideration of the market development were not sufficient in terms of differentiation against the existing technology. That means the goal setting was, as a result, not sufficient.

While the above comment includes my inferences, in the R&D with the objective of product realization, it is important to review these points and plan ahead with the cooperation of the partner company.

3 Continuation of the technology

Question (Norimitsu Murayama)

I think your comment "the technology resides in people, and the continuation of technology is the responsibility of the organization" is an extremely important issue. Can you tell us your specific ideas or comments on the continuity of technology?

Answer (Akinari Sonoda)

I think the continuity of the technology is difficult in AIST, because the institutes undergo reorganizations and terminations where the name of the institute is obliterated each time. Of course, it is not possible to pass on all the technologies, and perhaps certain technologies must be selected. For example, the technology that will be replaced by new technology and will never be used in the future may disappear, but the major technology that will be the main stream should be passed on by forming a group that includes all generations (age groups). The former Agency of Industrial Science Technology wasn't too bad in terms of continuation of technology, because it employed people to supplement the personnel quota. For the continuation of technology, the ideal is to have groups of five to seven people share common technologies at all times. One idea may be to have a larger category of the groups.

Integrated development of automotive navigation and route guidance system

— Product development for realization of dreams and standardization for social acceptance —

Hajime ITO

[Translation from *Synthesiology*, Vol.4, No.3, p.157-165 (2011)]

The automotive navigation system has been realized and has become popular along with the rapid development of electronic technology. The needs of people to reach destinations efficiently have pushed its development along with the projects of automotive development. Many vehicle-mounted technologies and many technologies supporting the navigation system such as communication and road data have been realized through many years of collaboration of powerful and innovative people among government, academia and industry. The technologies are to meet Intelligent Transportation Systems (ITS) international standards. Since the navigation interface system is an onboard device observed and operated during driving, securing safety, especially that related to human factors is an important issue. In this paper, the history of the development of the navigation system, research on human factors and standardization to enable social acceptance are described.

Keywords : Navigation, route-guidance system, ITS, human factor

1 Background

The number of automobile possession increased rapidly and the performance of automobiles improved dramatically in the 1970s. However, considering the matter from the aspect of transportation, the roads were insufficiently constructed in terms of both quality and quantity, the networks were incomplete, the street signs were sparse and difficult to read, and the commercially available roadmaps were crude. A driver was met with considerable challenge when driving to an unfamiliar destination due to the above factors, as well as due to the Japanese addresses centering on town names (unlike the street names being indicators in the United States and Europe).

On the other hand, other than the instruments such as the speedometer that were mandatory for driving, the only equipment aboard a car was a clock and an AM radio, and navigation meant using the compass and the roadmap. [Presence of demand]

The precursor of automotive navigation (herein after, will be called “navigation”) was the instrument used for marine and flight navigation. The navigation method is the identification of the current position and bearing. In the early days, this was accomplished by a sextant and a clock, and more recently by radio beacons. Since the travel range of an automobile is narrow and limited to roads, these methods were insufficient for automotive navigation.

Therefore, the United States started the R&D of satellite positioning, beacon, and route guidance system from the 1960s[1]. [Presence of example]

In Japan, projects for traffic control and navigation were commenced by various agencies and ministries from the latter half of the 1970s. This kicked off the researches for the elemental technologies and the systems for navigation.

The 1980s was an age when automobiles started to be controlled by electronics. High performance, downsizing and lightweight, and low cost were achieved in various fields (semiconductor and circuit, sensor, software, display, simulation, and other technologies) supported by the rapid development of electronic technologies. The application and diffusion of communication technology as well as the rapid development of satellite technology were also contributing factors. [Development of supporting technologies]

The navigation started from the engineer’s dream of “making a device that will guide you to a destination that you are visiting for the first time”. The ideal is door-to-door navigation. Moreover, the user is not necessarily a highly trained driver or navigator like with ships or airplanes. In chapter 2, the changes in navigation as a commercial product will be explained according to the key phrases shown above in brackets [ ]. We shall also see how the technological issues shifted in the process of product realization. In chapter 3, how the technological issues were solved is explained. In

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navigation, safety must be ensured to obtain acceptance of society, since it is a device operated and viewed while driving. Therefore, in chapter 4, the R&D for human factors, the activities to establish international standard, and the development of guidelines for promoting social acceptance will be described.

The technologies that comprise navigation span across wide-ranging fields. Therefore, as shown in Fig. 1, the technologies for product realization and the supporting technologies, as well as the activities for social acceptance will be described. The technologies that have become obsolete are shown in dotted lines. While Ikeda *et al.*[2] specifically discusses the on-board and infrastructure technologies needed for navigation from the standpoint of a navigation manufacturer, in this paper, I write from the standpoint of the car manufacturer that places importance on the integrity as a on-board equipment and its social acceptance.

2 History of planning and product realization

One of the objectives of the car manufacturer is to sell the car, and it is important how much the functions and equipment in the car provide satisfaction to customers in terms of convenience, safety, entertainment, and design. It is a matter of cost-effectiveness.

The navigation was developed from the engineer's dream that the customers might be pleased to see such a product.

Since its launch, the navigation became standard equipment in high-priced, high-grade cars, and many highly competitive aftermarket (market for non-genuine parts and equipment) products were introduced. As a result, it became an element that must be included in the basic structure and design of the instrument panel where the navigation will be installed, early in the process of automobile planning. This involved wisdom and effort spent on the numerous aspects of design, evaluation, and manufacturing, such as the car design, strength, durability, visibility and operability during driving, ease of installment and removal, electromagnetic compatibility, and collision safety.

2.1 Early planning: Realization of technology to satisfy the [presence of demand] and [presence of example]

The objective of the navigation is, as stated before, to guide the driver to the destination. The product planning will involve making a device that indicates the route in a legible, understandable, and precise manner while driving.

The first product was the electronic compass launched in 1980, and this received and displayed the current bearing

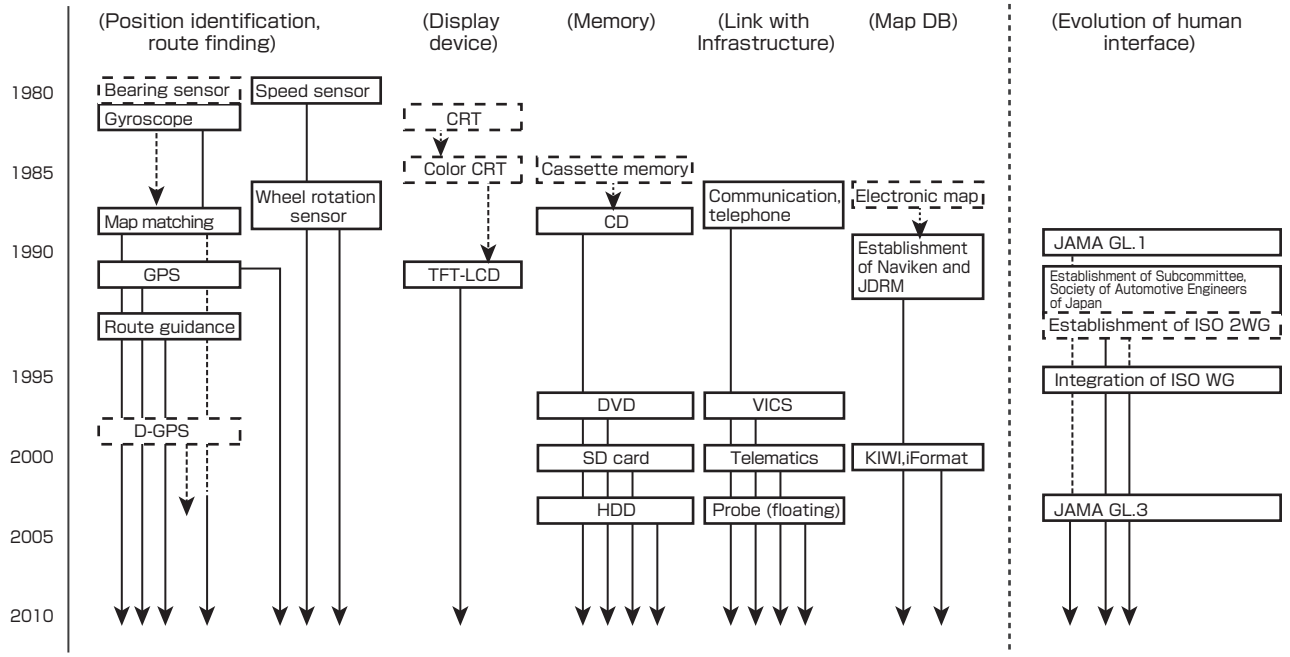

Fig. 1 Development of technology

of the car as electronic data. The current location and destination on the roadmap were sought using the displayed bearing of the car, direction of the road, and landmarks. The second product was NAVICOM that used dead reckoning, where the current position was estimated from the distance traveled and the bearing data of the electronic compass, to display the direction to the destination and the remaining distance from the start point (current position) to the destination point. It was installed in Toyota Celica XX in 1981. Nissan launched a similar product at the same time. Honda's Electro Gyrocator employed the method of using the gas rate gyroscope to calculate the changes in azimuth rather than the bearing. The fact that similar products were launched at the same time indicates that the engineers' dreams were shared with society, and they tried to realize their dreams using the emerging electronic technology. The Electro Gyrocator set the map display by employing the CRT[Note 1)] display screen. In 1985, Toyota Soarer was equipped with the Electro Multivision that used a color CRT to display diagnosis, fuel consumption monitor, highway map, drive information (suspension condition), manual for on-board equipment, TV (worked only when the car was not in motion), and others. These were part of the information display function installed in later navigation devices. To provide the manual and map information, the cassette tape that was used generally for music was used as the memory medium.

2.2 Development phase after market introduction: Use of [supporting technology]

In 1987, the Electro Multivision, which was a product close to the current navigation device and deployed the CRT display and dead reckoning, was installed in Toyota Crown. The navigation was added as one of the functions of the on-board information device that started from Toyota Soarer. This car used CD[Note 2)] as the memory medium containing map information, and digital map display was possible. The digital map data was initially prepared by the individual automobile companies, but unification movement occurred[2] since the development and maintenance costs of the maps were great. The memory evolved from cassette tape to CD and DVD[Note 3)], and then to SD[Note 4)] memory card and HDD[Note 5)]. This led to the increased speed and capacity of data storage, and enabled multiple functioning. As the memories for audio and computer developed, these technologies were used where appropriate to automobiles.

In 1991, the display shifted from CRT to TFT-LCD[Note 6)] with significant achievement in thinning, lightweight, and low voltage. Installability in cars increased dramatically. Also, the positioning precision was increased due to the use of GPS[Note 7)] that was considered to be a specialized military technology. In dead reckoning, the current location is obtained by calculating the travel distance information and azimuthal/angular velocity information from the sensors, and if the sensor information contains errors, accumulated positional errors will result. In GPS, the vehicle position is obtained continuously as long as the reception is alive, and temporary errors can be corrected. Also, the position can be corrected by map matching where the swept path of the car and the map data are compared[2], and this improves the positional precision, and enables various functions such as route guidance, swept path display, and point registration based on the route-finding software technology. Hence, a practical navigation became possible with the introduction of 32-bit microcomputer. This was a step toward door-to-door navigation that is the goal of car navigation.

2.3 Turning point

2.3.1 Turning point of route guidance: Use of telecommunication

1) Development of VICS and others

In 1996, VICS[Note 8)] was created by the collaboration of the National Police Agency, former Ministry of Posts and Telecommunications, and former Ministry of Construction. VICS is a system where the navigation device receives the traffic information (such as traffic jam, expected time of arrival, accidents/stalled cars/construction areas, speed and lane limitations, position of parking lots, and vacancies of parking lots) that are transmitted by optical beacon, radio beacon, and FM multiplex broadcasting, to obtain information for selecting the shortest route, as well as for displaying information. Currently, it is estimated that this is installed in about half of the car navigation devices. This means that the car no longer runs alone, but is linked with the infrastructure, can exchange information, and select/determine the best route.

Also, the ITS[Note 9)] on-board device that integrates the DSRC[Note 10)] and the navigation device is being introduced. This provides the navigation, VICS, and ETC[Note 11)] in a single on-board device, whereas they used to be provided individually.

2) Issue: Central navigation

Rather than the individual cars doing the route finding, it may be more efficient and precise if the data for current position and destination are uploaded, and the infrastructure such as the traffic control center would offer routing and guidance while considering traffic jam control. This is a future issue.

3) Additional external information

Many applications of the navigation display are expected. One is the collision avoidance system. The display for cars that approach from the blind side in an intersection and warning for traffic jams ahead of a blind curve using the road-to-vehicle communication are being tested.

2.3.2 Turning point of map database: Use of drive control

This is the application of map data to driving. Of the roadmap data, the road information such as incline and curves are used to automatically conduct shift up/down of automatic transmission, speed control, and suspension tuning, and these are expected to be useful for safe driving. Although some cars already possess the shift-down function of automatic transmission before a curve, such application may determine the information to be included in the next-generation map information, and therefore, may be a major issue in the future.

2.3.3 Creation of new services

Telematics[Note 12)] is becoming widespread. This is a service provided by the car manufacturer to its customer to aid driving by exchanging information such as traffic jams through dialog on the telephone or interactive communication. The emergency communication service that provides rescue response in case of accidents and breakdowns is currently in operation.

3 Changes in the technology

3.1 Navigation technology: Position identification technology as a core technology

As mentioned in subchapter 2.1, car navigation started with the application of electronics to the compass. Since electronic data for bearings were necessary for dead reckoning, the geomagnetic sensor was employed. Although geomagnetism was a small value around 3×10^4 nT, its disadvantages were increased errors due to the magnetization of the vehicle body, power lines, railroads, and mountains. One of the causes of the body magnetization was the electric current in the overhead wires while driving through a railway crossing, in addition to the partial magnetization that occurred when the iron material is pressed in the pressing process during automobile production. Also, one of the characteristics of geomagnetism is that the magnetic pole and the true poles of the earth do not match, and it is usable only with limited precision in countries with small land area like Japan and where the declination fits within approximately 5 to 9 degrees west. In countries like the United States, the distance between the east and west coasts is so large that the declination is too large to be usable. Therefore, when introducing the electronic compass, its use was limited for use in Japan. The demagnetization device for the whole automobile was created as a measure against magnetization during production, and the completed products were demagnetized. To continuously check the magnetization accumulated by driving, the car was rotated 360 degrees and the geomagnetic sensor output was electronically corrected.

By estimating the current position (dead reckoning) by calculating the travel distance and speed (from vehicle speed sensor for speedometer; later from wheel rotation sensors) and bearing data (electronic compass), and by calculating and displaying the distance and bearing to the destination, the NAVICOM and then the early navigation[3] were realized. On the other hand, the Electro Gyrocator obtained the changes in azimuth using the gas rate gyroscope, but later this was downsized and the product evolved by using on-board optical fiber gyroscope and vibratory gyroscope[2].

The situation improved when it became possible to continuously receive the current position by using the GPS of the American military satellites. The early GPS for nonmilitary use had poor accuracy of about 100 m, and reception was cut off in some places such as the shadows of buildings, underground, and tunnels. The current position was estimated using the GPS data and map matching. However, there were road structures that caused errors such as the overlapping layer of regular roads and highways. Therefore, the navigation was usually corrected by the speed and distance signals built into the automobiles, the detection of rotational difference of the left and right wheels, and the acceleration sensors and gyroscope built in the device. The differential GPS system that corrected the GPS data using fixed (broadcasting) stations with known positions was introduced, but this was terminated as the GPS increased in accuracy. In the future, the position precision is expected to improve through the GPS data supplementation by the quasi-zenith satellite Michibiki that is being developed in Japan.

3.2 Roadmap database: Core technology 2 – placing the car position onto the map

The second technological development was the development of the roadmap database. The database is the data for drawing the map that serves as the interface for the user, and for defining the road network. The network is expressed by the link (the road) and the node (intersection), and is used for route finding, required time calculation, traffic jam information processing, and others. There are various levels of roads from community roads to highways, and different people are often in charge of management, and considerable cost is required for the database creation as well as its update and correction. Therefore, while the databases were started by individual manufacturers, the Naviken (currently, the Navigation System Researchers' Association) and the Japan Digital Road Map Association were established to standardize the format, data, and registration method. Later, the Japanese car manufacturers, navigation manufacturers, and map companies created the map data for navigation known as the KIWI format. This was standardized as JIS D 0810, and later as ISO/TS[Note 13)] 20452 at the ISO/TC204/WG[Note 14)]3 (see subchapter 4.1 for ISO/TC204). From the beginning, there were arguments that it was unnecessary to include the map data for remote areas where no one would go, and the mechanism for providing the necessary map data by telecommunication, for example iFormat, was introduced. The GIS[Note 15)] is being researched mainly by the Geographical Survey Institute of Japan, Ministry of Land,

Infrastructure, Transport and Tourism, and advances in this field are expected.

3.3 Evolution of human interface: Core technology 3 – route information display for drivers and safety of the operation

The hardware for displaying the map started from CRT to the currently mainstream TFT-LCD that is lightweight, thin, and energy saving. Map display technology include the north-up display that simulates reading the paper map, heading-up display where the direction of travel is displayed at the top, blow-ups of intersections, and turn-by-turn display that shows the distance to the intersection where the turn will be made and the direction of the turn. The bird's-eye view display is currently widely accepted. This is an easy-to-use map display where the detailed close-area map and the rough distant-area map are provided. Also, there are various display methods including the use of symbols along with better image discrimination by use of multiple colors. With the increased resolution of the display, visibility and legibility increased, but the selection is up to the driver's preference. There seems to be a national preference, and turn-by-turn display is popular overseas, and for hardware, the low-cost, small, and removable PND[Note 16)] diffused widely.

For operation, the ordinary switch, touch panel switch where the user touches the screen, voice recognition, and remote control are employed.

Initially, the navigation was installed in the lower part of the center cluster, and duration was needed for eye movement while driving. From the human factor research, it was known that a higher position would be better, but there was resistance to changing the traditional interior design and there were problems with the placements of ducts and outlet of air conditioning. With the appearance of TFT-LCD, the installment position was reviewed, and now it is installed in the upper part of the center cluster to ensure good visibility and legibility while driving without interfering with driving maneuvers, as well as collision safety. In Toyota Crown Majesta and BMW, the turn-by-turn display is shown in the HUD[Note 17)] to reduce eye movement while driving.

3.4 Projects in Japan and overseas: System creation with infrastructure and on-board device through government projects

The fourth technological development is the establishment of various projects to consider the technology and system including navigation.

In the United States, there were projects such as the Route Guidance with Map Matching System, which is a newspaper delivery navigation by Robert French[1], and the ERGS[Note 18)] and IVHS[Note 19)] led by the FHWA[Note 20)] in the early 1970s. In Europe, there were R&D projects promoted through government-industry-academia collaborations[4] such as the ALI[Note 21)], DRIVE[Note 22)], and T-TAP[Note 23)].

In Japan, some projects started in the 1970s included: the large-scale project CACS[Note 24)] of the Ministry of International Trade and Industry; AMTICS[Note 25)] of the National Police Agency; and RACS[Note 26)] of the Ministry of Construction. In the 1990s, more projects paved the way to the age of ITS: ASV[Note 27)] of the Ministry of Transportation; ARTS[Note 28)], AHS[Note 29)], and Smartway of the Ministry of Construction; UTMS[Note 30)] and DSSS[Note 31)] of the National Police Agency; and SSVS[Note32)] of the Ministry of International Trade and Industry. After R&D and demonstration tests, these projects became the IT[Note 33)]/ITS strategy of Japan. In 1996, the five ministries announced the ITS Grand Design[Note 34)], and the "advancement of navigation" was stated therein. An organization called ITS Japan[Note 35)] that brought together the government, industry, and academia was created with national backup. The Ministry of Posts and Telecommunication provided support for the radio administration.

About 30 years have passed since the start of the navigation, and there is still potential for development in terms of technology. In the future, further developments are expected, such as: the improvement of current position accuracy; the enhancement of route finding such as the fastest and most ecological routes and routes according to the driver's driving skill, as well as avoiding traffic jams; the incorporation of information for new roads, accidents, and roads under construction; and the guidance for how to approach destinations. The expectation for Japanese technology is great in areas of information exchange using the DSRC, improvement of traffic jam detection through the probe system, and the quasi-zenith satellite Michibiki mentioned earlier.

4 International harmonization for human interface: Effort on safety to promote social acceptance

4.1 Guideline for social acceptance and preparation for international standardization

While the engineers created the navigation that they dreamed through the technologies and efforts of many people as described above, they not only created the product but also engaged in activities to get it accepted in society. Although the navigation helps driving, the display of information such as maps forces the user to take the eyes off the road, and there was a concern from the beginning that it may be distracting. When the product is developed and introduced into the market, problems through inappropriate use may occur; and the engineers were aware that if that happened, the technology that may be useful to the people would be eliminated from society. In DRIVE, a European project, this concern was stated clearly, and the human factor

considerations were done from the beginning[5]. In Japan, the visual timing or how the driver used the navigation was studied in RACS[6]. The human factor research was conducted concurrently with the technological development of the product mainly by the car manufacturers. The activities to standardize the human interface design and to establish the guideline were done by the industry.

In Japan where the navigation was introduced to the market for the first time in the world, under the support of the ministries, "Guideline for In-vehicle display systems" for the industry was drafted and published by the Display(CRT) Experts Group, JAMA[Note 36)] in 1990, shortly after the market launch. There, the map display of minor roads in cities and the operation for destination setting while driving were banned. This was to indicate to society that the industry was considering the safety of using the device when it was introducing a new technology called navigation to society.

Around 1990, looking at the future prospects for the ITS device, interest in development and international standardization of ITS increased. In 1993, ISO/TC[Note 37)]204 (TICS[Note 38)], currently renamed ITS) was formed as an organization to promote international standardization. In 1994, the First ITS World Congress was held in Paris, and thereafter it is held in rotation annually in Asia-Pacific, North America, and Europe, to promote the technology and product. The ISO activities enabled the creation of the standard with international harmonization and played the role of supporting the development of ITS, and there is no doubt that the navigation that was spreading in Japan contributed greatly.

In Japan, the TC204 Committee for Japan (currently ITS Standardization Committee) and TC204 Technical Committee took the lead and contributed to the national interest in both technological development and standardization.

The ISO/TC204/WG11 (Route Guidance and Navigation Systems) was in charge of the system, message set, and interface. The author was the international expert of ISO/TC204/WG13 (Human Factors and MMI[Note 39)], hereinafter will be called WG13) and ISO/TC22/ SC[Note 40)]13/WG8 (TICS On-board MMI, hereinafter will be called WG8) from 1993 to 2003. The initial responses of the European experts were: "Is it okay that people drive and watch TV in Japan?" or "Isn't navigation unnecessary because you can get to the destination if you look at the road sign, street name, and building number?" Therefore, at the First WG8 Meeting in Paris in 1994, I used the video "Why navigation system was necessary in Japan" that was prepared by the Human Interface Subcommittee (named MMI Subcommittee at the time) of the Society of Automotive Engineers of Japan. This committee represented Japan in the role of international standardization of human factors, and helped the adjustment of opinions in Japan, preparation of data, and diffusion of the results of international meetings in Japan.

4.2 International standardization of the design requirements of navigation

The international standardization started at the two WGs of ISO (Table 2). The base of consideration was the aforementioned JAMA guideline "Guideline for In-vehicle display device systems" provided by Japan, and the

Table 1. Standardization of major human interface guidelines, standards, and regulations[7]

1990	JAMA Guideline 1.0: Elimination of minor roads from the screen, incapacitation of destination setting function while driving
1992	Establishment of ISO/TC204
1993	Establishment of ISO/TC204/WG13
1994	Establishment of ISO/TC22/SC13/WG8 Dialogue management principles (released 2002), auditory presentation of information (released 2004, revised 2010), driver visual behavior (released 2002), visual presentation of information (released 2002), suitability of TICS for use while driving (released 2003), message priority (released 2004), deliberation started
1995	JAMA Guideline 1.1: Limitation of the number of displayed letters while driving
1999	JAMA Guideline 2.0: Change to minor roads in cities allowed to be displayed when on the actual road Road Traffic Law Article 71: Prohibition of handholding the cell phone, prohibition of gazing at the video screen while driving
2002	JAMA Guideline 2.2: Display device must be installed within 30 degrees of visual angle Road Traffic Law Article 109: Principle of display, operation, and displayed information in car-mounted device Start deliberation of the occlusion method at ISO/TC22/SC13/WG8 (ISO released 2007)
2004	JAMA Guideline 3.0: Regulation of maximum operation time of operable function while driving Road Traffic Law Article 71 revision: Strengthened penalty for handholding of cell phone while driving Start deliberation of LCT[Note 46)] law at ISO/TC22/SC13/WG8

Table 2. Items of standardization (at start of TC204/WG13 and TC22/SC13/WG8)

No.	Title	Content	Item Convenorship
1	Human factor literature collection	Database creation for TICS human factor	USA
2	Human factor of car navigation system	Limitations seen from human factor	USA
3	Human factor of driver-vehicle system	Limitations seen from human factors such as ACC[Note47)] and FVCWS[Note 48)]	USA
4	Integration	Message priority, addition of warning integration	Japan
5	Visual information of presentation	Requirements of display viewing	Italy
6	Auditory information of presentation	Warning by sound/voice	France
7	Driver visual behavior	Test condition for recognizability of display while driving	UK
8	Dialog management principles	Recommended values for information to reduce driver workload	Sweden

HARDIE[Note 41)] guideline, which was the result of DRIVE II provided by Europe. The European guideline included items such as "map with highlighted route shall not be displayed" which did not match the actual situation of the Japanese navigation. The rationale was that the driver should not be forced to think, but only should be given instructions to do things. This was an item to be considered in the later standardization work.

In 1995, the WG13 was deleted and integrated into WG8. At the time, it was feared that when the driver was flooded with information, the driver would fail to process the information and might ignore the safety information. Hence, the method of presenting the information was considered. Japan became in charge since it was most advanced in product realization. Therefore, the concept of message priority was introduced at the ISO/TS 16951 Message Priority that is part of Table 2 No.4. This clarified the ranking method for the priority of information that was important for safety and that for which immediate action must be taken. For the integration of warnings, Japan and the United States are preparing the ISO/CD[Note 42)] 12204 Warning Integration.

4.3 Revision of independent guideline that matches the actual usage and legislative development

As a result of following the guideline, the JAMA Guideline was revised in 1995 and 1999 as shown in Table 1. In the Road Traffic Law of 1999, the viewing of moving images such as TV while driving was banned. This was mainly to regulate the TV viewing that was unchecked at the time. The moving image was carefully defined to prevent the ban on viewing the navigation screen. In 2002, the JAMA Guideline Ver. 2.0 was revised as Ver. 2.2. The main addition was the position of the display device, and it stated that the display should be placed within 30 degrees angle of vision. The same year, the Road Traffic Law was revised in accordance with the Guideline, and legislative development was achieved.

As mentioned in subchapter 4.1, since viewing and operation while driving would lead to distracted driving, it became necessary to regulate the viewing and operation from the perspective of safe driving.

4.4 Response to driver distraction

The key point of the discussion was to what extent the distraction behavior by the driver in moving the eyes from the front visual field to the navigation display to read, determine, and operate while driving could be tolerated. This issue was also considered in the United States, and discussions started at the AAM[Note 43)]. As a result, the measurement and evaluation methods for driver distraction were started at the WG8 in 2002. JAMA conducted tests on the measurement of the viewing behavior of navigation and instruments and on the effect of eye movement on driving. The occlusion method, where viewing and operation were done with glasses with liquid crystal shutter that was suggested by the United States was concurrently done, and the range allowed for driving was considered experimentally. Based on these tests, the JAMA Guideline Ver. 3.0 was published in 2004. The test method ISO 16673 Occlusion Method was established in 2007, and it was already established as a guideline in Japan prior to the international standardization. I would like to emphasize that just as the Japanese have led the navigation products in the world, Japan also has led the world in the standardization of safety.

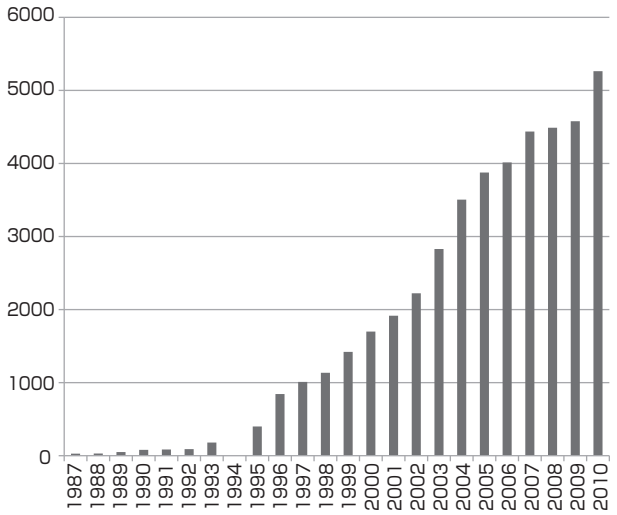

Fig. 2 Number of shipments x 1,000[8]

Considerations are done in the WP29[Note 44)] and IHRA[Note 45)]/ITS WG of the United Nations Economic Commission for Europe, and items with different levels of enforcement such as standards, codes of practice, guidelines, and laws are being established. The car manufacturers and navigation manufacturers worked on the social introduction and product development while considering the usability, safety, and compliance to international standards. This became the foundation for the government-industry-academia collaboration, and contributed to the expansion of the market as shown in Fig. 2.

5 Conclusion

The reasons for the world diffusion of navigation are the presence of demand for a device that can guide the driver to the destination, the engineers of various fields shared and considered this interest, the necessary technology appeared at the right moment of history, the manufacturers were willing to develop this as part of promoting their products, the sales of cars increased dramatically and the market grew, the support was obtained from the government organization from their expectation for creating a new industry, and it was developed in several countries due to worldwide ITS promotion movement. The results were attained by the aggregation of wisdom, and through the fusion, integration, and development of various technologies and situations. I expect contribution to the area of enhanced intelligence and automation of future automobiles. In chapter 4, I described the concurrent development of the technological developments for the product and for safety. Ujike[9] is conducting such concurrent development in the field of 3D imaging, and this approach is expected to work effectively in building the social acceptance for products that people use daily.

It should also be stated that efficient travel of an automobile to the destination not only reduces the psychological and physical workload on the driver, but also has good effect on the environment through reduced fuel consumption.

The navigation for which Japan leads the world is installed in about 40 % of the cars in Japan. It has served as a good example for the personal navigation in cell phones and smart phones. Although Japan has taken the lead in the field of navigation, currently, the overseas companies take lead in production volume and revenue with the appearance of on-board PNDs. I hope we can make actual profit from navigation, and not just be known as brand names.

Acknowledgements

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Notes

Note 1) Cathode ray tube (Braun tube)
Note 2) Compact disc
Note 3) Digital versatile disc
Note 4) Secure digital memory card
Note 5) Hard disc drive
Note 6) Thin film transistor liquid crystal display
Note 7) Global positioning system
Note 8) Vehicle information and communication system
Note 9) Intelligent transport systems
Note 10) Dedicated short range communication (an example of short range communication; ETC is an application)
Note 11) Electronic toll collection
Note 12) Word created from Telecommunication + Informatics
Note 13) Technical specification
Note 14) Working group
Note 15) Geographic information system
Note 16) Personal navigation device
Note 17) Head-up display
Note 18) Electronic route guidance system
Note 19) Intelligent vehicle highway system
Note 20) Federal Highway Administration (U.S.DOT)
Note 21) Autofahrer-Leit und Informationssystem
Note 22) Dedicated road infrastructure for vehicle safety in Europe
Note 23) Transport telematics application programme
Note 24) Comprehensive automobile traffic control system
Note 25) Advanced mobile traffic information and communication systems
Note 26) Road/automobile communication system
Note 27) Advanced safety vehicle
Note 28) Advanced road traffic systems
Note 29) Automated highway systems
Note 30) Universal traffic management systems
Note 31) Driving safety support systems
Note 32) Super smart vehicle system
Note 33) Information technology
Note 34) "Grand Design for Intelligent Transport Systems"
Note 35) Initially called Vehicle, Road, and Traffic Intelligence Society (VERTIS)
Note 36) Japan Automobile Manufacturers Association
Note 37) Technical committee
Note 38) Transport information and control systems
Note 39) Man-machine interface
Note 40) Subcommittee
Note 41) Harmonization of ATT roadside and driver information in Europe
Note 42) Committee draft
Note 43) Alliance of Automobile Manufacturers (U.S.A.)
Note 44) World Forum for Harmonization of Vehicle Regulations
Note 45) International harmonization research activities
Note 46) Lane change task
Note 47) Adaptive cruise control
Note 48) Forward vehicle collision warning system

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Completed the master's course in Applied Physics at the Graduate School of Engineering, Nagoya University in 1971. Joined Toyota Central R&D Labs, Inc. in 1971, and engaged in research of on-board millimeter-wave radar. Transferred to Toyota Motor Company (currently Toyota Motor Corporation) in 1973, and worked on the development of predictive collision radar for Experimental Safety Vehicle. Led the design for new products including Cruise Computer, Electronic Compass, Navicom, auto wiper, Speak Monitor, Back Sonar, digital meter, HUD, Optitron meter, center meter, and others. Leader of Body Section, Research Division 13, Higashi Fuji Lab in 1991, and Deputy general manager of Body Engineering Division 1 in 1993. Dispatched and transferred to Yazaki Corporation in 1998, and engaged in the development of ITS for commercial vehicles. Director of Yazaki Meter Co., Ltd in 2001, and managing director in 2006. Technical advisor of Trust Tech Inc. in 2010. Participated in the ARTS, UTMS, and ASV projects from 1991. International expert of ISO/TC204 and TC22 WG from 1993. First chairman of the Human Interface Subcommittee, Society of Automotive Engineers of Japan; member of TC204 Domestic Technical Committee; official of ITS Japan from 2004; and member, ITS Industry Promotion Study Group, Ministry of Economy, Trade and Industry in 2005.

Discussions with Reviewers

1 Employment as international standard etc.

Question (Akira Kageyama, Innovation Headquarters, AIST)

The description from setting of standard to international standardization while placing importance on the human interface issue from the product planning stage is appropriate for *Synthesiology*. Moreover, international standardization often involves the battle of national interests. Concerning this point, is it possible to indicate how many of the proposals from Japan which commercialized the car navigation as an integrated system for first time in the world were employed as the ISO and other international standards?

Answer (Hajime Ito)

Thank you for your evaluation. I think car navigation is a product that Japan can be proud of. It excels not only in electronic and communication technologies, but it was created by the wonderful fusion of individuals, companies, government ministries and agencies, organizations, and committees. At the ISO/TC22/SC13/WG8, the working group for standardization to which you refer to in your question, the theme for which over five countries pledged cooperation was placed on the table. Then, the presidency holder created a place for discussion, and each country added modifications. Since all countries except Japan, U.S.A., and Australia were European, we were disadvantaged in number of votes. However logical discussions were carried out under the greater cause of "safe driving", and Japan is now recognized as the leading country, through the experimental proofs of the draft in Japan, the cooperation of JAMA, and the legislative actions of the ministries. As a result, the message priority and warning integration proposed by Japan became the standard. Moreover, Japan provided modifications and agreements for the themes of non-Japanese presidency holders such as the occlusion method, and about 10 proposals were standardized as ISO. This means that the Japanese national interests are met, and the ISO is being established under the leadership of Japan with approval of the world in terms of technology.

2 Diffusion of car navigation

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

In the technological development of car navigation, you discuss in the first half that the open use of the GPS system and the diffusion of electronic map played important roles. On the other hand, the second half is the description of the human factor research and the role of international standardization that are main statements of the author. The fact that the diffusion of the car navigation to the masses started around 1995 fortifies the author's hypothesis. Therefore, I think the author's discussion will become more convincing if you describe the number of diffusion of car navigation published by JEITA and the movement toward international standardization.

Answer (Hajime Ito)

In addition to the technological development and infrastructure preparation such as GPS and VICS, the product power increased through the improved usability and safety guarantees. The efforts of the manufacturers, cooperation of the research institutes and academia, standardized usability, and safety all came together to increase the product power. The product started to spread from the latter half of the 1990s. I added Fig. 2 to chapter 4 to show the increased shipment of navigations.

3 Integration of technology

Question (Akira Kageyama)

Is it possible to show the changes of car navigation systems and what kinds of technologies were integrated using a table of elemental technologies and time axis? I think if you keep the text expression brief and show the technology-time table, the picture will become comprehensible and enhance the reader's understanding.

Answer (Hajime Ito)

I entered the technological elements and time axis as the development of technology in Fig. 1. I included the technological elements mentioned in the paper as much as possible to help the reader's understanding of the paper. I think one can readily see the addition of new technologies and the discard of technologies that have gone out of use.

Innovative electron microscope for light-element atom visualization

— Development of low-voltage electron microscopes in Triple-C project —

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[Translation from *Synthesiology*, Vol.4, No.3, p.166-175 (2011)]

Today, the demand for techniques to directly visualize the atomic-level structures of nano-materials and so-called soft matter (organic molecules, bio-materials, etc.) is rapidly increasing. Observing these objects using conventional transmission electron microscopes (TEM) and scanning TEM (STEM) often results in serious irradiation-induced structural damage, and the images produced have an unsuitable contrast due to the high electron-acceleration voltages. We believe that reducing the acceleration voltages to several tens of kilovolts will enable direct imaging with less damage and help produce images with a higher contrast. However, correcting various aberrations, such as spherical and chromatic aberrations (Cs and Cc, respectively) and high-order geometrical astigmatisms, is necessary to achieve atomic-level spatial resolution. In our Triple-C project, we have developed low-voltage TEM/STEM systems equipped with new Cs and Cc correctors for carbon-based nano-materials.

Keywords : Structure characterization, electron microscopy, aberration correction, nano-material, soft matter, single molecule, single atom, electronic state

1 Introduction

Currently, electron microscopy plays an increasingly important role in the characterization of nano- and bio-materials amidst the acceleration of research and development in these fields. High-performance transmission electron microscope (TEM) and scanning TEM (STEM) are expected to enable the direct visualization of structures at the single-atom/molecule level, particularly for carbon nano-materials (carbon nanotubes (CNTs), graphenes, etc.) and so-called soft matter (e.g., organic molecules and bio-related materials). The technology employed in electron microscopy[1][2] has improved considerably since the 1970s. However, previous technological developments were generally aimed at achieving higher spatial resolution by employing ultra-high electron acceleration voltages. The use of electron microscopes that were once considered cutting-edge and operated at ultra-high voltages in the order of a million volts (MV) has become limited to the observation of thick crystalline materials that are generally stable under electron-beam irradiation, such as metals, alloys, and inorganic compounds. On the other hand, the observation of non-crystalline light element materials such as soft matter by using ultra-high voltage microscopes has often been hindered by serious irradiation-induced damage to the specimens and insufficient signal intensity. The development of innovative electron microscopes is essential for overcoming these technical difficulties as well as for directly observing the dynamic behavior of single molecules and for detecting and identifying single light-element atoms.

We recognize the advantage of using low acceleration voltages for observing light-element materials such as carbon nano-materials and have pioneered techniques for directly imaging their atomic-level structures using TEMs and STEMs with 120 kV operation. In 2004, single gadolinium (Ga) atoms incorporated into carbon nano-materials were identified by electron energy-loss spectroscopy (EELS) using a STEM[3], and hexagonal networks of carbon atoms in CNTs were unambiguously detected by a TEM[4]. In 2007, individual carbon atoms that formed six-member rings in CNTs were visualized using a TEM equipped with a spherical aberration corrector[5][6]. In 2008, carbon hexagonal networks in CNTs were imaged using an aberration-corrected TEM operated at an even lower acceleration voltage of 80 kV[7]. TEM images of single-walled CNTs (SWCNTs) observed under the conditions employed in these studies are shown in Fig. 1, where the effects of spherical aberration correction and different acceleration voltages on spatial resolution and image contrast are clearly found.

Currently available TEM and STEM systems have contributed to the characterization of nano-materials, as mentioned above. However, if we presume that they will be applied to the high-resolution imaging of soft matter such as bio-molecules, they need to be further developed

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to decrease the irradiation-induced damage to specimens and improve both spatial and time resolution. No existing electron microscope is specially designed for characterizing such light-element materials. It is therefore essential to develop innovative microscopes based on concepts that are completely different from those used for previous ultra-high voltage microscopes, in order to realize the direct imaging and identification of individual atoms and molecules of soft matter. Based on these requirements, we attempt to overcome two difficult parameters that have been considered incompatible with each other with regard to conventional electron microscopes: extremely low electron acceleration voltage and atomic resolution. In 2006, we launched a full-scale project supported by JST-CREST[8] to develop new electron microscopes suitable for the high-resolution observation of soft matter with less damage to the specimens and increased sensitivity. This is the first project aimed at constructing completely new electron microscopes that are specially designed to work at low acceleration voltages.

2 Scenario for achieving our research goal

Our project to develop new low-voltage electron microscopes is supported by JST-CREST[8]. It was started in October 2006 and will end in March 2012. The originally planned design for a low-voltage microscope and its presumed application are schematically shown in Fig. 2, in which Cs and Cc denote spherical and chromatic aberrations, respectively. Based on the currently available TEM/STEM systems and the problems associated with them, we have decided to intensively develop the following three components as the most important elemental technologies for the first stage of this project.

- Low acceleration voltage electron gun: highly stable at 30–60 kV with excellent monochromaticity and luminance.
- A spherical aberration corrector having higher correction performance than existing products to fully compensate for the disadvantages affecting spatial resolution due to the use of low acceleration voltages.
- A chromatic aberration corrector having a new optical system to realize chromatic aberration correction that has been almost unprecedented so far[9].

During the second stage of the project, low-voltage electron microscopes were constructed by integrating the components including those picked up above, and their performance was examined. We originally planned to employ a TEM/STEM dual-use model equipped with both spherical and chromatic aberration correctors, as shown in Fig. 2. We later revised the plan to be more practicable and more efficient based on the progress made in the first stage, and we finally constructed two microscopes with different setups optimized for their respective applications. The performance of these microscopes was examined with the main consideration of how closely the spatial resolution d approaches its critical value, as determined by the acceleration voltage E. Therefore, instead of d, we focused on the ratio d/λ, where λ denotes the wavelength of electrons accelerated at E. Taking account that the highest spatial resolution of d = 0.05 nm previously recorded at 300 kV[10] corresponds to d/λ = 25, we aimed to obtain a d/λ smaller than 25 at a much lower E by using our new microscope.

After the completion of the performance examination of the microscopes, this project has now entered the third stage, where the designed microscopes are practically used for the observation and analysis of various nano- and light-element materials. Here, we intend to demonstrate the advantage of our low-voltage microscopes by providing scientifically valuable results that can appeal to a wide audience. We primarily use carbon nano-materials as specimens to verify the effects of using low acceleration voltages in TEM, STEM, and EELS observations, while referring to our extensive data on the same materials previously obtained by using conventional microscopes with higher voltages. At the same time, we assign this stage for detecting and solving possible latent problems in our microscopes to make them more practicable.

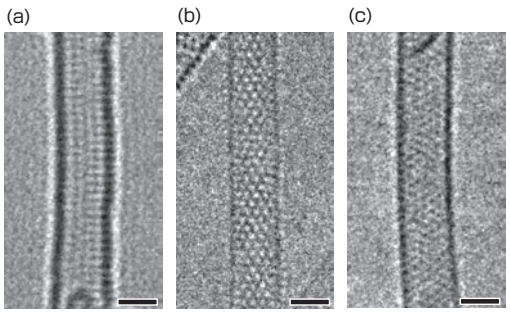

Fig. 1 Comparison of TEM images of SWCNTs
(a) Recorded at an acceleration voltage of 120 kV without spherical aberration (Cs) correction, (b) recorded at 120 kV with Cs correction, (c) recorded at 80 kV with Cs correction
Scale bar = 1 nm

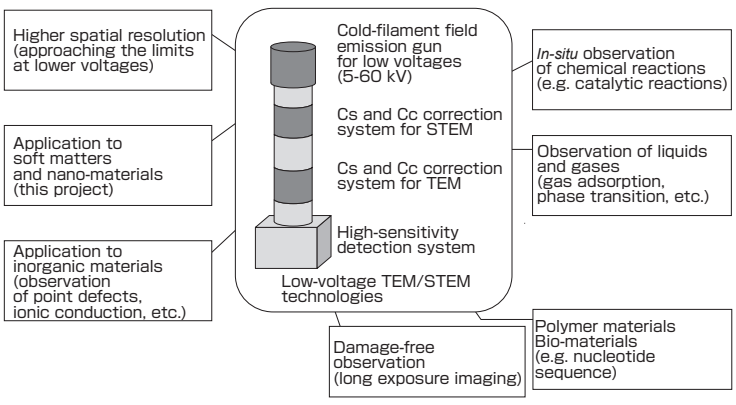

Fig. 2 Outline of low-voltage TEM/STEM and future prospects

This project has been implemented, by following the scenario outlined above, to realize next-generation, high-performance low-voltage electron microscopes based on technologies that have all been developed within Japan. We named the project Triple-C because it focuses on the following three C's: spherical aberration (Cs), chromatic aberration (Cc), and carbon (C) nano-materials. This project has been carried out through a collaboration between JEOL Ltd., The National Institute for Material Science (NIMS), and the National Institute of Advanced Industrial Science and Technology (AIST). This project allows us to combine the expertise of all these organizations, such as the theories on electron microscopy and spectroscopy, experience in developing instruments, knowledge of nano-material science and experimental skills. The JEOL team developed each component during the first stage, and constructed the microscopes and examined their performances during the second stage. The NIMS and AIST teams took charge of the preliminary planning of this project, the application of the low-voltage microscopes to nano-materials during the third stage, and reference experiments using conventional microscopes. To achieve the best results from this joint project, we fully cooperated with each other for each experiment and shared information through meetings that were held approximately every two months to check on the project's progress.

In this paper, we review the development and performance of new low-voltage microscopes as carried out by the JEOL team as the principal part of our Triple-C project. We also introduce some typical scientific results and problems associated with the microscopes with regard to the characterization of carbon nano-materials by the AIST team.

3 Elemental technologies

3.1 Low-voltage electron gun

The electron gun of a microscope has the important function of stably generating and accelerating an electron beam at a fixed voltage. It is required, in particular, for the electron guns in the Triple-C project to produce a high luminance (current density) and a small energy spread (ΔE). High luminance is necessary for identifying light-element single atoms by STEM-EELS at a high signal-to-noise ratio (S/N). A small ΔE contributes to a minimization of the blurring of images due to the chromatic aberration of the lens system. Assuming that the acceleration voltage E slightly changes to $E+dE$, the degree of electron-beam broadening due to chromatic aberration is proportional to dE/E. This implies that spatial resolution of a microscope is more seriously affected by chromatic aberration at a lower E. It is therefore essential to make the ΔE of the low-voltage electron gun as small as possible. Note that ΔE is generally evaluated as the full width at half maximum of the EELS zero-loss peak in electronvolts.

We adopted cold filament field-emission guns (CFEG) for our low-voltage microscopes because they have great advantages both in luminance and energy spread. The electron emitter and construction of the accelerating tubes, which apply voltages to electrons, were optimized for use at 30-60 kV. We also implemented measures for reducing the noise in high-tension electric sources and circuits for higher CFEG stability. As a result, excellent energy spreads of 0.27 and 0.30 eV were obtained at acceleration voltages of 60 and 30 kV, respectively, as shown in the EELS zero-loss peaks in Fig. 3[11].

3.2 Spherical aberration corrector

In electron microscope lenses, magnetic fields are applied to focus the electron beam by using the refracting effect of Lorentz forces in the fields. Although the electron beam passing through the lens system should ideally converge on a certain point along the optical axis, the focal point is actually spread out to some extent by various aberrations of the lenses, resulting in blurring and/or distortion of the projected images. In particular, spherical aberration of the objective lens of TEM is a major limiting factor of the spatial resolution. Recently, the correction of spherical aberration has been realized by using several stages of magnetic multipoles, which were incorporated in the rear of the objective lens in the microscope column[12]-[14] .This correction system itself generates negative spherical aberration to cancel the original positive aberration of the lens. A commercially available spherical aberration corrector developed by CEOS GmbH, which has become more popular both for TEM and STEM in recent years, consists of double hexapoles and transfer lenses. Each hexapole applies a three-fold magnetic field with a different azimuth, whereby the entire system corrects spherical and geometrical aberrations such as three-fold astigmatism at the same time[13].

This correction system has largely contributed to the improved spatial resolution of conventional TEM and STEM that are generally designed for operation at 100 kV or higher.

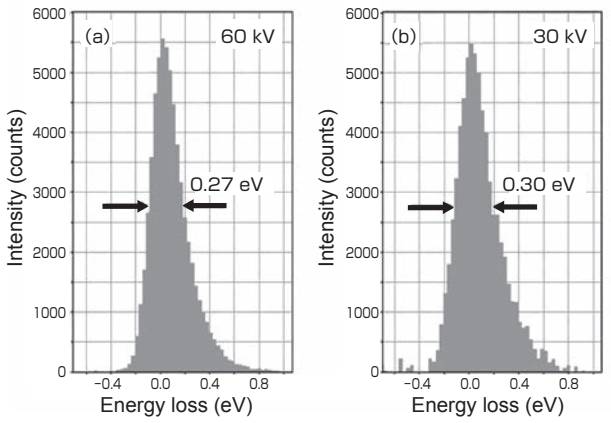

Fig. 3 Evaluation of energy spread of low-voltage electron gun
Recorded at acceleration voltages of (a) 60 kV and (b) 30 kV

However, assuming that the application of this corrector to our microscope at 30–60 kV in Triple-C project, it was predicted that the spatial resolution would be limited by the residual six-fold astigmatism, which is fundamentally inevitable in the case of this double-hexapole system. Therefore, we started to search for a completely new method to enable the correction of both spherical aberration and high-order geometrical astigmatisms up to six-fold, and finally developed an innovative correction system consisting of triple magnetic dodecapoles and transfer lenses[15]-[17].

Figure 4 shows the construction and calculated electron-beam trajectories of the conventional double-hexapole type and our new triple-dodecapole type (named as Delta type) correctors[17]. For the calculated trajectory of the conventional corrector (a), six-fold symmetry is more obvious in the higher angle region at the end of the second hexapole. This is caused by the six-fold astigmatism that is inevitably generated by the combination of three-fold magnetic fields between the double hexapoles as described above. Such six-fold astigmatism is also generated between the first and second dodecapoles of the Delta corrector, and between the second and third dodecapoles as well. In this case, however, the astigmatisms can be completely canceled out by carefully adjusting the azimuth of the magnetic field in each dodecapole. As shown in Fig. 4 (b), the calculated trajectory for the Delta corrector (b) is almost circular even at higher angles at the end of the third dodecapole, indicating that the residual six-fold astigmatism is negligible.

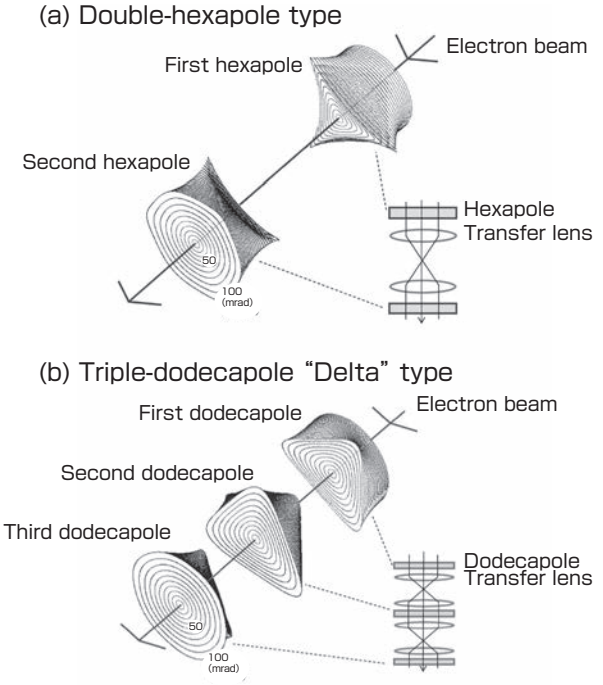

Fig. 4 Construction and calculated electron-beam trajectories of spherical aberration correctors
(a) Double-hexapole type, (b) Delta (triple-dodecapole) type

3.3 Chromatic aberration corrector

Through the Triple-C project, we have developed a new chromatic aberration corrector for TEM in addition to a Delta spherical aberration corrector. As described in subchapter 3.1, the degree of electron-beam broadening due to chromatic aberration is proportional to $\Delta E/E$, which implies that spatial resolution is more seriously affected at a lower E. Therefore, chromatic aberration correction of the objective lens significantly contributes toward improving spatial resolution and image quality at 30 kV, even when the microscope is equipped with our new low-voltage CFEG. In this project, we developed a completely new system for chromatic aberration correction, for which two thick quadrupole fields are applied to generate a combination concave-lens effect[17]-[19].

Figure 5 shows the calculated electron-beam trajectory of our new chromatic aberration corrector consisting of two thick dodecapoles and several transfer lenses. Each dodecapole of this corrector is used to superimpose magnetic and electrostatic quadrupole fields, where the deflection sensitivity of an electron beam depends on the acceleration voltage in a different manner compared to the magnetic field of the objective lens. The two-fold stigmatism introduced at the first dodecapole is canceled at the second dodecapole, and the entire system functions as a concave lens with negative chromatic aberration. We installed this corrector in the microscope and examined its performance by slightly changing the acceleration voltage from 30 kV. We found that the defocus remained unchanged even when the acceleration voltage was changed by ± 0.025 kV, which confirms that the chromatic aberration was successfully corrected.

4 Integration of elemental technologies

4.1 Construction of low-voltage electron microscopes

We constructed experimental systems of low-voltage electron microscopes by integrating the elemental technologies described above and then examined their performances. Two microscopes with different constructions optimized for their use were developed separately, enabling us to efficiently proceed with their examination and reach the stage of

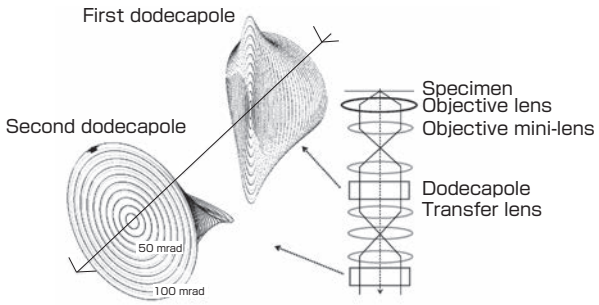

Fig. 5 Construction and calculated electron-beam trajectory of new chromatic aberration corrector

their practical application as early as possible. The major components of these experimental microscopes are listed in Table 1. The first microscope is a spherical aberration-corrected TEM/STEM for 30-60 kV, while the second microscope is a spherical and chromatic aberration-corrected TEM for 30 kV. They were initially developed as specially designed low-voltages microscopes. We obtained valuable results regarding their performances as detailed below.

4.2 Performance of the first low-voltage microscope (TEM/STEM)

We started the operation of our first experimental microscope (Fig. 6) equipped with two Delta spherical aberration correctors for TEM and STEM modes in 2008. Through our preliminary experiments using a conventional electron gun (Schottky-type FEG) for a 200 kV-class commercial microscope, we confirmed that spherical aberration and high-order geometrical astigmatisms up to six-fold were canceled by the Delta correctors both in TEM and STEM modes. We then installed the new low-voltage CFEG and an EELS spectrometer in the microscope.

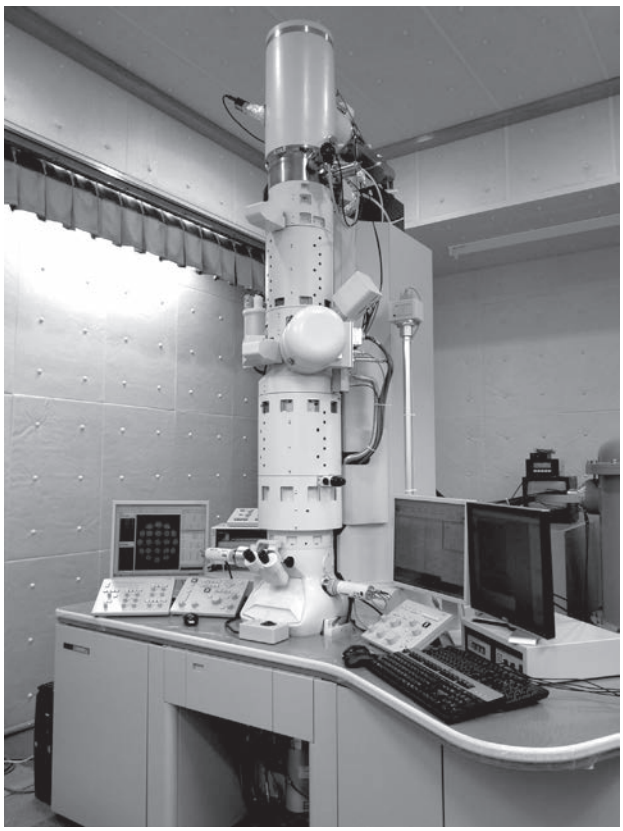

Fig. 6 External view of the first experimental microscope (spherical aberration-corrected low-voltage TEM/STEM)

Table 1. Main functions and constitution of experimental low-voltage electron microscopes

	First system	Second system
Main function(s)	TEM/STEM/EELS	TEM
Acceleration voltage(s) (kV)	60, 30	30
Low-voltage electron gun	○	○
Spherical aberration corrector (for STEM)	○	–
Spherical aberration corrector (for TEM)	○	○
Chromatic aberration corrector (for TEM)	–	○
Spectrometer for EELS	○	–

○ : equipped, – : not equipped

We evaluated the spatial resolution of this microscope in STEM mode by using it to observe silicon (Si) <110>, which is conventionally used as a standard sample for high-resolution STEM[11]. Both of the annular dark field (ADF-) STEM images observed at 60 and 30 kV (Fig. 7) clearly show the so-called dumbbell structures, where the projected atomic columns in each “dumbbell” are separated by 136 pm. Furthermore, the smallest lattice spacing observed here was 96 and 111 pm at 60 and 30 kV, respectively, as shown by fast Fourier transformation (FFT) of the ADF images. Regarding these distances as spatial resolution d, the ratios of d to the wavelengths of electrons λ, d/λ, were found to be 20 and 17 at 60 and 30 kV, respectively. Our microscope thus exhibited the highest spatial resolution in terms of d/λ, which exceeded the past record of $d/\lambda = 25$, corresponding to $d = 0.05$ nm obtained at 300 kV[10].

We then examined spatial resolution of the microscope in TEM mode by using it to observe gold (Au) nanoparticles[11]. Lattice fringes of Au<200> with a separation of 204 pm were unambiguously imaged both at 60 and 30 kV (Fig. 8), and smaller lattice spacing of 79 and 91 pm were also resolved at 60 and 30 kV, respectively, as shown by FFT of the TEM

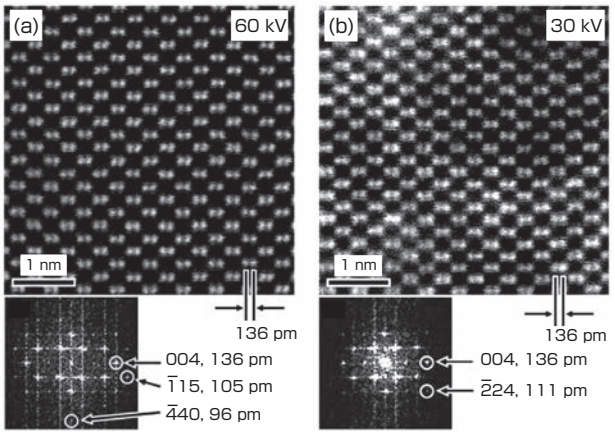

Fig. 7 Performance examination of the first low-voltage microscope in STEM mode
Recorded at acceleration voltages of (a) 60 kV and (b) 30 kV
Si<110> was used as test specimen.

images. These results show the excellent spatial resolution of our microscope in TEM mode as well as in STEM mode. Comparing the TEM image of a SWCNT obtained at 30 kV (Fig. 9) with those of conventional microscopes (e.g. Fig. 1), we can easily recognize that the performance of our microscope is comparable to existing spherical aberration-corrected TEM systems operated at 120 kV.

4.3 Performance of the second low-voltage microscope (TEM)

Our second experimental microscope is a 30 kV-TEM equipped with a chromatic aberration corrector in tandem with a Delta spherical aberration corrector. As described in subchapter 3.3, its chromatic aberration corrector has an innovative optical system based on the combination concave-lens effect of superposed electrostatic and magnetic fields. We checked the fundamental operation of this microscope such as aberration correction in 2010, taking measures to reduce electric noise to improve its stability. We are currently verifying the effect of simultaneously correcting chromatic and spherical aberrations in TEM observation for various standard samples.

Figure 10 shows a TEM image of Si<110> recorded by using this microscope temporarily equipped with a conventional electron gun. Even small lattice spacing of 125 pm was resolved, as shown by FFT, suggesting that the spatial resolution of this microscope is already comparable with that of our first microscope operated in TEM mode at the same voltage of 30 kV. We expect that the performance of this second microscope will be further improved to achieve higher resolutions by installing a new low-voltage CFEG (completed in September 2011) and by optimizing the alignment of the optical system including two aberration correctors.

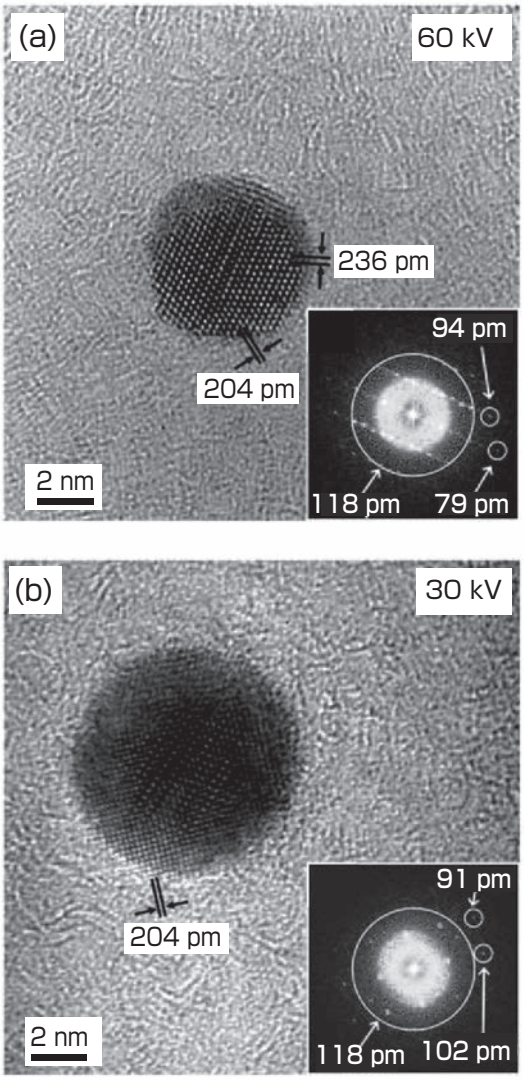

Fig. 8 Performance examination of the first low-voltage microscope in TEM mode
Recorded at acceleration voltages of (a) 60 kV and (b) 30 kV
Gold nanoparticles were used as test specimens.

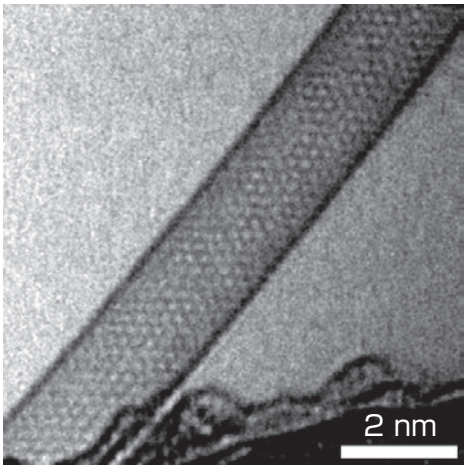

Fig. 9 TEM image of a SWCNT recorded at an acceleration voltage of 30 kV

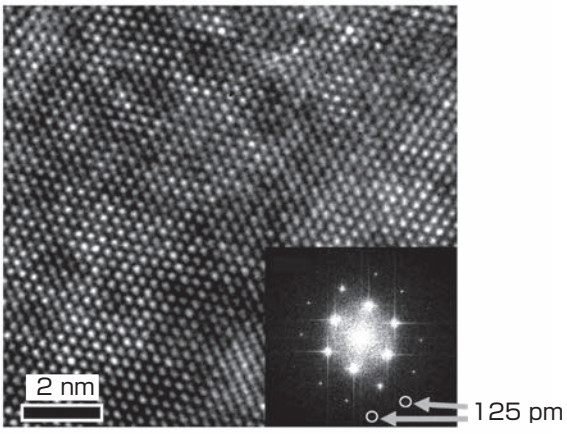

Fig. 10 Performance examination of the second low-voltage microscope (TEM)
Recorded at an acceleration voltage of 30 kV
Si<110> was used as test specimen.

5 Application of low-voltage microscopes and their problems

We have already completed the fundamental performance examination of our first microscope, which was developed prior to the second microscope, and have started using it to make scientific observations. In this chapter, we describe some typical results obtained by using the first microscope along with the problems associated with its application.

5.1 Identifying single metal atoms inside fullerenes

We carried out the STEM-EELS analysis of fullerene-incorporated SWCNTs (so-called nano-peapods) using our first microscope to detect individual metal ions encapsulated inside the fullerene cages and to identify their elements. Due to the serious irradiation-induced damage of fullerenes, which causes rapid coalescence and/or opening of their carbon cages[20][21], it was impossible to directly observe the original isolated state of these metal ions in previous STEM observations made at 100 kV or higher[22]. Our microscope enables the STEM-EELS analysis of nano-peapods with drastically reduced damage at 60 kV[23].

Figure 11 shows the results of the STEM-EELS analysis for a nano-peapod sample containing calcium-encapsulated fullerenes $Ca@C_{82}$. In the bright-field (BF) STEM image (a), the structures of seven fullerene molecules appear to be maintained without undergoing significant beam damage. Seven calcium ions (Ca^{2+}) inside these carbon cages are not clearly seen in this image due to their low contrast, but they are successfully detected by EELS elemental mapping for calcium (b), as indicated by the arrows. We thus found that low-voltage STEM-EELS enables the direct detection and elemental identification of individual Ca^{2+} ions with drastically reduced beam damage to the samples. Such a technique will greatly contribute to the analysis of biological specimens, especially in the elucidation of the mechanisms of ion channels, which play important roles in neurotransmission. Although the observation of ion channels has often been attempted by using electron microscopes in the past, identifying individual ions inside and obtaining high-resolution images of the channel structures has never been achieved because of the serious beam damage that occurs at higher acceleration voltages. The high-performance, low-voltage electron microscopy that we detailed here should be indispensable for the atomic-level characterization of structures and mechanisms inherent in biological specimens.

5.2 Mapping the electronic state on a graphene edge

Graphene is a single layer of carbon atoms that forms a honeycomb network. Owing to its unique and excellent properties such as its theoretically predicted and/or experimentally proven electronic characteristics, graphene is now regarded as a strong candidate for functional materials to be used in constructing next-generation nano-electronics. Because electronic properties of graphene significantly depend on the atom arrangement on its edge, it is quite important to understand precisely the correlation between local structures and electronic states in this material. Through the Triple-C project, we succeeded in STEM-EELS mapping of the electronic states of graphene edges without introducing serious beam damage[24].

Figure 12 shows the results of STEM-EELS analysis for a peripheral area of graphene at 60 kV. Possible local structures of three carbon atoms indicated by the colored arrows in the ADF-STEM image (a) are illustrated in (b), and the EELS spectra observed at these atoms are shown in (c). Note that two carbon atoms on the edge (colored blue and red) give characteristic EELS peaks at different energies (indicated by the black arrows), which were not observed for an inner carbon atom (colored green). We ascribed these EELS peaks to the electronic states peculiar to the carbon atoms on the graphene edge. Our atomic-level analysis thus provided the first direct proof that carbon atoms on a graphene edge possess different electronic states from those of inner atoms on the same layer.

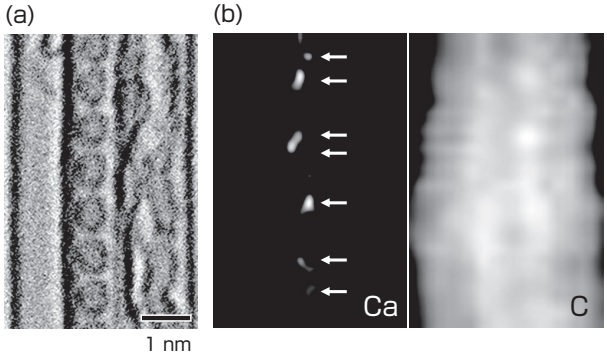

Fig. 11 Elemental analysis with low-voltage STEM-EELS
(a) ADF-STEM image, (b) elemental maps for calcium and carbon (left and right, respectively)
Nano-peapods of calcium-encapsulated fullerenes $Ca@C_{82}$ were analyzed at 60 kV.

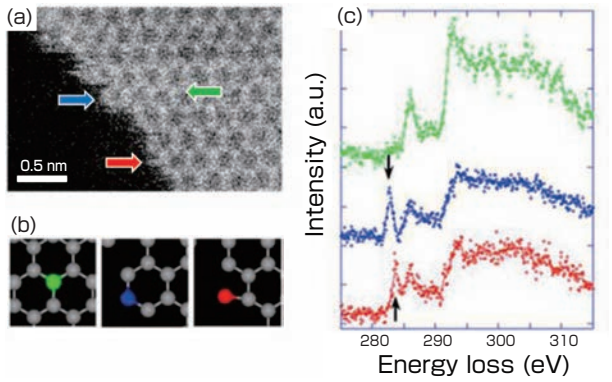

Fig. 12 Observation of electronic states with low-voltage STEM-EELS
(a) ADF-STEM image, (b) possible local structures, (c) EELS spectra of individual carbon atoms
Graphene was analyzed at 60 kV.

5.3 Known practical problems with low-voltage microscopy

In the experiments described above, we found some practical problems associated with our low-voltage microscope that would not occur for conventional observations made at higher acceleration voltages without aberration correction. For example, the etching effect of residual gaseous species in the microscope column, which causes the gradual loss of atoms in a sample during observation, is more obvious at lower voltages, while the knock-on effect of electrons itself is drastically reduced. In addition, even a slight change in condition of the CFEG emitter can significantly affect the spatial resolution and image quality of the microscope, where spherical aberration and various astigmatisms are finely corrected by the Delta corrector. We are currently taking measures to solve these problems by reinforcing the vacuum system of the microscope, and by optimizing the emitter shape and its operating conditions. Since we have proven the potential of our low-voltage microscopes as described above, our final goal is to improve them to the level that they can stably and easily exhibit their highest performance even for practical uses such as for material research and development.

6 Future prospects

In this paper, we reviewed our Triple-C project, through which we have developed completely new low-voltage electron microscopes for the first time. The advantage of using low acceleration voltages was not recognized in the field of electron microscopy when we started the concrete planning of this project in 2006. However, the situation completely changed within a few years of launching this project. A foreign group has also started developing low-voltage microscopes based on a similar concept[25], and some existing projects originally planned to improve the performance of middle-voltage microscopes for 80-300 kV have been modified for low-voltage systems[26][27]. Low-voltage TEM and STEM are now regarded as the main advanced forms of electron microscopy, and the competition between full-scale projects to develop such microscopes is intensifying worldwide. Each project is aimed at achieving a spatial resolution close to 0.1 nm at 50 kV or lower by using newly developed chromatic aberration correctors such as those employed in our project or by introducing conventional monochrometers. Low-voltage microscopes can be considered an innovation in electron microscopy that follows spherical aberration correctors developed in 1990s. These innovations are expected to satisfy the growing requirement for microscopes to be able to observe new targets such as nano-materials and single organic molecules.

As low-voltage microscopes become widespread and are put into practical use, they are expected to contribute significantly in the characterization of various kinds of materials, especially the materials used in the fields of chemistry and biology. If these microscopes can enable us to more easily observe the dynamic behavior of molecules and atoms, we can immediately apply them to important investigations, such as the structure analysis of ion channels and the *in-situ* observation of catalytic reactions. For example, direct observation of the reconstruction of individual molecules in the presence of metal clusters should help us further understand the mechanisms responsible for catalytic reactions at an atomic level, thereby making a huge impact on society. If we can observe in real time how a particular functional group in a molecule is excited by light or heat and how the electronic state of a particular atom is changed, we will be able to obtain fundamental data through which we can elucidate the mechanisms responsible for various chemical reactions at the atomic level.

Low-voltage electron microscopy and spectroscopy, which cause less irradiation damage to samples, are beneficial for analyzing not only soft matter but also inorganic materials. When characterizing crystalline materials, for example, they can provide us with new viewpoints on the physical properties of samples such as the formation and annihilation processes associated with point defects. We may also be able to gain a better understanding of the correlation between the atomic-level structures and the electronic states of individual quantum objects such as CNTs and fullerenes based on high-precision EELS analyses.

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Discussions with Reviewers

1 Author contributions

Question (Shuji Abe, Evaluation Department, AIST; Toshimi Shimizu, Nanotechnology, Material and Manufacturing, AIST)

This paper is co-written by eight authors, and mainly presents the results of the collaboration between AIST and JEOL. We understand that this work has been carried out as a part of the JST-CREST joint project in which AIST, JEOL and NIMS are participating. We expect author profiles are provided above, but can you explain the contributions of these organizations and members?

Answer (Yuta Sato)

This project has been carried out through collaboration between JEOL, NIMS and AIST. Eight researchers from each of JEOL and AIST, and two from NIMS have participated in this project (in total, excluding technical assistant staffs). In order to realize unprecedented low-voltage electron microscopes within a given period, we have had to combine our expertise in the fields such as theory of electron microscopy and spectroscopy, equipment, materials and phenomena to observe (solid-state physics, material science, nano-science, biology, etc.). The JEOL team, as a microscope manufacturer, developed each component, constructed two microscopes and examined their performances. The NIMS and AIST teams took charge of preliminary study for planning this project, the application of the low-voltage microscopes to scientific observation, and reference experiments using conventional microscopes. We described these contributions in Chapter 2 of the revised manuscript.

2 Competitors' projects

Question (Toshimi Shimizu)

This paper shows that the authors' group has pioneered in developing low-voltage electron microscopes equipped with chromatic and/or spherical aberration correctors. In chapter 6, however, it is also stated that low-voltage microscopes are now regarded as the main advanced forms of electron microscopy, and the competition between full-scale projects is intensifying worldwide. It is not clear to me whether such a world trend originated from the authors' project, or whether it independently emerged as integration of newly developed elemental technologies. I think additional description on the world trend and on the benchmarks of this project is effective in presenting more clearly the features of this project.

Answer (Kazutomo Suenaga)

In our revised manuscript, we emphasized that this is the first project in the world to construct totally new low-voltage electron microscopes. In addition, we stated that a foreign group also started developing low-voltage microscopes based on a similar concept just after we launched this project, and some other existing projects decided to cover low-voltage systems as additional targets. We presume that the performance of our first experimental microscope, which is the world's first system specially designed for low acceleration voltages, has affected the competitors' projects both directly and indirectly. Although it is difficult at this stage to specify how far such effects have spread over, we revised chapter 6 to refer to the world trend according to your comment.

3 "Soft matter"

Question (Shuji Abe)

I find that the term "soft matter" often appears in this paper, while the application of the low-voltage microscopes is currently focused on carbon nano-materials. In my opinion, carbon nano-materials themselves are not classified as soft matter, because they are known as robust materials. For future application of your low-voltage microscopes to real soft matter such as bio-materials, do you think their performance is high enough even at this stage, or further technical improvement is necessary?

Answer (Yuta Sato)

Low-voltage observation of soft matter is a final goal of our project. In our preliminary experiments, we used carbon nano-materials as test specimens to examine the effect of low acceleration voltages. CNTs and graphene are known to possess high mechanical strengths, and expected to be more stable under electron-beam irradiation than soft matters in general. Nevertheless, we had to give up many scientifically important experiments on these materials in the past, due to serious irradiation-induced damages occurring in conventional microscopes even at relatively low voltages such as 120 and 80 kV. In this project, we have achieved drastic reduction

of such damages and improvement of sensitivity by newly developing low-voltage microscopes, which enable EELS analysis of single carbon atoms, for example. Performance of our low-voltage microscopes in respect of spatial resolution has already been improved to a high level as we originally aimed. Our project now enters the next stage, where the microscopes are applied to observation of soft matter to further examine the effect of reducing beam damages. At this stage, it is quite important to elucidate irradiation-induced damages on soft matter and their unknown mechanisms based on the observed data, and to optimize operation condition of the microscopes such as acceleration voltage and beam current. This final stage is essential to promote practical use of low-voltage microscopes, and we recognize that it is our duty, especially of AIST team, to contribute from both standpoints of developers and users.

4 Practical use of low-voltage microscopes

Question (Toshimi Shimizu)

Once the observation of various soft matters with high sensitivity is realized by using low-voltage electron microscopes, it should have not only a great impact on the researchers in this field but also considerable ramifications on other fields such as material and life sciences. From the results presented here, it seems that the first low-voltage microscope of this project can immediately be applied to practical use even at the present state. I think the status of this project as *Full Research* would be more clearly shown, if you mention the processes to realize practical use of the microscopes and to solve the existing problems.

Answer (Yuta Sato)

Our first microscope has stably exhibited excellent performance at the present stage of the project, convincing us that its practical use will be realized in the near future. At the same time, we recognize that some factors of the microscope can affect its performance more seriously than expected by disturbing the observation or limiting the spatial resolution. It is essential to solve such problems for future application of the microscope, so we have inserted subchapter 5.3 into the revised manuscript to state the current problems and measures we are taking to solve them.

Research and development of systems science and technology

[Translation from *Synthesiology*, Vol.4, No.3, p.176-181 (2011)]

The Center for Research and Development Strategy (CRDS) of the Japan Science and Technology Agency (JST) established the Systems Science Section to review what should be promoted in the area of systems science and technology. As the research disciplines are becoming finely segmented, systems aim to achieve integration, and there is a common theme shared with *Synthesiology*. We interviewed Principal Fellow Hidenori Kimura who leads the Systems Science Section.

***Synthesiology* Editorial Board**

Participants of the roundtable discussion

Hidenori KIMURA	Principal Fellow, CRDS-JST
Naoto KOBAYASHI	AIST (Senior Executive Editor, *Synthesiology*)
Motoyuki AKAMATSU	AIST (Executive Editor, *Synthesiology*)

Akamatsu

I think the systems science and technology that Dr. Kimura is promoting is close to *Synthesiology* in the sense that both aim for full utilization of science and technology in society. I would like to ask about the systems science and technology, the relationship between *Synthesiology* and systems technology, and the technology needed to solve the future social issues.

Kobayashi

Although the evaluations of the East Japan Earthquake and the nuclear power plant accident have not been completed at this point, and it seems too early to address them in this discussion, I think they heavily reflect the problems of systems.

Kimura

Although it is not clear how much of the facts is known at this point, one of the issues raised was robots. There were projects (1983~1990) for advanced robots for hazardous environment in the fields of oceanography, space, disaster, and nuclear power. The question is "Was the reason why these robots were not deployed because of some technological problem or human problem?" The researches are gravitated toward elemental technologies. It has become clear that "such things can be done" is not enough, and this is one example where the systems technology is important.

Kobayashi

In the nuclear power plant accident, I think there were problems in all three systems including the system of hardware, the system of interaction between hardware and humans, and the system of human groups of how people should respond including politics. In that sense, it is very important to extract the issues as systems and to take measures accordingly.

Systems science and technology exists for problem solving

Akamatsu

What is the background for bringing up systems science and technology at JST? Why systems science and technology now?

Kimura

I think you can call today the "age of systems". Currently, we are struggling within our systems. Therefore, I thought it was important to lay a path as a science here. If you consider "systems technology" as the tool to analyze, design, and implement the systems and "systems science" as the organization into universal science of artifacts, systems science and technology is the way to construct and develop a large-scale system in a complex society.

Kobayashi

That means that systems science and technology is science and technology to solve problems. In *Synthesiology*, we set the objective, write the scenario to achieve the objective, and select the synthesis methods to achieve the objective. It is not simply a combination of elements. I think that is the characteristic of science in this field. On the other hand, Dr. Kimura and Dr.

Yoshikawa frequently mention “design science”. Does systems science and technology fall in that realm?

Kimura
I certainly think it is one of the design sciences.

Akamatsu
So, it is “systems technology” first. You say the systems technology is needed for problem solving, the systems science is its base, and the system exists originally for problem solving.

Kobayashi
Since problems cannot be solved with elemental technologies alone, we must have systems. It is said that Japan is weak in systems science and technology and systems thinking, but I think Japan had been doing well in the world for over hundred years since the Meiji Period. Why are we said to be weak in the field of systems?

Kimura
I think we are very strong in a certain phase, and once the Japanese systems science and technology shined brightly. For example, we successfully built the shinkansen (bullet train) system from 1960s to 1970s, the Dendenkosha Information Processing System (DIPS) of the former Nippon Telegraph and Telephone Public Corporation, and the integrated production management that enabled 10 million ton annual production of ironworks. These could not have been achieved without well-developed systems thinking.

Kobayashi
Taking the example of my field of specialty, Japan became advanced relatively early in optical communication technology. That was because the R&D capabilities of the individual technologies such as fiber, semiconductor material, and optical device were high, and the performances of the products were excellent. That allowed us to create the network and system faster than anyone else in the world. It is very interesting that, from the 1960s to early 1980s, we were able to create the shinkansen and the optical network that were not catch-up technologies.

Kimura
Back in those days, the systems technology was indeed very powerful in theory and practice. When I was a student, the guys who were good in math were considered to be the big ones. There were many systems science departments in the universities, and I think it matched the spirit of the era. However, since the 80s, the emphasis shifted to the deep exploration of elemental technologies.

Kobayashi
Does that mean that the academia of the world headed in that direction?

Kimura
I think it was only Japan. The word *monozukuri* (manufacturing) appeared in the beginning of the 1990s, so it was around that time. Although my analysis is not complete, one factor is arrogance. The Japanese manufacturing industry dominated the world, and elemental technologies became prominent. I think there was a feeling that we won because of our excellence in elemental technologies.

Akamatsu
I guess we did not recognize that the real reason for the “win” was systems technology. If the criterion for the “win” is set to be exporting overseas, the reason would necessarily become elemental technologies.

Kimura
Taking the example of iron, the integrated ironworks with annual production of 10 million tons was built in Japan for the first time in the world in the middle of the 1960s. The United States Steel Corporation produced about 5 million tons, and Japan doubled that capacity. The reason why it was held at 5 million tons was because the system was so complex. Iron and steel are produced by order, so they are single production products. The production line had to be dedicated to individually ordered products, and this was managed by visual inspection. Complete computerization of this process not only raised the production scale but also dramatically improved the quality. However, the contribution of the systems technology was not acknowledged. This was reflected in personnel evaluations. The systems people never became board directors! They said that the Japanese iron conquered the world because of its excellent quality as a material and the iron industry

Dr. Naoto Kobayashi

Dr. Hidenori Kimura

would essentially be a material industry. I think this thought was prevalent in other industries as well.

Akamatsu
Although the value was in the manufacturing system, people emphasized the elemental technology of the "product", and thought that the value lay therein.

Kimura
There was no room to recognize our arrogance and we failed to capture the reality and prepare for the next. People thought that Japan would continue to rule the world, and also thought that the Japanese style management conquered the world.

When the Japanese industry shifts

Kobayashi
I've heard that the manufacturing industries have been gravely hit by this earthquake and disaster, With the Oil Shock in the early 1970s, the rapid economic growth of the heavy industries led by iron, steel, and shipbuilding ended, and the main players of industry shifted to automobiles and electric industries. With the current state of automobiles, we don't know whether the EV (electric vehicle) will become the mainstream in the future. I feel that the Japanese industry must make the shift after the East Japan Earthquake, and this may be the time to reexamine systems science and technology once again.

Akamatsu
When something goes wrong, people tend to seek out the culprit of the supposedly man-made disaster, but that is very dangerous. Reducing the matter to a personal fault is similar to the thinking of reducing the matter to an element. As we recover from the earthquake, we are not looking at the situation systemically if we reduce the problem to who made the mistakes.

You mentioned the shinkansen system as an example where the systems technology truly shined. Mr. Shima, the head engineer of the former Japan National Railways, managed the technological development of the shinkansen. He said, "We did only ordinary things. One must think ahead and thoroughly." I think he thoroughly thought about what things were needed to run the shinkansen and carefully built the needed things. The people who excelled at the time thought and made things in terms of systems very routinely. However, they did not advocate, "This is the system," and it was not communicated. At the time, the word "system" was used as in the context of something like the "computer system," and the use in the sense of systemic way of thinking did not diffuse. I don't think it was incorporated well in education.

Dr. Motoyuki Akamatsu

Kimura
The word "system" was not really used very often. However, the shinkansen and NTT's DIPS were very state-of-the-art. The 10 million ton integrated production of iron and steel was the victory of systems technology, and stood at the top of the world. Although there might have been arrogance, we need to work hard to achieve them again.

Akamatsu
When looking at the past to learn, we reduced our challenges to elements since we thought we were winning by elemental technologies. Unless we state that the challenge is the system, nothing can be solved even if we emphasize problem solving.

Strategic research for systems construction is necessary – Do not proceed blindly

Kobayashi
That the "challenge is the system" is a very good analysis. When you say system, there are systems with which we design certain structures from the beginning and then built them robustly, and there are those where partial optimization is done in the autonomous decentralized style. These differ according to how the issues are solved. Are there many methodologies for designing the system?

Kimura
We should not fall into partial optimization. If you are autonomously decentralizing, you must intend to design a system of autonomous decentralization from the beginning.

We proposed that the "research for systems construction strategy is necessary". This was proposed late in the discussion of the Systems Science Section, CRDS, and is an essential factor lacking in Japanese science and technology. I am a researcher in the field of control, and in designing a control system, we don't blindly implement the controller for a large plant. The plant is thoroughly analyzed in a model-based study, the model is created, the model is put in the computer, the parameters are optimally designed, the simulations for whether these are okay are done repeatedly, and finally, if all goes well, it is implemented. That is the cardinal rule.

However in Japan, demonstration research is started right away. While the basic research for elemental technology is done thoroughly, people think that basic research is not necessary for systems. Of course, demonstration research is

necessary for confirmation at a certain phase, but aren't there things that must be done beforehand? If a demonstration is done, that only means that things turn out a certain way for a certain scenario. If the environment changes, a different story may unfold. We must carefully build the systems construction strategy, and all sorts of different scenarios must be considered. That is how it is done overseas in most cases.

Akamatsu
I think it involves the question of funding. We can get money for making something, while it is hard to get money for designing the system or doing simulation. It tends to be easier to get funding for elemental technologies. The scenarios for why this research is necessary or what it would lead to are treated as unimportant, but rather, we cannot get approval unless we present some performance index, such as "if we build this device the speed will become several times faster".

Kimura
I think that is a major negative tradition of the administrative organization.

Science and technology that meet social expectations

Kobayashi
The academic journals evaluate highly the addition of some new fact based on the world's academic criteria. In *Synthesiology*, of course, new knowledge is necessary, but we emphasize the selection of the elemental technologies and why they were selected, how they were synthesized, and the final goal is the practical use of the research result in society. As the essential items of the paper, we require the research objective and relevance to society, the scenario, how the elements were selected and integrated, and what were attempted for realization. I think it has similarities to the discussion of the R&D for systems science and technology.

Akamatsu
When one writes the scenario for *Synthesiology*, one must see the subject or the research topic as a system. We focus on what kind of structure the elements have.

Kimura
The systems science and technology claims that a single whole function is achieved by integrating the individual elements with various functions, but this can be achieved only by someone with a highly systemic mind.

The Science Council of Japan has expressed grave concern about the fact that the Fourth Science and Technology Basic Plan is a problem-solving type. There is a question about where the scientist's autonomy will go if the problems are given. In the problem-solving science and technology, how should autonomy of scientists and engineers be protected? Dr. Yoshikawa called the connection of the research objective and society as the "science and technology that meet the social expectation". This is one major issue.

Kobayashi
I think one must first consider the strategy. The topics for problem solving can be set by the researchers themselves, and how they should be approached can also be set freely. This way of thinking is important. For example, when research is considered as layered in relation to society, whether it be basic or applied, if we can create a research strategy that we all agree upon in any layer, the research result can be evaluated according to the relationship with the research strategy. That is my way of thinking. Therefore, the important point is to incorporate the "connection between the research object and society" within the research strategy.

Kimura
Science and technology cannot be separated simply into curiosity-driven and project-oriented. Strategies always exist within the scientific research, and in a certain sense, even pure science and technology attempt to solve problems.

Akamatsu
There is curiosity before a research topic is born, and it becomes a research challenge because it is interesting. To solve that challege is to systemically think and break down the structure of the topic that the researcher thought would be interesting. Many people may not be aware of that, though.

Kimura
I don't think there's any research without curiosity.

Education and law needed for systems construction strategy

Kobayashi
Before, there were solid systems in Japan as exemplified by the shinkansen and DIPS, but you indicated that the systemic thinking or the potential for thinking about the systems has decreased. What is necessary for us now?

Kimura
The Basic Act on the Promotion of Core Manufacturing (Monozukuri) Technology was established in 1999, the Institute of Technologists was established, and this law formalized the yearly production of the Manufacturing Basic White Paper. When the technology of the world was shifting to systems and software, or shifting "from things to action", Japan was going against that flow. Therefore, in this age, I think we should make something like a basic act on the promotion of core systems technology.

Akamatsu
Maybe it is education. If a graduate student in a doctorate course

does nothing but study some theme given by the professor, it will be difficult to understand the topic as a system.

Kobayashi
There are many people with PhDs at the core of policy making in the international institutes and foreign governments. There are extremely few administrators with PhDs in the central government ministries and agencies of Japan. I think we need to fortify the PhD courses and change the university education itself. When we talk about education, the teachers must change, too. It would be better if they could teach that the elemental technologies are of course important but it is important to systemize them. I hope we can steer toward that direction.

Spiral is important for both synthesiology and systems science and technology

Akamatsu
Yes. To design a system is also to determine the order by which the system should be operated, and I think there are many things that can be solved by first designing it and then operating it. Spiral is created as the system interacts with the real world.

Kimura
That is certainly true. We are investigating why the systems failed to work in the East Japan Earthquake. I have a feeling that the greatest point is that the concepts of disaster prevention and rescue were not linked together. The spiral was not working. On the other hand, there are many laws such as the Special Measures Act and Disaster Relief Act, and these laws state the protocols of how to establish headquarters when a certain disaster occurs and what to do next. Yet the situation changes from moment to moment. People move and the environment changes and the system itself must be updated accordingly.

When a disaster strikes, one can make the primary damage prediction by understanding the scale of the earthquake and the epicenter. As more information is gathered, the damage predictions can be fine-tuned, and we must also decide what kind of relief system should be created based on the predictions. This must be done in a spiral way.

Akamatsu
While there may be disaster prevention for times of normal situations, the spiral movement does not work properly if there is a lack of disaster prevention against the aftershocks that may occur after the main earthquake.

Kobayashi
As Dr. Kimura said, it is important to repeat the modeling process where the analysis, simulation, and synthesis are done.

Kimura
Yes. In synthesiology, does the spiral course continue after the research is completed?

Akamatsu
We haven't gotten to that stage yet. The ability to evaluate the research when it is sent out to society is necessary. When the spec requirement arises, we must look ahead and not stop at mere acceptance of spec. When one spiral course is run, the limiting condition changes completely from the first layer and redesigning must be done. Running the spiral course involves such redesigning.

Kobayashi
For social implementation, we must involve the industry. Therefore, I hope the people of industry who did the actual implementation look back at how they did it and write a paper on the methodology.

Systems science and technology is the promoter of fusion of humanities and sciences

Akamatsu
The activities of the Systems Science and Technology Committee finished last year, and a proposal was submitted. What do you think is the most important factor for the discipline to grow or to promote this way of thinking?

Kimura
I think it is necessary to incorporate the systems science and technology into innovation. One must make specific proposals and then build up actual results. Since there is no section in the Ministry of Education that is in charge of this, we are discussing this matter.

Kobayashi
If we consider science and technology as a system, I think the systemization of various fields and businesses becomes necessary. It has been said that the fusion of humanities and sciences is necessary at the universities, but it is not going well. Compared to the professors of sciences, the professors of social sciences are not too willing. However, considering the systems for the future, it will not be about science and engineering only.

Kimura
I think there is a possibility that the systems will be the promoter of the humanities-sciences fusion. Systems are becoming major topics in humanities. There is a hot debate going on in the social sciences on what is a social system.

Kobayashi
Are there any examples of successful efforts in humanities-sciences fusion or systems science and technology in the United States, Europe, or Asia?

Kimura
The International Institute for Applied Systems Analysis (IIASA) of Austria was established in the early 1970s, and it has both the sciences and the humanities researchers. After the publication of *The Limits to Growth*, the IIASA was established with enthusiastic support of the United Nations to seek themes where people could collaborate together during the Cold War. This institute has spent considerable effort on the population problem and CO_2 reduction. It created the Regional Acidification Information and Simulation (RAINS) model, and this is one of its successes. China has its stronghold in systems science. There is the Institute of Systems Science in the Chinese Academy of Sciences, and it is very big. Also, there are economists and social scientists as well as physicists at the Santa Fe Institute, which is the leader of complex systems. There is no research institute for systems science in Japan.

Kobayashi
I hope we get successful cases like the shinkansen. It doesn't have to be of that big a scale.

Kimura
I really hope so, too. What I wish to propose is the systemization of the rescue organizations and the implementation of high-tech in the rescue system. Since the East Japan Earthquake, the Japanese science and technology has lost authority in the world. We must create a universal rescue system, and show the rest of the world how the rescue and relief operation should be done.

Akamatsu
We can see which items will function and which will not if we have such a system. By systemization, we should be able to make a decision when the situation changes. I hope we can carry out the recovery process systemically.

Kobayashi
I think the systems science and technology and *Synthesiology* overlap in several areas. We have recently become aware that the spiral movement and feedback are very important in our discussions of the *Synthesiology* papers. As Dr. Kimura says, rather than having a rigid design from the beginning, it is important to have the system revolving.

Kimura
In Japan, once the plan is made, it cannot be changed. It is necessary to ensure temporal evolution by correcting this shortcoming.

Akamatsu
I think "problem research" is the keyword. One tends to think that the problem is given, but that's not true. One has the ability to spontaneously come up with a problem, and it can be solved only by breaking it down into a system. Since synthesiology seeks the methodology for creating the scenario, I think the aim is very similar.

Kimura
In the future science and technology, the systems science and technology and synthesiology will increase their weights. How is *Synthesiology* taken at AIST?

Akamatsu
I don't think its awareness is high. However, we started an education program called the Innovation School three years ago, and use *Synthesiology* as one of the texts. We talk to the young researchers who just received their doctorates about how to grasp the scenario of the research, how to build the research, and from which perspective things should be seen. The young researchers respond quite positively.

Kimura
I guess it is gradually spreading. In JST, the understanding of systems science and technology is still low. There are many people who say, "Why do research on systems?" or "Isn't it something anyone can do?" However, the systems science and technology was added to the list of promotion subjects in the Fourth Science and Technology Basic Plan, so I think something will start to happen.

Kobayashi
For science and technology, analysis must be done thoroughly by a model, simulated, and then valuable money can be invested. I hope the systems science and technology will diffuse widely.

This roundtable discussion was held at the Center for Research and Development Strategy (CRDS) of the Japan Science and Technology Agency (JST) in Chiyoda-ku, Tokyo, on April 22, 2011.

Profile

Hidenori KIMURA
Completed the doctorate course at the Graduate School of Engineering, The University of Tokyo in 1970. Doctor of Engineering. Professor, School of Engineering, Osaka University; Professor, Graduate School of Engineering, The University of Tokyo; team leader of the Biological Control Systems Laboratory, Riken; and director, BSI-Toyota Collaboration Center, Riken in 2007. Officer, Transdisciplinary Federation of Science and Technology (TRAFST); and Senior Fellow, CRDS-JST. Fellow of IFAC and IEEE. Received the George S. Axelby Outstanding Paper Award, Control Systems Society, IEEE; the Automatica Prize Paper Award, IFAC; and others. Received the Giorgio Quazza Medal from the International Federation of Automatic Control (IFAC) in 2011.

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

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, clear originals that can be used for printing or image files (resolution 350 dpi or higher) should be submitted. In principle, the final print will be 15 cm × 15 cm or smaller, in black and white.
3.3.5 For photographs, clear prints (color accepted) or image files should be submitted. Image files should specify file types: tiff, jpeg, pdf, etc. explicitly (resolution 350 dpi or higher). In principle, the final print will be 7.2 cm × 7.2 cm or smaller, in black and white.
3.3.6 References should be listed in order of citation in the main text.

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

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

4 Submission

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

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

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Letter from the editor

There is an essential difference between "analysis" where the partial knowledge is extracted from the entirety of the known subject and "synthesis" where the entirety of the new subject is built up from partial knowledge.

The papers of this issue are interesting. The subjects are air conditioning system, water purification system, automotive navigation, electron microscope, and service. All of them deal with the creation of some new artifact. They describe the consortia or joint researches that practice the integration of known elements, or the new development of the necessary elements.

Why are artifacts created? It is because we expect them to be valuable. The synthesized artifact exerts its function by interacting with the environment. However, excellent function does not necessarily increase the value of the artifact. It merely remains to be an artificial object unless it works in the environment, exerts function, is traded in the market, satisfies the people's subjective utility, and increases the social value. Only then, it becomes valuable. The value not only encompasses market diffusion, but also involves social acceptance and a cultural ripple effect. In either case, it is social because the essence of value is "spread". A treasure stored secretly is not necessarily valuable. Therefore, social value cannot be discussed only in terms of functional maximization and cost minimization.

From this viewpoint, the paper "Integrated development of automotive navigation and route guidance system" describes in detail the author's activities for international standardization to obtain social acceptance. This is a valuable paper from which we can learn much. In the paper "Designing products and services based on understanding human cognitive behavior", the statements that the interaction between an artifact and humans is necessary to create values in the real world which is a complex open system, and that it is accepted by society through this awareness, are very important.

In the roundtable discussion "The R&D of system science and technology" with Dr. Hidenori Kimura, many important points are mentioned. One is the reference to "social expectation" stated by Dr. Hiroyuki Yoshikawa, former President, AIST. Whether the "discovery of social expectation" is an analysis by the observer or a synthesis by the participation of the acting body is the future theme for *Synthesiology*.

Finally, I would like to discuss the positioning of the papers published in *Synthesiology*. The word "analysis" has the meanings of division methodology as well as the objective of clarification. "Synthesis" has the meanings of integration methodology and the objective of construction. Therefore, there are four categories: analysis by analysis, analysis by synthesis, synthesis by analysis, and synthesis by synthesis. I think the statement of the paper will become clearer if the papers submitted to the journal clarify in which category the reasoning is developed.

Editor
Kanji UEDA

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