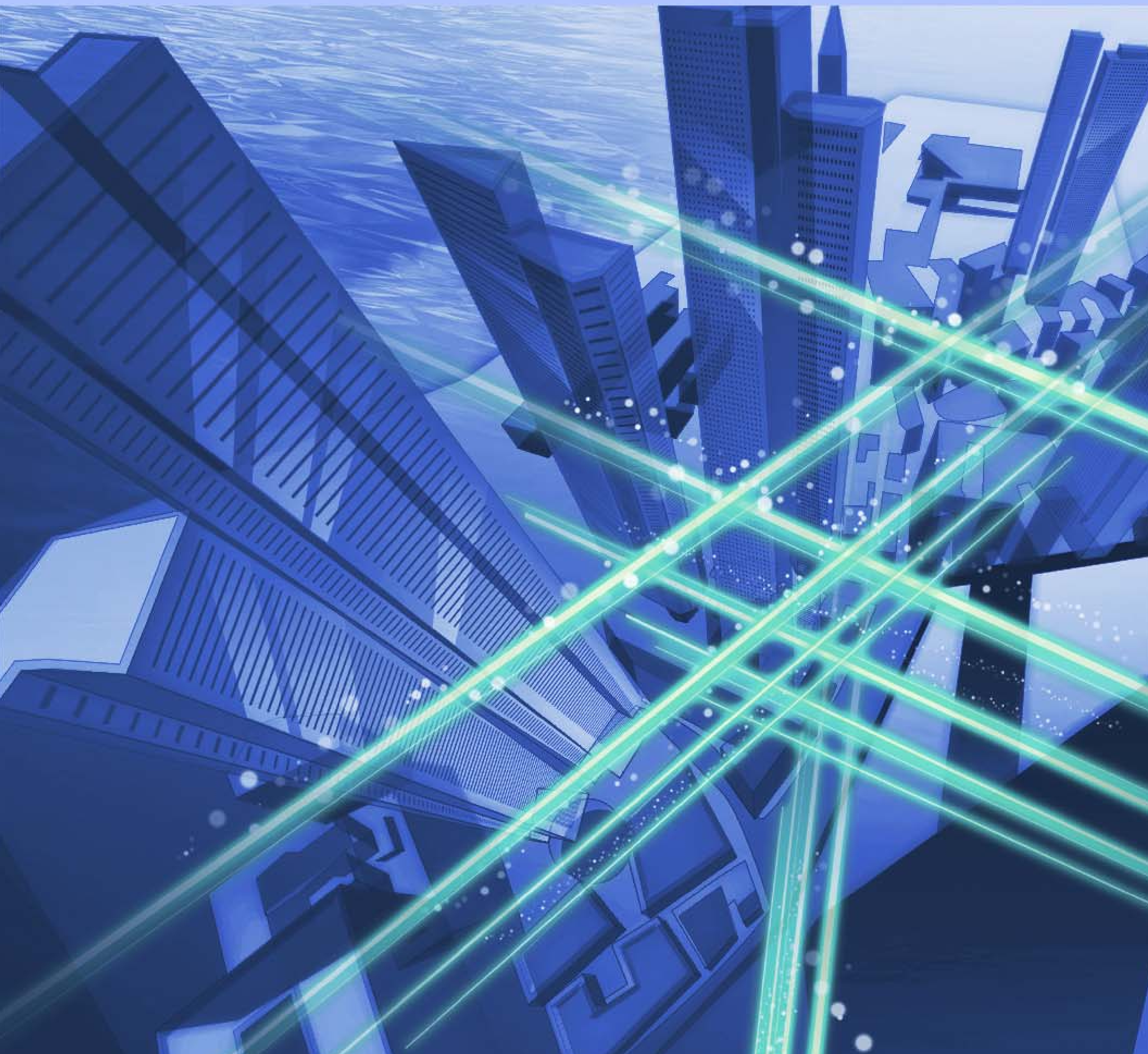
NTT Technical Review

6
2021



June 2021 Vol. 19 No. 6

NTT Technical Review

June 2021 Vol. 19 No. 6

Regular Articles

- Neutron-energy-dependent Semiconductor Soft Errors Successfully Measured for the First Time

Global Standardization Activities

- Recent Standardization Activities of Optical Connectors in IEC

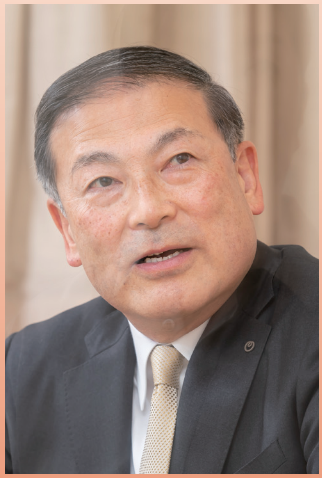
Practical Field Information about Telecommunication Technologies

- Sulfur Damage and Its Countermeasures in Telecommunication Equipment and Facilities

External Awards

Passing on Expertise and Enthusiasm in the New Era through IOWN Initiatives and Making Front-line Employees Shine

Hiroshi Tanabe
Senior Executive Vice President and Senior Executive Manager of Digital Transformation Headquarters, NTT EAST



Overview

In today's society, in which technological innovation and market changes are accelerating, NTT EAST is committed to solving problems of local communities while valuing the ties that it has cultivated with those communities over the more than 100 years in the telephone business. We interviewed Hiroshi Tanabe, senior executive vice president of NTT EAST, about his thought on the use of technology to solve social problems and why he has been focusing on helping front-line employees shine.

Keywords: ICT, digital transformation, front line

Meet the expectations of local communities by considering changes in ways to use information and communication

—A little over a year has passed since you were appointed senior executive vice president. How do you feel about the unprecedented situation since then?

First of all, I would like to thank all our employees and partners for their support and cooperation during this difficult period of the novel-coronavirus (COVID-19) pandemic. Looking back on this unprecedented situation from a technological perspective, tremendous achievements in medical technology have been made. It took only about a month after COVID-19 was identified to pinpoint the causative virus and its genome sequence. After that, PCR and other testing methods were established, and within a year of COVID-19 identification, vaccines were being manufactured. Another example of the extremely high level of technology was the impact of droplets exhaled on other people was simulated using a supercomputer. Although my knowledge of pandemics is based on novels, such as "The Plague" and "The Red Zone," I am reminded of today's advances in medical technology in light of the fact that during past pandemics, medical workers on the front line had no choice but to wait for the disease to end without knowing how to fight it. Regarding the present pandemic, I express my heartfelt gratitude to the medical personnel who are struggling to cope with increasing cases caused by the spread of variants of COVID-19.

In this environment, as exemplified by the spread of

teleworking, the ways to use information and communication technology (ICT) have changed dramatically over the past year. To support this dramatic change, we have invited a researcher, who also belongs to the University of Tsukuba, the Information-technology Promotion Agency, Japan, and other institution, to join our company, and developed and provided a virtual private network-based remote desktop service called "thin telework system" as a support tool for teleworking, which has been well received.

Many local governments have chosen NTT EAST as a partner in the GIGA School Initiative of the Ministry of Education, Culture, Sports, Science and Technology, which aims to create an educational and ICT environment that nurtures children's creativity in Society 5.0. I am grateful that we can be of service to society during this difficult period.

—It must have been hard for the front-line employees to take countermeasures against COVID-19 infection.

Until March 2020, since we did not know the impact of the COVID-19 pandemic on our customers, we carried out repairs and construction work to enable telework. As I mentioned above, as the reality of COVID-19 has gradually become clearer, we have been able to take countermeasures to ensure the safety of our customers, all persons concerned, and our employees.

Furthermore, the outbreaks and clusters of infection in call centers have been reported worldwide. Our business is supported by many people at our call centers, which respond to telephone-service breakdowns and general inquiries about products and services, and we have been able to suppress cluster outbreaks and minimize infections among our call-center workers by taking countermeasures using our past knowledge.

Taiwan has succeeded in containing the COVID-19 pandemic by using digital technology. I believe that we can contribute to prevent the spread of virus in Japan by further using our technology in cooperation with medical facilities. One example is the use of our Digital Twin Computing to connect the real world with cyberspace. I think that by using this technology to perform calculations, such as simulating infection routes and identifying the source of clusters, and feed the results back to the real world, it will be possible to prevent the next pandemic. Such technology has great potential, and I want us to contribute to society by implementing it.

We want to be firmly rooted in the community in new areas

—Even in the face of the COVID-19 pandemic, NTT EAST continues to take on challenges, doesn't it?

About three years ago, to establish firm roots in the local community in new areas, we started an initiative in which branch managers and area business managers visit customers to listen to their problems and requests. The majority of the comments we received were issues related to the primary industries of agriculture, forestry, and fisheries.

With those comments in mind, we are striving to contribute to solving the problems faced by local companies and governments by making full use of our strength in ICT. Specifically, to support agriculture, which is a major industry in many regions, we have started various businesses. NTT AgriTechnology was established in July 2019 to revitalize the local economy and advance urban development by using advanced technology to discover new possibilities and value in the agricultural industry. Biostock was established in July 2020 to build a sustainable regional recycling ecosystem in the livestock and dairy industries. NTT e-Drone Technology was established in February 2021 to develop industrial drones initially for agricultural use.

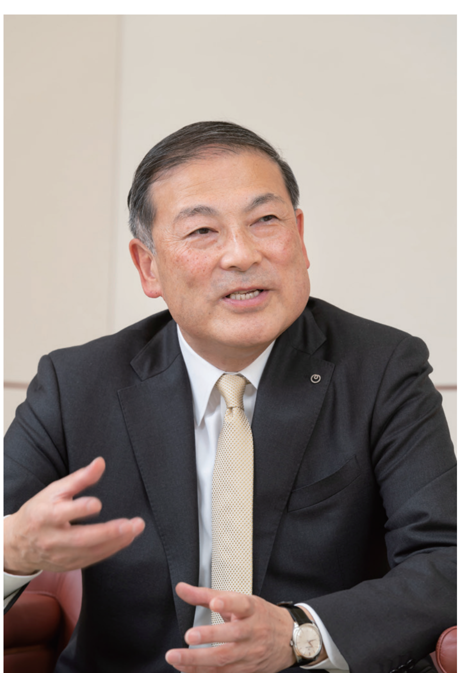
—The term "digital transformation (DX)" has become familiar, and expectations for ICT to solve social issues are rising.

In addition to the businesses described above, we have launched several companies that use our ICT to solve customers' problems.

It is expected that working styles that use cloud technology, including teleworking during the COVID-19 pandemic, will become the standard rather than being transient. Although the needs to improve business operations and promote DX by introducing public cloud services are becoming apparent, many customers are hesitant to introduce cloud services because they do not know much about them. To solve this problem, in July 2020, Nextmode was established to support our customers' sustainable growth through our network and cloud-computing capabilities.

What's more, to create new connections and experiences as well as new cultures and societies while contributing to regional revitalization through e-sports (the domestic market for which will reach about 10 billion yen in 2022), NTTe-Sports was launched in January 2020. NTT ArtTechnology was also established in December 2020 to contribute to regional revitalization and economic circulation by disseminating valuable culture and art of regions through digitalization and connecting region to region and connecting regions to the world.

I believe that we can leverage our strengths in various fields. In collaboration with universities, we have had quite a few collaborations with faculties of engineering, however, we are also promoting collaborations with researchers in other fields, and I want to further strengthen those collaborations from now onwards. Universities are rooted in the local community, and many professors are not only experts but are also active as hubs for solving local problems. There may be some fields that require ICT, so I want to combine our strengths with those of these experts to solve local problems.



Passing on expertise and enthusiasm

—You have been with NTT for 34 years. What's the journey been like?

I am very attached to NTT Technical Journal (original Japanese version of NTT Technical Review). One year after I joined NTT, I was assigned to the Technology Development Department, where I was told to gather all the back issues of "*Tsuuken Geppou*" ("The Monthly Journal of the Electrical Communication Laboratory," the predecessor of NTT Technical Journal) and "*Shisetsu*" (Facilities) and create a detailed chronology of various communication technologies and the ideas of the people in charge of those technologies. Therefore, I dug up those dusty issues from the library of the NTT Hibiya Building and tabulated them in chronological order. When I was asked to be interviewed for this issue, the first thing that sprung to mind was the file containing those back issues.

I was then engaged in developing structures around cables and optical-related systems. At the time, I was doing basic research at NTT laboratories, writing specifications at the Technology Development Department to introduce those research results in business, and discussing specifications with manufacturers and persons in charge at the site of introduction every day to make them tangible. On one occasion, I was told by a senior colleague to read a vast amount of documents in the library before a meeting. Those documents described discussions about costs and technologies that had been held over the previous few years. By reading those documents before the meeting, I learned the background of the discussion, and I understood what was being discussed. I was reminded of my naivety every time I read those documents—which my seniors had left behind as proof of their exhaustive pursuit of their mission to provide high-quality services to customers. This custom can be described as having established a mechanism for passing on—from seniors to juniors—background and enthusiasm related to the development of technology.

However, we live in an age that demands speed, and unlike the days that I described above, NTT-driven technology is no longer dominant, so we are not necessarily at the center of technology. It is important how quickly we can put technologies and services from around the world into an easy-to-use form for customers. The Innovative Optical and Wireless Network (IOWN) will allow NTT to take the lead in creating partnerships, and I believe that NTT's expertise and enthusiasm for research and development in the new era will be handed down from generation to generation through this initiative.

—What have you valued when passing on your expertise and enthusiasm?

When I look back on my life journey as an engineer, I think my main concern over the past ten years has been how to polish the front-line employees' skills so that they can shine at work. Thirteen years ago, I was transferred to Iwate Prefecture as a branch manager. At that time, the front-line work was not the first focus of attention, namely, new employees had not been assigned to positions, and existing employees were struggling to do their jobs. To overcome these difficult circumstances, even after returning to the headquarters, I was thinking of a system for supporting and training front-line employees.

Although ten years have passed since the Great East Japan Earthquake, I still recall how our employees at the Iwate branch worked with the spirit of "We will protect the communications in this area ourselves" after the disaster struck. Since many problems in disaster sites often have to be dealt with manually, it is vital to have that kind of spirit. In fact, I want to draw attention to the fact that front-line employees deal with customers with pride and outstanding productivity not only in the event of disasters but also in normal times.

Given those circumstances, I have been focusing on productivity, changing the work style and culture in the field, and upgrading work through DX. Through these activities, I have tried to get people to understand that change is required, even on the front lines, so that those on the front lines can shine. Currently, I am the head of the Digital Transformation Headquarters, and I believe that this kind of effort is necessary regardless of whether you are working in the field or at the headquarters. By embracing DX, we hope to further strengthen our ability to connect our diverse technologies and expertise with the needs of our customers throughout Japan and provide solutions to customers' problems.

—You've been through a lot of intense situations. Do you have any unforgettable experience?

Even today, I feel the anguish caused by the Great East Japan Earthquake. On the day of the earthquake, I was at NTT EAST's headquarters in Hatsudai in Tokyo while on a business trip, and immediately after the earthquake had struck, I had no way to return to the Iwate branch. In the early morning of the day that I was finally able to return to Iwate via Akita airport, I got a phone call from an employee at the disaster site. The employee said, "When people see us wearing NTT work clothes, they ask us to convey their messages to their families that they are safe," and asked me if it is OK to meet such requests. When I replied, "First you must restore the facilities," the caller said, "Do you know what is going on at the site? You are always telling us to work for the community!" and hung up the phone. I still remember how proud I was of the employees when I returned to the branch and saw not only the employee who had conveyed the message of the victims but also all the other employees working hard on site to restore the damaged facilities and support our customers. What's more, the employees who were due to retire at the end of March 2011, shed tears when they said, "I cannot retire at this time. I want to be allowed to work until this crisis is over." Even now, my heart aches at the fact that the only thing I could do was to say "Thank you for your tremendous efforts" to the employees who worked so desperately to contribute to the community and complete their mission to connect communications as social infrastructure.

This experience has led me to focus on highlighting the front lines and helping front-line employees shine; however, if I feel strongly that things are fine the way they are, we won't be able to meet the expectations of our customers. Just as the means of communications has changed from fixed-line telephones to cell phones, the expectations of customers have also changed over time. I also think it is important to expand the spirit of pride in one's work that has supported these front lines in new directions. I want to make the front lines shine by multiplying new fields and communications.

—What is your message to those who are engaged in research and development?

I think that NTT's research labs can now be given clear direction on the basis of IOWN, and I feel the enthusiasm and momentum of researchers toward that goal. I hope our researchers will lead the NTT Group—and society as a whole—with confidence and pride in the fact that nothing is wasted in research and development.

Interviewee profile

■ Career highlights

Hiroshi Tanabe joined Nippon Telegraph and Telephone Corporation in 1987. In his career at NTT EAST, he became manager of the Iwate branch office in 2008; senior manager of the Plant Department, Network Business Headquarters, in 2011; executive manager of the Engineering Department, Network Business Headquarters, in 2013; board of director in 2015; executive vice president in 2018; senior executive vice president, senior executive manager of the Digital Transformation Headquarters, president of NTT E-Asia, and president of NTT e-Drone Technology in 2000.

Being Different Is a Compliment. Practice Talking Logically about Future Plans

Masaaki Nagata
Senior Distinguished Researcher, NTT Communication Science Laboratories

Overview

Research on machine translation using neural networks has made rapid progress, and the accuracy of machine translation has improved considerably. Although websites and smartphone apps providing machine translation have become more popular, issues with accuracy remain. To address such issues, researchers are studying more advanced translation technology that reflects context, situation, and culture. We interviewed Masaaki Nagata, senior distinguished researcher at NTT Communication Science Laboratories, who is researching context- and situation-based neural machine translation, about the progress of his research and what it means to be a researcher.

Keywords: natural-language processing, machine translation, neural network

Our research has been highly appreciated at one of the top international conferences on natural-language processing

—Please tell us about your current research.

Since 2013, when I was interviewed last time, I have been researching technology for translating one language into another. During this time, the target of my research changed from statistical machine translation based on translating words and grammar to neural machine translation based on context and situation (**Fig. 1**). Artificial intelligence (AI) technology has advanced rapidly since around 2014, for example, AI beat humans in the game of Go. As a result, major changes have emerged in each research field related to AI. In speech recognition, AI can not only recognize speech, which was considered difficult, but can do so with dramatically improved quality. In machine translation, in which I have been researching, translation accuracy has rapidly improved since 2016, and human parity, namely, human-like translation, has become possible. The time has come when we can suddenly do what was previously thought impossible. In the course of searching for future research themes while considering these trends, I realized that many issues remain to be addressed. One such issue is the fact that the meaning of a translated sentence may change in accordance with the preceding and following sentences. To address such issues, I arrived at the theme of *context- and situation-based neural machine translation*.

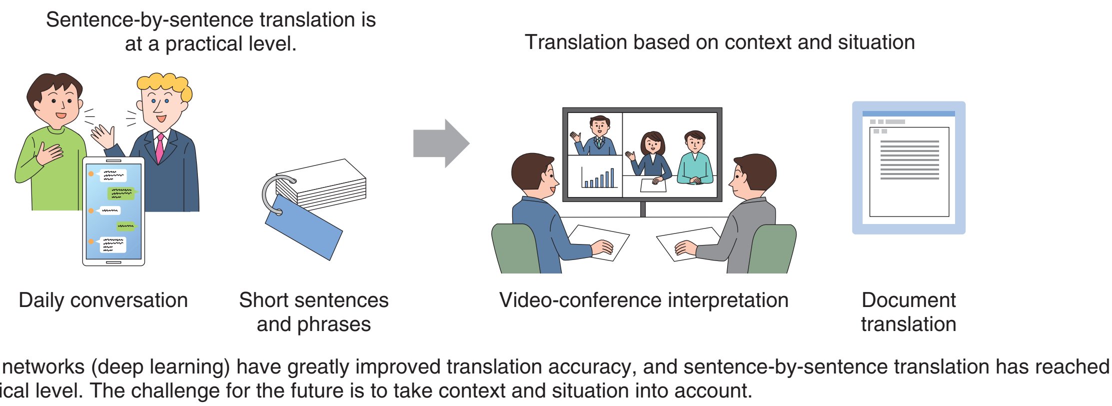


Fig. 1. Current and near-future goals of machine translation.

If you use the translation function of a website or smartphone app, the accuracy of the translation is so high that you might think that machine translation is better than humans for composing, for example, English for student homework. At a bicycle rental shop, I encountered a situation in which a Japanese shopkeeper and non-Japanese speaker were communicating via the translation function of a smartphone. As I watched the exchange, I was so impressed that I thought to myself, "Wow, translation technology has come this far!" However, the conversation between them was not smooth. This is because subtle phrases and nuances could not be translated.

This lack of smoothness is a slightly troublesome feature of neural machine translation. While the translated text might be as grammatically accurate as a native speaker's text, it may not faithfully reproduce the meaning of the source text. Conventional machine-translation systems use a sentence as the basic input unit. Accordingly, even if the translation accuracy of each sentence equates to sentences produced by humans and if a target text consists of multiple sentences, such as a document or conversation, is machine translated, the translated anaphoric relationships do not match the source text because context and situations are not taken into account. In other words, the translations are inconsistent.

—You are advancing research to further evolve such current technology.

To deal with the above translation inconsistency, we must address the following three issues. The first issue is that the subject and object are often omitted in Japanese conversation; therefore, they should be identified from the context and translated. The second issue is to make sure that the translation reflects the characters of the persons in question. This includes, for example, gender bias, as in associating the word "neurosurgeon" with men, even though there are female neurosurgeons. The third is to find and reflect appropriate meanings and expressions of those having multiple meanings.

Let me give an example of translation considering context and situation when translating Japanese into English (**Fig. 2**), where the English translation of the second Japanese sentence is determined in accordance with the first Japanese sentence.

In the example shown in Fig. 2, "I'm afraid that the doctor is running a bit late this afternoon. It might be about 20 minutes before he can see you." is the correct translation from Japanese. However, because the subject "doctor" is omitted from the second Japanese sentence, the machine translation often determines the subject is "we" and presents "It might be about 20 minutes before we can see you." There is also a problem of gender bias. In English, when choosing a pronoun, it is often necessary to specify the gender. Judging that "the doctor is a man," the machine translation is likely to choose the pronoun "he" for the doctor.

When Japanese is translated into English in this way, if the subject and object (which are often omitted in Japanese) are not properly interpreted, the meaning will change, and the translated words will not match the context. For example, in the Japanese sentence "昨日、渋谷に行った。すごい人だった。" ("*Kinou, Shibuya ni itta. Sugoi hito datta.*" (Romanized version) or "I went to Shibuya yesterday. There were a lot of people."), the nuance of "すごい"

	Source language	Target language
Preceding sentence	申し訳ありませんが、先生は午後少し遅れているんです。 (*Moushiwake arimasen-ga, Sensei wa gogo sukoshi okureteirun-desu.*)	I'm afraid that the doctor is running a bit late this afternoon.
Input sentence	診察するまでに 20 分ほどかかると思います。 (*Shinsatsu suru madeni 20-pun hodo kakaru to omoimasu.*)	Correct answer: It might be about 20 minutes before he can see you. Wrong answer: It might be about 20 minutes before we can see you.

	Source language	Target language
Preceding sentence	昨日、渋谷に行った。 (*Kinou, Shibuya ni itta.*)	I went to Shibuya yesterday.
Input sentence	すごい人だった。 (*Sugoi hito datta.*)	Correct answer: There were a lot of people. Wrong answer: He was a great man.

Because gender distinction applies to English pronouns, the problem of gender bias also affects translations of "doctor" and "person."

Fig. 2. Example of translations that require contextual consideration.

("*Sugoi*" or "great") should be translated into English as "a lot of people" in this context. However, if the sentence "*Sugoi hito datta*" is interpreted in a different way, without reflecting the context from the preceding sentence, it will end up being translated into English as "He was a great man." Although that translation is also correct on a sentence-by-sentence basis, it does not correspond to the preceding sentence, "I went to Shibuya yesterday."

No matter how high the accuracy of the translation, it will never be perfect, so it is important to identify mistranslations. In statistical machine translation, if you want to find the source (Japanese) text that corresponds to the mistranslated (English) text, you can see the internal correspondence between the source and target texts by holding the cursor over the mistranslated text. However, neural machine translation interprets the entire text to create a semantic vector then translates in accordance with that vector, so it is impossible to specifically identify the corresponding text.

To solve this problem, I proceeded with my research with the goal of identifying the correspondences of the input and output sentences, which is called "word alignment" and "sentence alignment."

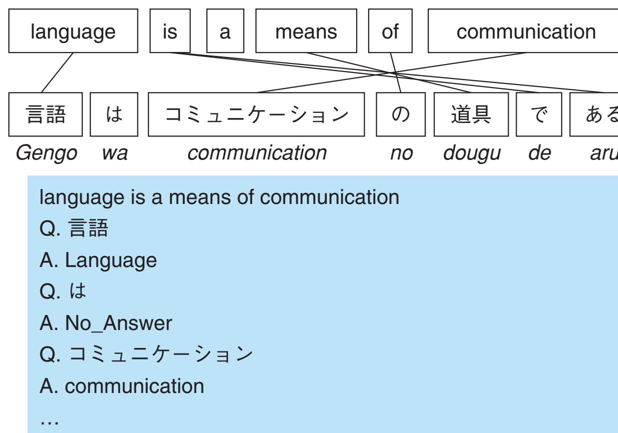
In 2020, at the Conference on Empirical Methods in Natural Language Processing (EMNLP), one of the world's largest international conferences in the field of natural-language processing and computational linguistics, we announced that we can identify pairs of words that are translations of one another by considering their context in the sentences [1] (**Fig. 3**). This "cross-language span prediction" method was recognized as pioneering and remarkably accurate.

Do something different and be as controversial as possible

—You have achieved outstanding research results. What do you value in your research activities?

I try to do things differently from other people and be as controversial—in a good way—as possible. I consider it a problem and very inconvenient that neural machine translation cannot identify word alignment. To solve this problem, I searched for and tried a different method from those of other researchers and discovered by chance that it is easy to train a neural network on whether one word and another word are semantically close, even if the words are in different languages. In fact, word alignment can be obtained with high accuracy if enough data, namely, correct word alignment between about 300 sentences, are available. During the process leading up to that discovery, I first looked at the semantic vectors of words learned by multilingual BERT (Bidirectional Encoder Representations from Transformers)*. I noticed that despite not using the so-called bilingual

* BERT: A semantic representation model of a language (developed by Google) that has been pre-trained from a large amount of text by using a deep learning method called Transformer. Multilingual BERT is a single model trained from text in 104 languages.



For each word (span) in the Japanese sentence, find the word sequence (span) that is a translation of each other in the English sentence. The correspondence is determined from the semantic vector representation of the two spans.

Fig. 3. An example of word alignment based on cross-language span prediction.

corpus, which is a database of multilingual bilingual sentences, in the trained model, similar words exist in a relatively close place in the vector space.

The reason for that finding is twofold. First, even if the languages are different, some parts are written in common notations such as numbers and alphabets. Second, there are commonalities that exists between languages that have similar characteristics. For example, Japanese and Chinese overlap because both languages use Chinese characters. When I looked at that reason in more detail, I thought that there might be a situation in which common notations and words become pivots, and each language expands its own world around those pivots. From that idea, I deduced that it is actually very easy to train a neural network on whether a word and another word in the vector space are semantically close, and if there are correct-answer data for word correspondences between about 300 sentences, word alignment can be obtained with high accuracy.

This groundbreaking discovery was made possible through repeated trial and error, as well as my desire to do something different and controversial. This way of thinking may have come from my experience of studying in the United States in my early thirties. I went to the United States for research twice. I was first a visiting researcher at Carnegie Mellon University (CMU), where I learned that when they say "He is different," they use "different" as a compliment. I then spent time at AT&T, and Dr. Kenneth Church, who was my supervisor, said, "I do things differently and try to be controversial," and I deeply related with his attitude as a researcher. Those experiences changed my view that "being different" is a good thing.

I also learned the importance of self-review after researching in the United States those two times. To do something different, you have to understand what other people do, so I am still diligently reviewing where my research stands and what I do not understand.

—Your experience in the United States has greatly influenced your career as a researcher.

CMU also taught me the mindset of a researcher. During the summer and fall, when new semesters start at universities in the United States, guidance sessions on research and other topics are held. At that time, I learned that research is to be at the forefront of human intelligence and use one's wisdom to elucidate things that are not yet understood. I was fortunate to have the opportunity to learn at the early stage of my research career about the basic concepts of what research entails and how I should contribute. I also remember that in the United States, the evaluation criteria for a doctoral degree, such as research methods, results, and level of achievement, were specifically indicated, so it became easier for me to set my own goals and approach to research.

NTT has an outstanding tradition called "theme planning." It involves presentations of research projects by researchers in their first and second years after joining the company. During these presentations, the speakers present their research plans in a logical manner for the next three to four years. It is similar to the thesis proposal adopted at graduate schools in the US. Talking about what you have researched is something that you will naturally learn by gaining experience as a researcher; however, logically talking about future plans requires training. I think it is very beneficial to give that opportunity to young researchers in a systematic manner. I also think that understanding your own foothold and clarifying your mission through such activities will lead to research that is different from that of others and will produce research results worth discussing.

On the basis of the approach that I described above, I always try to look at my research objectively and work on something new. I recently started studying graph neural networks to reflect real-world circumstances beyond language in neural machine translation. Graph neural networks have been put to practical use in a variety of applications such as predicting arrival times via Google Maps. This function measures the movement of people between all road intersections and road links and predicts the time it will take to move from point A to point B at each time of day. Similarly, the recommendation function provided by Uber Eats associates information on the person placing the order with ordered items, etc. to predict what the person will order next time. I believe that the accuracy of machine translation can be further improved by reflecting information about real-world circumstances that cannot be verbalized by applying graph neural networks.

My unprecedented "I'm giving up!" declaration

—Looking back on your research career to date, what has left an impression on you, and what will you be working on in the future?

The declaration that I made in the summer of 2016, "I'm giving up research on statistical machine translation," left a lasting impression on me. I have been researching machine translation for about 30 years, and the technological changes brought about by the advent of neural machine translation have had a profound impact on the study of machine translation; in fact, its impact was so huge that it has cancelled out past research. As a result, researchers in the field of neural machine translation are all at the same starting line. Under these circumstances, I declared at a meeting announcing my research policy that "Statistical machine translation cannot beat neural machine translation, so I'm giving up researching it." In hindsight, saying that would have been unheard of.

I had been the leader of my team's research on statistical machine translation, so I felt as if I was retreating from the front line. However, with technological innovation, I could conduct research individually instead of in a team and was able to go back to being a researcher. It was a very emotional experience for me to be able to publish a paper as the first author again at the age when I was in a position to lead a team as a manager.

Going forward, I want to leave something behind that will serve as a foundation for research. I think that since data is the key to any research, that foundation is a bilingual corpus or translation database for research on machine translation. A bilingual corpus is a database of bilingual sentences, and a data source is necessary to create it. In the early 2000s, documents from international organizations were used as data sources; however, today, Google Translate, a typical example of an online machine-translation service, uses the web as its data source. Some people argue that it is unacceptable for a single company like Google to accumulate information exclusively. Accordingly, several attempts to create a bilingual corpus by extracting bilingual sentences on a large scale from the web archive of Common Crawl, a non-profit organization that aims to "crawl" the web and provide data to the public, have been made.

According to ParaCrawl, a project to create a large-scale bilingual corpus between European languages and English using data of Common Crawl, the accuracy of machine translation became equivalent to that of translation by humans when 40 million pairs of sentences were accumulated. That number of sentences in the Japanese language has not been accumulated, and if the current trend continues, the machine-translation industry in Japan will be left behind by that in Europe. For that reason, I want to enrich JParaCrawl, a Japanese-English bilingual corpus created by NTT, and contribute to the development of Japanese research on machine translation.

I witnessed a university professor who was about to retire organize his students in an attempt to create a large-scale database of Japanese-English sentence pairs called Tanaka Corpus, which was later incorporated into the "tatoeba" project [2]. At the time, I couldn't understand the passion of Professor Tanaka as I wondered what the point of starting something like this was when he was so close to retirement.

However, now that I am approaching retirement age, I understand the feeling. I also want to continue to be involved in activities to create a database that can be accessed by many people.

—Do you have any advice for young researchers?

The longer you pursue a topic of interest, the better off you will be. To that end, I want you to value two behaviors: to acquire the ability to explain your research to others in an easy-to-understand manner and to evaluate your research activities on a regular basis.

Skills to evaluate your research activities on a regular basis can also be developed through writing a research plan. At NTT, you are required to submit a one-year research plan every year. At that time, I review my research plan from the previous year, even though it was my "best effort" plan, I found that my predictions did not come true. However, after repeating the review a few times, you will learn what you can do and what you did as predicted and, conversely, what you cannot do and what you do not predict. As you gain experience, you will be able to formulate research plans on the basis of more-realistic predictions and develop the skills you need to communicate them clearly to a third party.

To work on a long-term project, the theme must be interesting. I was not so sure about my future prospects when I was younger. In the past, I tried to look ahead five or ten years, but it was in the first one or two years that the prospects held some reality. In this age of rapid change, it is extremely difficult to predict the future five or ten years down the line. Even under such circumstances, I think it is important to try to imagine as far as possible what you want to be in your imagined future.

Young researchers, there may be no other job in which you can stay active as long as a researcher. Therefore, find themes that you can research for a long time and continue your research activities focused on those themes.

References

[1] M. Nagata, K. Chousa, and M. Nishino, "A Supervised Word Alignment Method based on Cross-language Span Prediction Using Multilingual BERT," Proc. of EMNLP 2020, pp. 555–565, Nov. 2020.

[2] Tatoeba Project, https://tatoeba.org/eng/

■ Interviewee profile

Masaaki Nagata

Senior Distinguished Researcher, Group Leader, NTT Communication Science Laboratories.

He received a B.E., M.E., and Ph.D. in information science from Kyoto University in 1985, 1987, and 1999. He joined NTT in 1987. His research interests include morphological analysis, named entity recognition, parsing, and machine translation. He is a member of the Institute of Electronics, Information and Communication Engineers, the Information Processing Society of Japan, Japanese Society for Artificial Intelligence, the Association for Natural Language Processing, and the Association for Computational Linguistics.

Research and Development on Technologies for Transforming the Global Environment from a Space Perspective

Yuji Maeda

Abstract

NTT Space Environment and Energy Laboratories was established in July 2020 to develop innovative technologies for regenerating the global environment and achieving a sustainable and inclusive society. We are the first NTT laboratories with “space” in our name, but our purpose is not to conduct research on space itself. Rather, we study the Earth from the perspective of the space environment, including the Sun, and take on challenging studies with the aim of transforming the future of the global environment from dynamic viewpoints.

Keywords: space, environment, energy

1. Introduction

NTT embarked on new smart energy business ventures on the basis of NTT Group’s Medium-term Management Strategy “Your Value Partner 2025” announced in November 2018. Next-generation energy technologies, such as nuclear fusion, are beginning to look feasible. There are also growing expectations for the development of technologies, such as the Innovative Optical and Wireless Network (IOWN), that will break through the limitations of current technologies and contribute to the restoration of the global environment. Environmental, social, and governance (ESG) management with efforts to meet the United Nations’ Sustainable Development Goals has a significant impact on the sustainable growth of corporations. It is in this context that the NTT Group announced its Environmental and Energy Vision: Zero Environmental Impact in May 2020, and established NTT Space Environment and Energy Laboratories in July of that year to implement this vision. The purpose of the Laboratories is to develop technologies that will enable innovation in smart energy and transform the future of the global environment.

NTT Space Environment and Energy Laboratories aims to contribute to the regeneration and innovation of the global environment by re-examining the Earth and society from the higher and broader perspective of space without being restricted by conventional technologies.

2. The Laboratories’ vision

NTT Space Environment and Energy Laboratories has the following vision: to regenerate the global environment and achieve a sustainable and inclusive society to develop next-generation energy technologies that adapt to the environment and contribute to the elimination of environmental impact, i.e., zero impact.

The specific type of society that we aim for through this vision is an ultra-resilient smart city, as shown in **Fig. 1**. Our objective is not just to eliminate the impact of our society on the global environment but to bring about a society in which the impact of changes in the global environment becomes acceptable, in

Fig. 1. Image of ultra-resilient society.

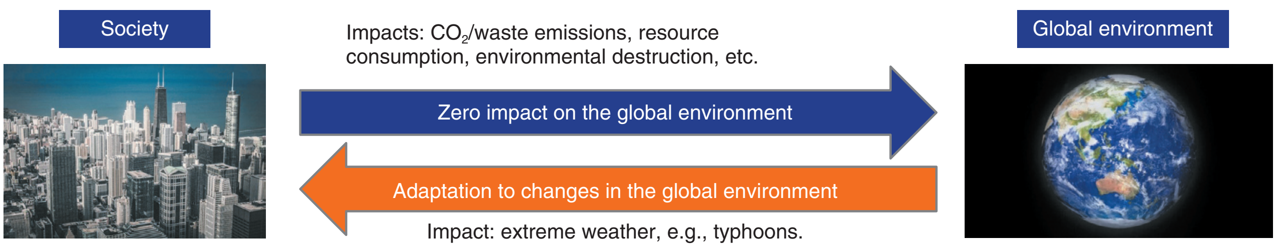


Fig. 2. Future image of the relationship between society and global environment.

which a zero power-outage state is achieved through local production of clean energy for local consumption, use of decentralized autonomous cooperative energy networks, and harnessing the power of severe weather conditions such as typhoons (**Fig. 2**). To achieve such an ultra-resilient smart city, we are conducting research and development of innovative technologies such as for the utilization of overwhelmingly clean next-generation energy, sustainable technologies including carbon dioxide (CO_2) conversion, ESG management, and proactive environmental adaptation.

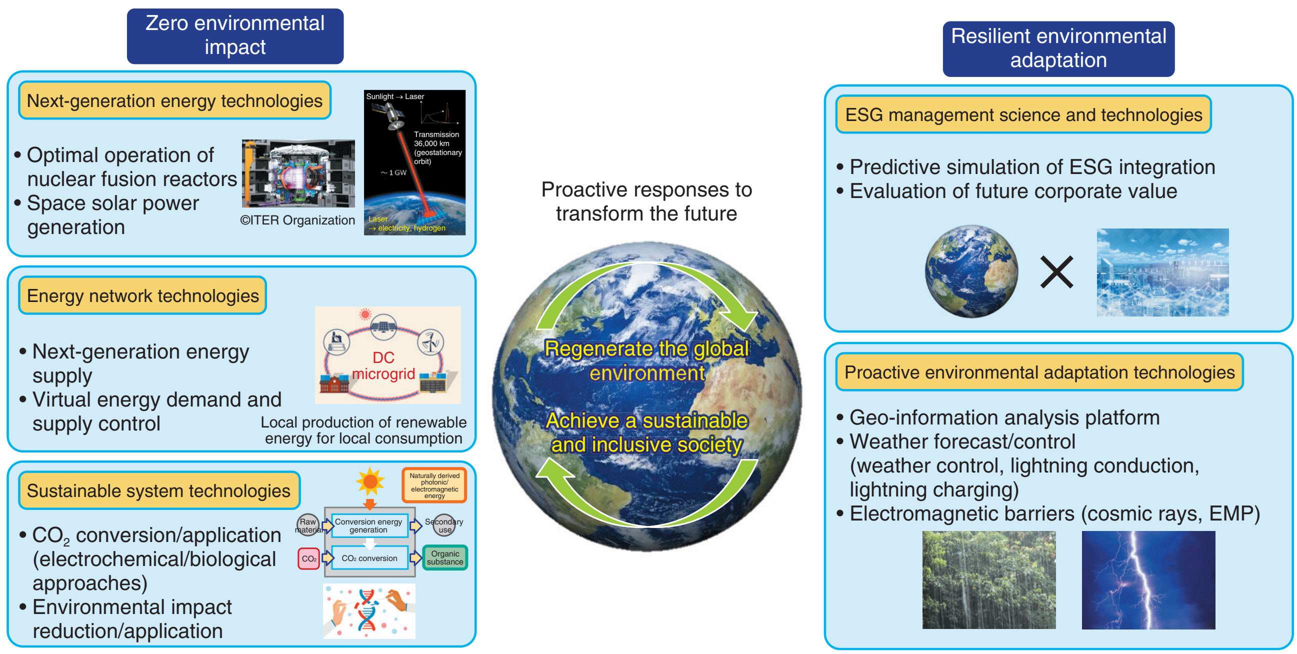
3. Research topics

A list of our research topics is shown in **Fig. 3**. The Laboratories is currently focusing on two research projects: Zero Environmental Impact Research Project and Resilient Environmental Adaptation Research Project. This article presents only an overview of these projects because the details of each are described in separate articles in this issue [1–4].

3.1 Zero Environmental Impact Research Project

As shown in Fig. 3, the Zero Environment Impact Research Project is working on three topics: technology to produce overwhelmingly clean next-generation energy [1], energy network technology to enable efficient distribution of energy [2], and sustainable system technology to reduce CO_2 in the air and water [1].

For next-generation energy, we are focusing on fusion energy and space solar power generation. Fusion energy is power generation using nuclear fusion. In May 2020, NTT concluded a cooperative agreement with the ITER International Fusion Energy Organization (ITER Organization). In November 2020, a collaboration agreement was concluded with the National Institutes for Quantum and Radiological Science and Technology, which is the domestic organization of the ITER Organization. We are seeking to support successful application of the ITER nuclear fusion reactor using IOWN. The ITER Tokamak Fusion Test Reactor is scheduled to begin operation in 2025. This is an attempt to create a "mini-Sun" with the plasma temperature inside the reactor reaching



DC: direct current
EMP: electromagnetic pulse

Fig. 3. List of research topics.

150 million degrees Celsius. IOWN's ultra-low-latency, high-speed, high-capacity network will be used to transmit the huge volume of sensor data coming from the test reactor to the operation center. We will also contribute to achieving optimal operation by using our Digital Twin Computing (DTC) to predict future outcomes from the collected data.

Space solar power generation is an ambitious research project in which a satellite in geostationary orbit at an altitude of 36,000 km above the ground wirelessly transmits energy from sunlight to the Earth 24 hours a day, 7 days a week. Several mechanisms have been conceived for wireless power transmission. We are focusing on using laser light. We will build on our photonics and photoelectric conversion technologies developed for telecommunications to achieve high-efficiency, ultra-long-distance wireless power transmission in the very near future.

Regarding energy network technology, we will apply the indoor direct-current (DC) power supply technology, in which we have considerable expertise, to the outdoors. We are aiming to build highly resilient, decentralized, autonomous cooperative energy networks by setting up DC transmission links between NTT buildings (central offices) and electric-power consumers' premises in their surrounding regions. The network will enable the participating companies to give and take power flexibly and efficiently. It will also enable power to be supplied stably in the event of a disaster. We are studying technology for simulating energy demand, generation, and storage in an integrated manner in cyberspace and reflecting the resultant optimal solution in the actual field to balance power supply and demand. We are also working on technology for flexibly reallocating information-processing loads for communications traffic and computation among multiple sites to efficiently use renewable energy, the generation of which is affected by weather conditions.

Sustainable systems technology is aimed at reducing CO_2 in the air and water. We intend to take two approaches. One (electrochemical) is to produce artificial photosynthesis using semiconductor and catalyst technologies. The other (biological) is to fully exploit the abilities of plants and algae. With the former, we use materials informatics*1 to identify

*1 Material informatics: A method for achieving efficient material development. It uses information-processing technology, including artificial intelligence, to identify candidates for compounds that have desirable characteristics, on the basis of a huge volume of chemical compound data, experiment results, and simulation results.

combinations of materials that cannot be discovered with conventional approaches on the basis of experimental rules and existing concepts. With the latter, we will use DTC to reproduce a wide range of plant-growing environments in cyberspace and reflect the results in real space after verifying the effects of genome editing and environmental control.

3.2 Resilient Environmental Adaptation Research Project

The Resilient Environmental Adaptation Research Project is working on two research topics: ESG management science [3] and proactive environmental adaptation [4].

ESG management has recently become one of the important criteria for investment decisions, prompting many corporations to adopt it. However, most corporations have difficulty in effectively linking the three ESG elements. To solve this problem, we are working on ESG management science and technology with a focus on minimizing risk in ESG management by using future prediction and future transformation. Specifically, we draw on DTC to analyze data about the environment and society and predict the future of both on the basis of scientific evidence. We aim to transform the future of the global environment and human society by taking proactive actions on the basis of those predictions. For example, the corporate value and well-being of a company can be evaluated on the basis of its future prediction results. We are studying methods of predicting what actions will enhance corporate value and presenting a future scenario.

In proactive environmental adaptation, we are working on four research topics to enable aggressive and physical adaptation to weather patterns and environmental conditions, which are becoming increasingly extreme. Enhancing prediction of weather conditions and disaster damage is most critical for environmental adaptation. NTT currently predicts potential damage to telecommunications equipment from forecasts provided by the Japan Meteorological Agency.

The first of the four topics is studying geo-information-analysis platform technology for enhancing such prediction. The key to this technology is an entirely new sensing technology whereby a satellite orbiting at about 500 km collects data from Internet-of-Things sensors (920-MHz band), bundles the data, and transmits them back to Earth [5]. We are using this sensing technology to collect and analyze data from sensors on and beneath the sea and in mountainous areas, none of which are currently well monitored. We are seeking to enhance the degree of accuracy of weather forecasts and disaster-damage prediction using the analysis results.

The second topic is studying technology for proactively controlling the weather on the basis of accurate weather forecasts. For example, water mass replacement*2 can be used to lower the temperature of the Japanese coastal waters that supply energy for extreme weather events such as typhoons and trainings (line-shaped rainfall systems), thereby weakening their power. We are investigating disaster green energy. For example, typhoon power can be harnessed to generate electricity. However, it is also necessary to study the potential impact of such weather control. Therefore, we plan to simulate and evaluate such impact by exploiting DTC to reproduce the global environment in cyberspace. This will include socio-economic systems, as referred to in the explanation of ESG management science and technology. We will also predict the future in cyberspace to derive optimal solutions and implement them in the real world.

The third topic is studying lightning as one of the targets of weather control. We already have advanced measures to protect telecommunications equipment from lightning strikes. We will build upon this to study lightning control and lightning charging. Specifically, we are investigating lightning-control technology that will predict the lightning-strike area with a high degree of accuracy and induce lightning to strike a drone and lightning-charging technology for storing lightning-generated energy. We are aiming to develop an airborne lightning-energy-absorption system that will operate autonomously using lightning energy and absorb energy before a lightning strike occurs.

The fourth topic is studying measures against cosmic rays, which can be considered a "weather problem in space." Malfunctions of semiconductors caused by cosmic rays emanating from the Sun and other stars in the galaxy are called *soft errors*. We are expanding our conventional technology for evaluating soft errors, not only to prevent soft errors on Earth but also to predict the impact of cosmic rays and electromagnetic pulses on devices and human bodies, which are directly exposed to them in outer space, and to develop electromagnetic-barrier technology, which

*2 Water mass replacement: Technology to replace warm seawater in the surface layer with cold seawater in the deep sea for cooling and power generation. There is a temperature difference of more than 30 degrees in some sea areas.

will proactively protect devices and human bodies against those phenomena. Since there are overheating risks and cosmic rays in space, it is difficult to use sophisticated electronic devices in that environment and difficult for humans to remain in space over an extended period. Once further progress is made on technology and IOWN, such facilities as space-based datacenters will become feasible.

4. Conclusion

The research projects introduced in this article are still in the embryonic stage. They have only just been initiated with modest resources, but our dreams are far more ambitious. We will strengthen our resources to take on challenges in new fields that we currently cannot undertake and work to contribute to the regeneration of the global environment and transformation of our future.

The resumption of economic activities after COVID-19 should move toward achieving a resilient society that solves problems such as climate change and marine pollution. This movement is accelerating in governments and industries around the world. Therefore, we will accelerate our research while reinforcing our resources and collaborating with partners in various industries. Stay tuned to follow the growth of our Laboratories as it works to develop innovative technologies in the environment and energy fields from a space perspective.

References

[1] K. Akiyama and K. Takaya, "Next-generation Energy-utilization and CO_2-conversion Technologies Contributing to Zero Environmental Impact," NTT Technical Review, Vol. 19, No. 6, pp. 17–21, June 2021. https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202106fa2.html

[2] T. Tanaka, H. Minami, T. Tanaka, N. Nakamura, T. Hayashi, M. Kozai, Y. Higuchi, N. Hanaoka, and M. Iwamoto, "Energy-distribution Platform Technologies toward Zero Environmental Impact," NTT Technical Review, Vol. 19, No. 6, pp. 22–29, June 2021. https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202106fa3.html

[3] Y. Tanaka, X. Zhang, and M. Shinozuka, "ESG Management Science and Technology for a Sustainable and Inclusive Society," NTT Technical Review, Vol. 19, No. 6, pp. 30–36, June 2021. https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202106fa4.html

[4] J. Kato, "Proactive Environment Adaptation Technology for Living Safely and Securely," NTT Technical Review, Vol. 19, No. 6, pp. 37–41, June 2021. https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202106fa5.html

[5] NTT press release issued on May 29, 2020 (in Japanese), https://www.ntt.co.jp/news2020/2005/200529a.html

Yuji Maeda

Vice President of NTT Space Environment and Energy Laboratories.

He received a Ph.D. in systems information science from Future University Hakodate, Hokkaido, in 2013. He joined NTT Telecommunication Networks Laboratories in 1991. He has been engaged in managing projects related to general emergency management such as those concerning natural disaster response and cybersecurity. He received the Scholarship Encouragement Award from the Institute of Electronics, Information and Communication Engineers (IEICE) in 1998. He is a senior member of IEICE and a member of the Institute of Electrical and Electronics Engineers (IEEE).

Next-generation Energy-utilization and CO_2-conversion Technologies Contributing to Zero Environmental Impact

Kazuya Akiyama and Kazuhiro Takaya

Abstract

This article outlines next-generation energy technologies to enable the use of overwhelmingly clean and inexhaustible energy sources, which are expected to be put to practical use, and carbon dioxide (CO_2)-conversion technologies to effectively fix CO_2 and reduce the total CO_2 emissions of business activities to zero or less.

Keywords: fusion energy, space solar power, CO_2 conversion

1. Initiatives to use next-generation energy

To achieve a sustainable society, the Next-Generation Energy Technology Group in NTT Space Environment and Energy Laboratories is working on two themes: technology related to *fusion energy*, which is an overwhelmingly clean and inexhaustible energy source, and space solar-power-generation technology.

1.1 Optimal operation technology for fusion reactors

The fusion energy technology will be used to optimize fusion reactor operations by using the Innovative Optical and Wireless Network (IOWN). In May 2020, we concluded a comprehensive cooperation agreement with the ITER International Fusion Energy Organization (ITER Organization, where "ITER" means "the way" in Latin) [1]. In November 2012, we also entered into a partnership agreement with the National Institutes for Quantum and Radiological Science and Technology to develop innovative environmental energy technologies ahead of the rest of the world [2]. Fusion energy is produced by the sun and other stars in the universe. It is a nuclear reaction in which light nuclei fuse to form heavier nuclei. For example, in DT nuclear fusion reaction*1 in which the nuclei of deuterium (D), which is an isotope of hydrogen, and tritium (T) are fused, helium and neutrons are produced, and the energy generated from the nuclear fusion reaction of only one gram of deuterium and tritium is equivalent to the heat generated from burning about 8 tons of petroleum (a full lorry). The ITER project is a very large international project (**Fig. 1**) with the goal of using fusion energy for power generation. The seven regions of Japan, Europe, the United States, Russia, South Korea, China, and India are promoting the project, and preparations are underway at Saint-Paul-les-Durance in southern France to commence operation in 2025. Fusion energy, combined with more distributed renewable energy sources such as solar and wind, is expected to provide a safe and reliable energy for the world for millions of years.

In the ITER experimental nuclear fusion reactor, deuterium and tritium, which are forms of hydrogen

*1 DT nuclear fusion reaction: D + T = He (3.52 MeV) + n (14.06 MeV). To overcome the repulsive force of electric charge and to collide D and T, a speed of 1000 km/s or more and heating temperature equivalent to 100 million degrees or more are required.

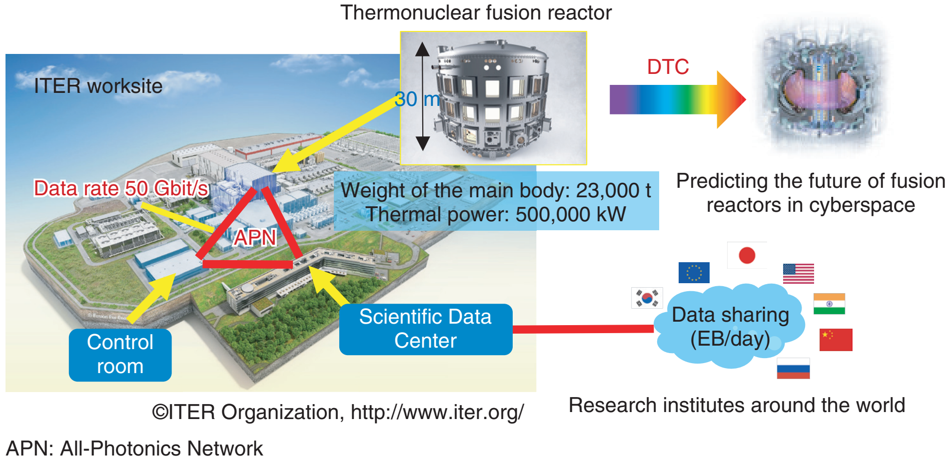


Fig. 1. Overview of ITER worksite and optimal operation technology for fusion reactors.

that serve as fuel, are confined in a doughnut-shaped magnetic field, heated to a plasma state, and further heated to 150 million degrees Centigrade to generate a nuclear fusion reaction. The ability to stably produce such plasma for extended periods is essential if we are to extract energy from a hydrogen fusion reactor. This requires an enormous volume of sensor data, up to 50 Gbit/s, obtained from the fusion reactor to be transferred to the control center, where optimal values for controlling the plasma shape must be instantaneously calculated and sent back to the reactor. To facilitate this, it is vital to further increase the speed and reduce the latency of the control network. In addition to the high-quality, large-capacity, and low-latency All-Photonics Network, which is one of the elemental technologies of IOWN, our goal is to achieve this by using disaggregated computing, which is a new computing architecture that enables high-speed and high-efficiency data processing. When a fusion reactor is put into full operation, experimental data at the exabyte (EB) level are generated per day. We believe that IOWN can contribute to the storage of such data in datacenters around the world and the high-speed replication between datacenters. We plan to further improve control technology by using Digital Twin Computing (DTC) to realistically reproduce a hydrogen fusion reactor in cyberspace, conducting highly advanced simulations, and predicting the future performance of a hydrogen fusion reactor.

1.2 Space solar-power-generation technology

Space solar-power-generation technology generates solar power on a satellite in geostationary orbit 36,000 km above the ground, transmits the energy to the ground by lasers or microwaves, and converts it back to electric power or other energy on the ground (**Fig. 2**). A satellite in geostationary orbit can receive

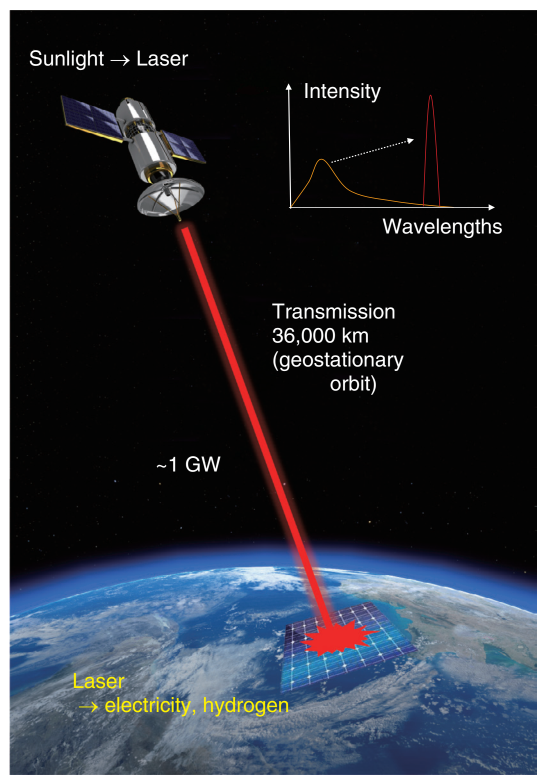


Fig. 2. Space solar-power-generation technology.

energy from the sun almost 24 hours a day, 365 days a year, and because the satellite is not affected by the absorption or scattering of energy by Earth's atmosphere, it can stably receive about 10 times more energy per unit area than on the ground. The Japan Aerospace Exploration Agency and other organizations are conducting research and development (R&D) with the aim of putting this technology into practical use after 2030, and if it is achieved, clean and inexhaustible energy can be used. Since the wavelength of lasers is about 3–4 orders of magnitude shorter than that of microwaves, we are investigating an approach using lasers because the beam divergence angle is small and it is easy to transmit over long distance.

There are three major technologies for generating space solar power. The first is effeciently converting sunlight into a laser on a satellite in geostationary orbit. Unlike the conventional method of laser oscillation using power generated from solar cells, we are conducting research on a system that executes laser oscillation with high efficiency by directly irradiating a special crystal with sunlight to excite a laser. The second technology accurately irradiates a target on the ground with a laser beam. Although the laser can be easily transmitted over long distance, a direction control accuracy of 0.3 μrad (2×10^{-6} degrees) is required to irradiate a laser beam with an accuracy of ± 10 m from a satellite in geostationary orbit. The effects of atmospheric turbulence must also be removed. Therefore, we are conducting research on optical systems with deep focal depths such as the Bessel beam[*2] and beam transmission systems that use adaptive optics[*3] used in astronomy to eliminate fluctuations in light propagating through the atmosphere. The third technology converts lasers into energy with high efficiency. Since laser light is a single wavelength, unlike sunlight in which light of various wavelengths is mixed, we are researching solar cells with high conversion efficiency at specific wavelengths. When a laser is converted into electric power using a solar cell, about half the energy becomes heat. Therefore, we are studying methods of storing energy in different forms such as hydrogen and ammonia using thermochemical reactions instead of converting lasers directly into electricity. We believe that this technology can be key to achieving a hydrogen-based society.

2. Efforts to reduce carbon dioxide (CO_2) emissions to zero or less

To contribute to the restoration of the global environment and achieve a sustainable society, the Sustainable Systems Group is engaged in the R&D of sustainable systems that reduce all environmental loads to zero or less and their implementation in society. Below zero means not only reducing emissions but also reducing what already exists. There are various factors in terms of environmental impact, and one is CO_2. Under the Paris Agreement, reduction of CO_2 emissions is required. Therefore, the Sustainable Systems Group has been conducting R&D on two approaches to reduce CO_2 (**Fig. 3**).

2.1 CO_2-conversion technology (electrochemical approach)

One approach is an electrochemical approach that applies the semiconductor technology used in communication devices and the catalyst technology used in fuel cells. This involves the R&D of CO_2-conversion technology for generating hydrocarbon fuels such as methane and formic acid, which is a storable hydrogen carrier, from water (H_2O) and CO_2 using light and electromagnetic energy such as solar light, as well as reducing the amount of atmospheric CO_2. This is also called *artificial photosynthesis*[*4] because it mimics the photosynthesis of plants that use sunlight and other light energy to synthesize carbohydrates from H_2O and CO_2. An advantage of the electrochemical approach is that it enables the production of storable fuel (source of energy) from natural energy sources such as solar light, which can be used in a variety of applications, and is expected to be a carbon neutral energy source.

There are still problems regarding practical application. For example, a semiconductor device (material) that generates hydrogen ions and electrons using the energy of sunlight is installed in water as an electrode, which ionizes (corrodes) the surface of the device and degrades its performance. Since the wavelengths of light that can be used as energy are limited

*2 Bessel beam: A type of non-diffracted beam in which the beam does not expand because of diffraction phenomena.

*3 Adaptive optics: A technique to improve image quality by measuring the fluctuation of an image caused by the atmosphere with a wavefront sensor and correcting it dynamically.

*4 Artificial photosynthesis: This technology imitates the action of plants to produce starch and oxygen from carbon dioxide and water using solar energy and generates organic substances from carbon dioxide and water by chemical reaction using solar energy and water used as raw materials.

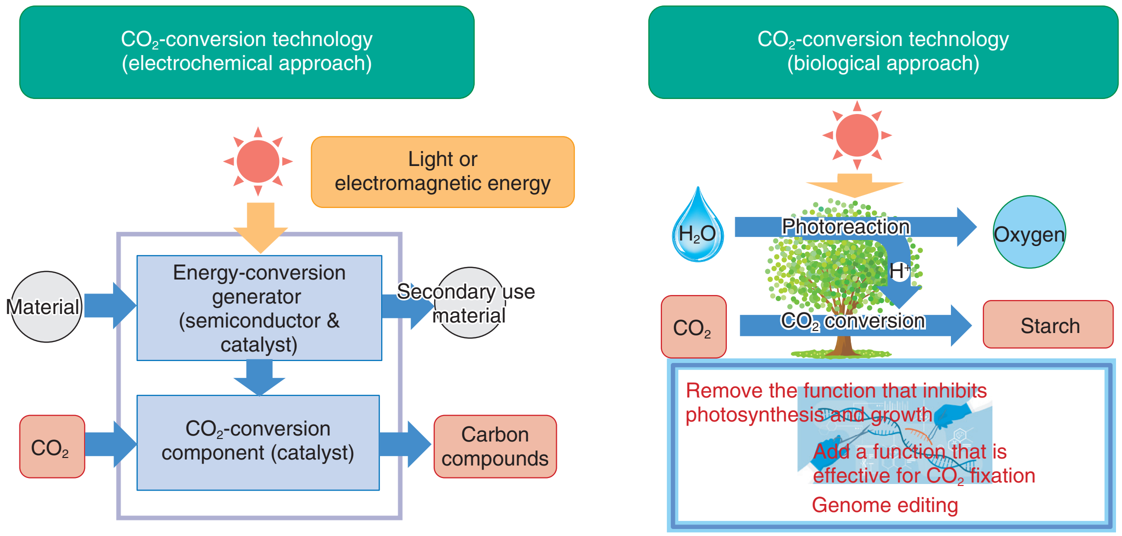


Fig. 3. Two approaches of CO_2-conversion technology.

depending on the physical properties of semiconductor devices, a wide bandwidth that can absorb energy of various wavelengths is required. It is also necessary to establish a technology to extend the life of catalysts for reducing CO_2 by reducing performance degradation due to repeated chemical reactions. Therefore, the group is collaborating with NTT Device Technology Laboratories, which has experience and skills in semiconductor devices and catalysts.

There are also operational and safety issues for the practical application of CO_2-conversion technology using the electrochemical approach. For example, many artificial photosynthesis systems currently under development are evaluated for their performance in laboratories and other environments that are relatively easy to control. For example, although highly pure and highly concentrated CO_2 is often added from gas cylinders in the laboratory, it is necessary to act on approximately 0.04% of the atmospheric concentration of CO_2 with high efficiency.Therefore, R&D on a technology called direct air capture (DAC) for directly recovering low concentrations of CO_2 from the atmosphere is being promoted. However, if the combination of an artificial photosynthesis system with DAC becomes essential, the cost becomes even higher, and an optimal design is required so that either one does not become a bottleneck. In addition, hydrogen and carbon monoxide are included in the gases used as raw materials for electrochemical reactions, and strong safety designs are required to prevent these gases from being released into the atmosphere in the event of an emergency. For practical application of CO_2-conversion technology using this electrochemical approach, it is not enough to simply pursue efficiency, it is also essential to search for optimal solutions that simultaneously solve operational and safety issues.

2.2 CO_2-conversion technology (biological approach)

The other approach to CO_2-conversion technology is the biological approach that maximizes the photosynthetic function of plants and algae through genome editing[*5] and optimal control of breeding and growth environments. Over the past 30 years, the area of forests around the world has been increasing, but it has been reported that the diversity and soundness of forests have been decreasing due to global warming and logging. This may indicate that the natural division of roles necessary for the symbiosis and coexistence of the vegetation forming the forest and the organisms and microorganisms living there are not optimum. Therefore, we are carrying out R&D for maximizing the photosynthetic capacity per plant by making full use of genome-editing technology and growing-environment control technology by accelerating the time when plants activate photosynthesis

*5 Genome editing: The technology to change the characteristics of an organism by editing a specific base sequence (DNA sequence) in the genome of the organism.

(early growth) and maintaining that time for a long period (long-term soundness). If we can increase the forest area where photosynthesis is enhanced per tree, we can achieve long-term carbon fixation through plants. If we focus on vegetables and trees, which are food and industrial resources, we can absorb more CO_2 during the growing season by promoting early growth while maintaining high quality, and after harvesting and felling, we can use vegetable and tree wastes for other carbon cycles. Regarding algae, we believe it is possible to efficiently absorb CO_2 dissolved in water and improve the environment of wetlands and seagrass beds by using genome-editing technology and environmental-control technology to proliferate algae within a short period.

The issues with CO_2-conversion technology using the biological approach are as follows. Trees, which can fix carbon over a long period and have a high photosynthetic capacity, have a large number of genes, and it takes a great deal of time to analyze genome and identify the genes that determine early growth and long-term health. Even if genome editing is carried out, it is not easy to confirm the effects of such editing because it takes many years for trees to grow.

Although genome analysis and editing are relatively easy regarding algae due to the small number of genes, a large amount of energy is required for resource recovery (machining) to increase added value after growth and for disposal of the parts of algae that cannot be used effectively.

Therefore, we are studying using DTC, one of the elemental technologies of IOWN, as a time-saving means to verify the effect of genome editing on trees. If an analytical model of plants and growing environments can be constructed in a virtual space and virtual growth simulations can be conducted, the effects of genome editing should be predicted in a short period without real verification such as cultivation. If it is possible to select genetic characteristics with low disease risk at the seed and seedling stages, selective breeding can be achieved. Regarding the issue of algal waste, we believe that it is important to efficiently link a number of carbon cycles such as providing algal waste as food and resources to other organisms.

3. Future developments

The challenges we are taking on concerning next-generation energy-utilization and CO_2-conversion technologies were outlined in this article. Technologies developed through optimization of fusion-reactor operation will be applied to other industries as a use case of cooperation among cyber-physical systems through real-time control. We plan to commercialize the space solar-power-generation technology by introducing it on the ground for supplying power to devices such as drones for long-term operation and supplying emergency power to evacuation centers and isolated islands.

To address these issues with the CO_2-conversion technology at an early stage, we will promote R&D focusing on where the effects of information and communication technology can be expected, such as physical properties of electrochemical materials, useful genomes of plants and algae, and virtual growth simulation.

References

[1] NTT press release, “Conclusion of a Cooperation Agreement with ITER,” May 15, 2020.
https://group.ntt/en/newsrelease/2020/05/15/200515c.html

[2] NTT press release issued on Nov. 6, 2020 (in Japanese).
https://www.ntt.co.jp/news2020/2011/201106a.html

Kazuya Akiyama
Senior Research Engineer, Supervisor, NTT Space Environment and Energy Laboratories.

He received a B.S. and M.S. in astrophysics from Nagoya University, Aichi, in 1995 and 1997. He joined NTT in 1997 and engaged in environmental and energy research (seconded to NTT WEST Technology Innovation Department from 2009 to 2013). In 2015, he assumed the position of general manager, Corporate Planning Department, ENNET Corporation. In 2017, he was assigned to the NTT Technology Planning Department and was involved in the establishment of joint ventures. In 2018, he was assigned to NTT Facilities and engaged in solution sales.

Kazuhiro Takaya
Senior Research Engineer, Supervisor, NTT Space Environment and Energy Laboratories.

He received a B.E. and M.E. in electrical and electronic engineering from Okayama University in 1993 and 1995. He received a Ph.D. in electrical engineering from Kyoto University in 2019. He has been engaged in research on carbon dioxide conversion technologies using electrochemistry and biology.

Energy-distribution Platform Technologies toward Zero Environmental Impact

Toru Tanaka, Hiroya Minami, Toshimitsu Tanaka, Naomichi Nakamura, Toshihiro Hayashi, Masaki Kozai, Yuji Higuchi, Naoki Hanaoka, and Miho Iwamoto

Abstract

The use of renewable energy has been increasing, but further adoption will require effective distribution of energy and energy resilience. The Energy Network Technology Group of NTT Space Environment and Energy Laboratories is researching and developing virtual energy demand/supply control technology to enable full use of renewable energy and next-generation energy-supply technology based on direct current microgrids to provide a stable supply of power to regional areas even if the supply of commercial power is interrupted. This article introduces these technologies.

Keywords: virtual energy demand/supply control, DC microgrid, renewable energy

1. Introduction of renewable energy and disaster response

A growing sense of crisis with respect to resource depletion and global warming has been driving the introduction of renewable energy, but additional factors such as environmental, social and governance (ESG) investing*1 and use of renewable energy as a region's main power supply are dramatically changing the situation surrounding energy. While high costs have historically made the widespread use of renewable energy difficult, national policies, such as feed-in tariffs, have dramatically lowered costs by promoting the introduction of large-scale renewable energy such as mega solar power plants and massive wind power generation. These policies have helped reduce price-related barriers to the introduction of renewable energy. Recent advances in investing and management with respect to the environment, such as ESG investment and the Task Force on Climate-related Financial Disclosures (TCFD)*2, have also become essential elements in corporate activities, and at the national level, initiatives toward the expanded use of renewable energy, such as its use as a country's main power supply, have already become a matter of course.

The amount of power generated from renewable energy fluctuates greatly with weather, so it will be difficult to balance the amount of power consumed the more that renewable energy will be used. There has been much effort in controlling demand, but there is still the need for a large-scale and high-speed means of absorbing such fluctuations.

A large-scale power outage that occurred in September 2019 due to a direct hit by a typhoon in Chiba Prefecture followed by another large-scale power outage in the Tokyo metropolitan area due to the Fukushima Prefecture Offshore Earthquake in February

*1 ESG investing: A type of investing that places importance on and selects companies that give serious consideration to environment, society, and corporate governance.

*2 TCFD: A framework established by the Financial Stability Board (FSB) at the request of G20 to promote information disclosures on corporate initiatives with respect to climate change.

2021 have again raised awareness of the importance of a stable power supply. Resilience measures centered about the national government in Japan have consequently been promoted such as constructing backup systems at evacuation centers.

However, when commercial power becomes unavailable, power from renewable energy cannot be transmitted, and there are concerns that the backup facilities will be difficult to maintain continuously. In addition to disasters that have already been experienced, it will be necessary to deal appropriately with new risks such as electromagnetic pulses (EMPs) and cosmic radiation accompanying the expanded use of electronic equipment.

In this article, we introduce virtual energy demand/supply control and next-generation energy supply as technologies for solving these problems.

2. Virtual energy demand/supply control technology

A variety of measures are being taken to absorb large changes in the power generated from renewable energy. These include predicting the amount of power generated; adjusting the amount of power generated in conjunction with thermal power generation, pumped-storage hydropower, etc.; controlling the amount of power consumed by air conditioning, lighting, etc. on the consumer side; and storing surplus power in storage batteries. There have been recent developments in and introduction of new demand/supply control systems, such as virtual power plants that group and control many small-scale power generation facilities and multiple consumer devices much like a single electric power plant, and systems that use storage batteries in electric vehicles (EVs).

However, if renewable energy in large quantities is introduced to a specific region, there is still the possibility that controlling power fluctuation at the time of a surplus or shortage will be quantitatively or temporally difficult in that region. There is therefore a need for large-scale and high-speed control of the amount of consumed power so that no surplus or shortage of power occurs in the power system of any region even for a moment. The NTT Group consumes approximately 1% of the power consumed in Japan, and since NTT telecommunication buildings and datacenters are scattered throughout the country, it has the potential of modifying power consumption between regions. This modification of consumed power can be achieved by controlling the volume of communication traffic and amount of information processing of computational data, etc. For example, information processing can be transferred from a telecommunication building in a region where rainfall has caused a drop in solar power generation and a shortage of power to a telecommunication building in a region where fine weather has resulted in a surplus of power. Therefore, the region with rainfall can lower power consumption and avoid tight supply/demand conditions while the region with fine weather can increase power consumption and make full use of the power generated by solar power generation. To achieve such a transfer of information processing across regions, the aim of our research and development efforts is to make the amount of information processing follow the amount of power generated from renewable energy, enhance tracking of the amount of information processing and the amount of power consumed by information and communication technology (ICT) equipment, and optimize the amount of information processing to transfer and the timing of such transfers to achieve a supply/demand balance in each region. To achieve such optimization, our research and development is also aimed at performing such control so as not to affect communication service quality and facility stability (**Fig. 1**). It must also be considered that a large number of storage batteries are installed in NTT telecommunication buildings as backup power supplies for communication services, so making use of these batteries as well as EV batteries at the right time in conjunction with EV operation information should make it easier to control the charging/discharging of even greater amounts of power.

As an initial step toward establishing the above technology, we constructed a container-type test bed at NTT Musashino R&D Center, installed a rectifier, solar array simulator, storage batteries, information processing servers, etc., and began testing energy demand/supply control (**Fig. 2**). The plan is to use this test bed to test demand/supply control with distant telecommunication buildings and datacenters.

3. Next-generation energy supply technology

Various regions in Japan have been establishing resilience measures to reduce power supply interruptions brought on by disasters such as large-scale earthquakes. NTT is also promoting measures to strengthen the earthquake resistance of its buildings, defend against flooding, and fortify backup systems. However, in addition to extreme weather, it is thought

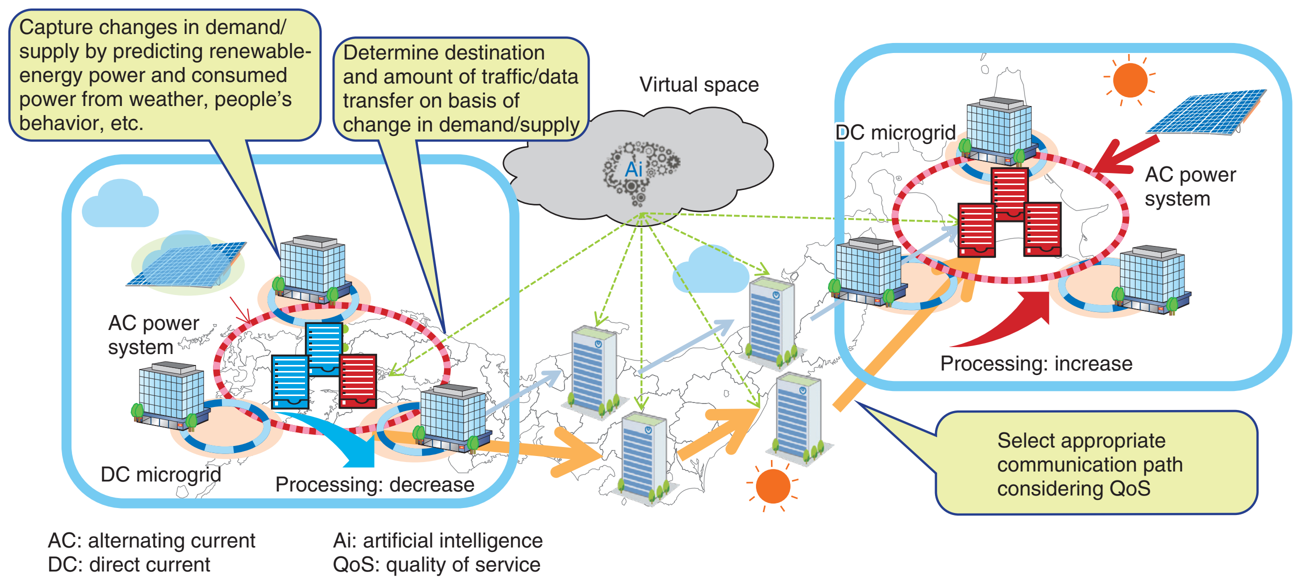


Fig. 1. Virtual energy demand/supply control technology.

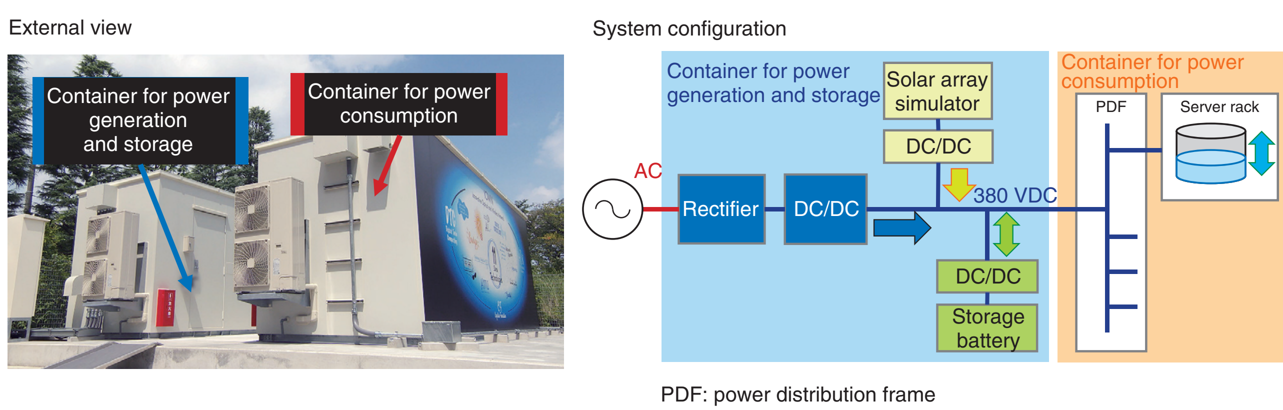


Fig. 2. Container-type test bed.

that the risk of damage, interruption, or erroneous operation of electronic equipment and power supply equipment still exists due to, for example, EMP irradiation resulting from a high-altitude nuclear explosion attack or cosmic rays emitted during solar flares. Such events are considered rare, but taking into account the further miniaturization and integration of semiconductor devices from here on and the further spread of electronic equipment and devices, damage to systems involving the power supply can have dire consequences for society. To solve this problem, the Energy Network Technology Group has undertaken the development of an energy supply system that enables a stable power supply in the face of all types of events.

The power supply system used in NTT telecommunication buildings had been a direct current (DC) system based on –48 VDC, but the recent increase in the power consumed by ICT equipment is prompting the introduction of a high voltage direct current (HVDC) power supply system that increases the voltage to 380 VDC. This HVDC power supply system (**Fig. 3(b)**) supplies DC power directly to ICT equipment that operates on DC, decreasing the number of conversion steps and reducing conversion loss compared with an alternating current (AC) power supply

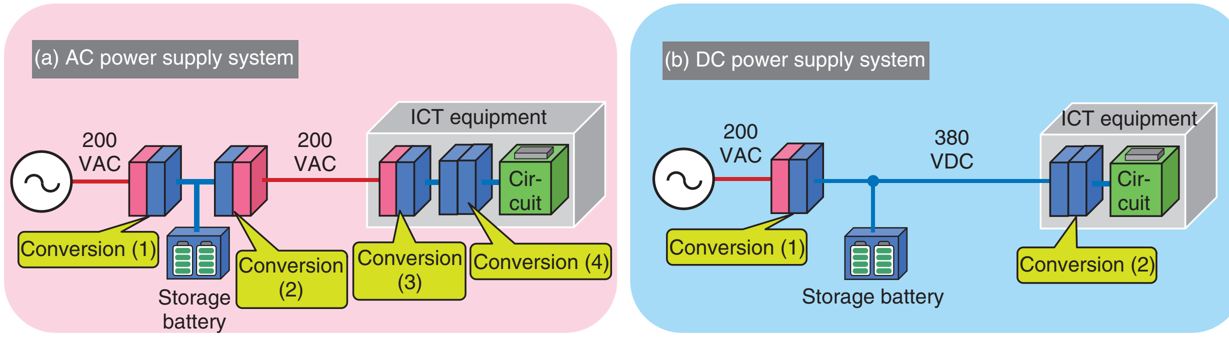


Fig. 3. AC and DC power supply systems.

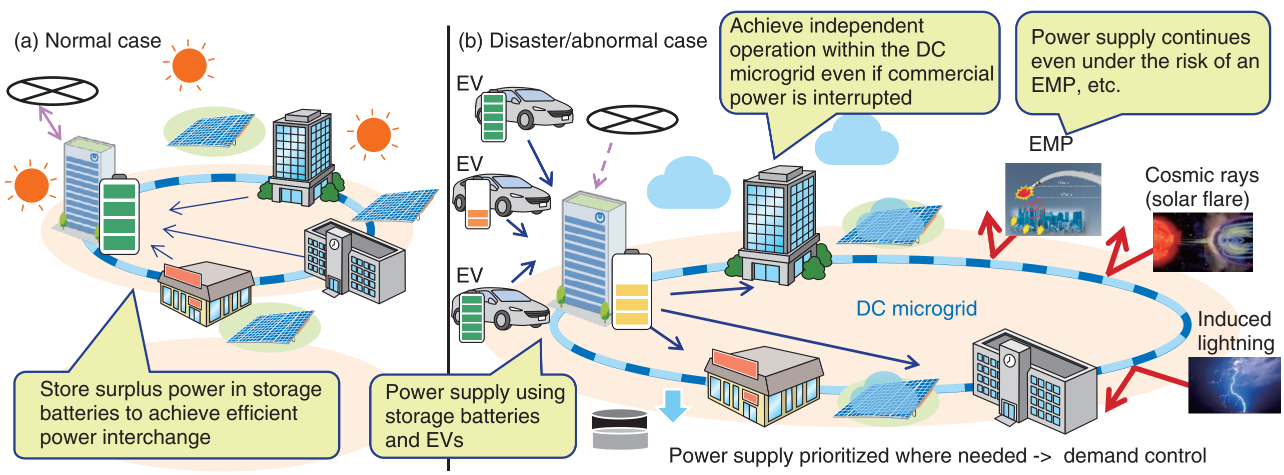


Fig. 4. Next-generation energy supply technology.

system (**Fig. 3(a)**). This makes for a high-efficiency system as well as an extremely reliable system since the storage battery used as backup is directly connected to the DC bus. We expect that this high-efficiency, high-reliability system can be used as a basis for constructing a DC microgrid that connects an NTT telecommunication building and local consumers to a 380 VDC network (**Fig. 4**). This would achieve a power supply system with efficient power interchange and no outages. In normal times, when a surplus amount of power is generated by renewable energy in the neighboring area, that power can be stored with good efficiency in storage batteries at the NTT telecommunication building (Fig. 4(a)). Furthermore, during a disaster or other abnormal occurrence, storage batteries for stationary use and those for EV use can be combined with renewable energy to enable power interchange even if the power supplied by a power company is interrupted (Fig. 4(b)). However, this DC microgrid has a configuration that connects multiple units of power-generating equipment and multiple consumers, which means that events, such as short circuits, grounding, and lightning, can have far-reaching effects. There is therefore a need for a stable power supply that is robust to even these types of events.

The Energy Network Technology Group is proceeding with a three-step study as shown in **Fig. 5**. Step 1 will involve connecting the supply side with the demand side in a one-to-one format, Step 2 will involve connecting multiple units of equipment and executing power interchange in a bidirectional format, and Step 3 will involve stabilizing the power supply by extending the DC microgrid in which the power is networked. In Step 1, which is now in progress, we are studying technology for connecting an

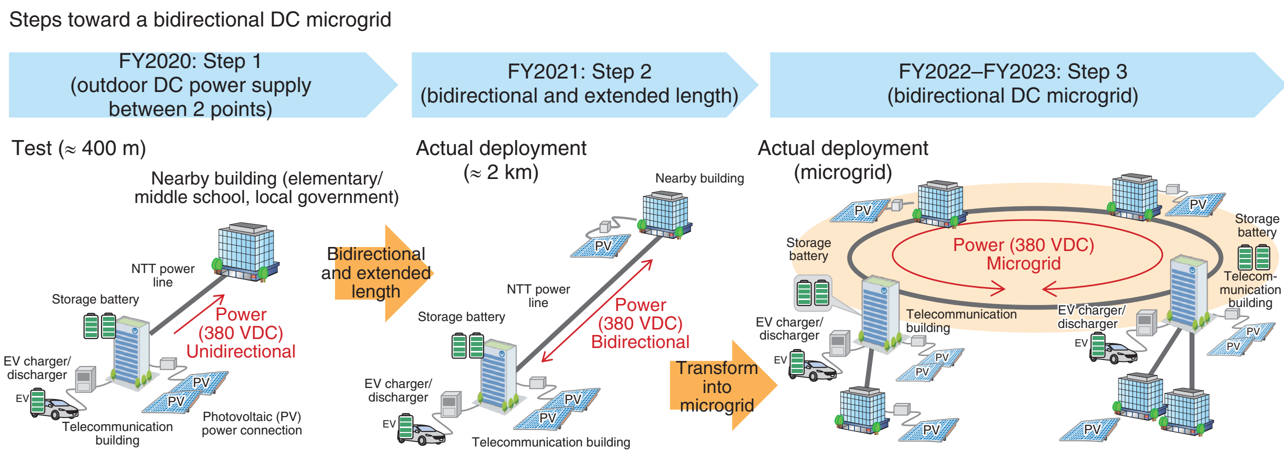


Fig. 5. Test steps toward a DC microgrid.

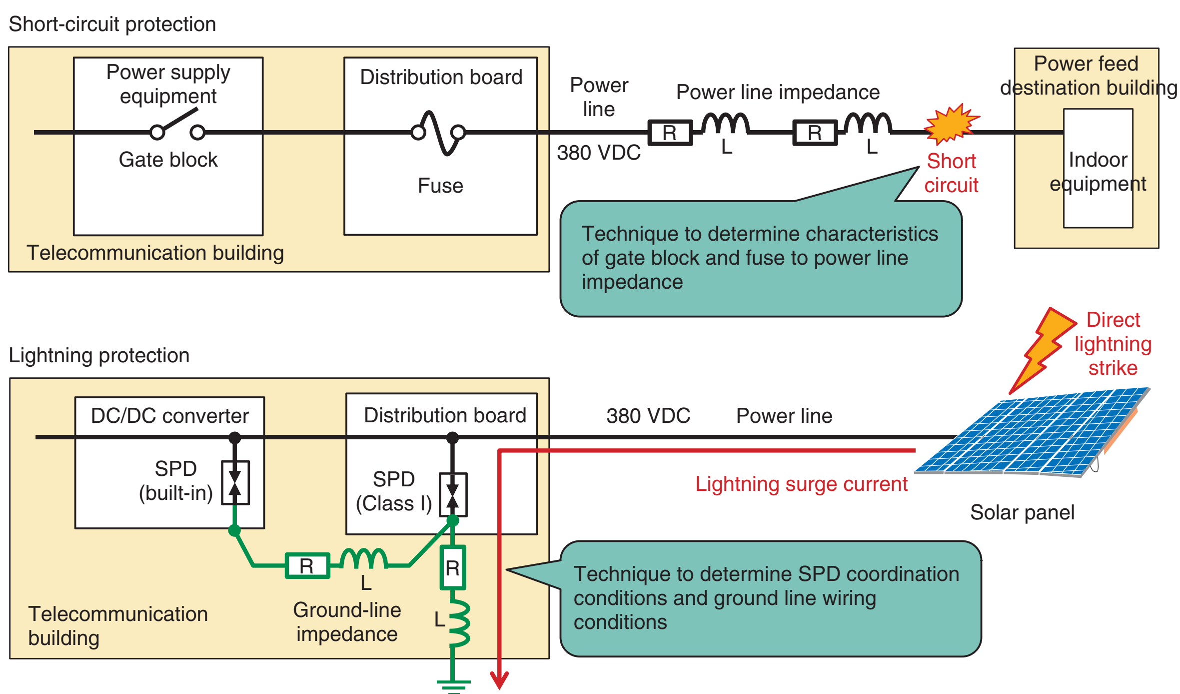


Fig. 6. Schematics of short-circuit protection and lightning protection.

NTT telecommunication building to an elementary or middle school acting as an evacuation center during a disaster in a one-to-one format (power supply distance: ≈ 400 m). Since we are extending 380 VDC power to an outdoor environment in this study, as shown in **Fig. 6**, we are giving priority to developing power quality technology involving electrical safety to prevent major accidents such as system fires or electric shock to workers. During a short circuit, the short circuit current decreases as the power supply distance from indoors to outdoors becomes longer, and since the current is DC, it is difficult to detect such an accident on the telecommunication-building side, which results in risk of failing to cut off the current safely. To solve this problem, we developed a mechanism that detects a short circuit with high accuracy and cuts off the current by incorporating an overcurrent protection function (gate block) inside DC power supply equipment in addition to the use of conventional fuses. Though a telecommunication building, in particular, requires high reliability, the risk of a penetrating lightning surge increases when a telecommunication building draws in power generated by a solar power generation system or other sources, so there is a need for technology for suppressing voltage. For this reason, we developed a technique that can significantly reduce the voltage accompanying a lightning surge by optimizing the wiring setup of surge protection devices (SPDs) and grounding wires. The provision of the above technologies is centered about NTT Anode Energy Corporation [1], which specializes in the energy business. It is currently expanding the testing of a backup power supply business in Chiba City [2].

On the basis of these technologies, we are also addressing the additional risks of EMP and cosmic radiation. In an AC system, the occurrence of such phenomena can lead to software errors in the control system that executes synchronization control,*3 increasing the risk of an interrupted power supply due to poor synchronization. A DC system, in contrast, directly connects the storage batteries to the DC bus, which lowers this risk. We will make maximum use of this feature of DC systems to establish a system that is robust to a variety of risk events that could otherwise interrupt the power supply.

4. Future developments

We will work to further develop the two technologies introduced in this article and take up the challenge of researching and developing a new network system that merges the information and energy networks. To this end, we will link these technologies to the All-Photonics Network in the Innovative Optical and Wireless Network (IOWN) proposed by NTT and disaggregated computing for high-speed and high-efficiency data processing through decentralized coordination of diverse, geographically distributed computing devices in accordance with the application. We will also improve the quality of the DC-microgrid power network through optical-type high-speed cutoff devices and work to integrate renewable energy and computing devices.

By migrating from the existing centrally managed energy network system to a new energy network system based on autonomous and decentralized cooperative control, we plan to contribute to the implementation of local production for local consumption that makes full and efficient use of renewable energy and to the creation of ultra-resilient smart cities that can supply power without interruption despite the occurrence of a variety of events.

References

[1] NTT Anode Energy, https://www.ntt-ae.co.jp/en/
[2] Joint press release issued by TNcross, NTT Anode Energy, NTT, and Tokyo Electric Power Company, “Joint Experiment toward Smart Energy City in Chiba City,” Apr. 23, 2020 (in Japanese). http://tncross.co.jp/information/detail20200423.html

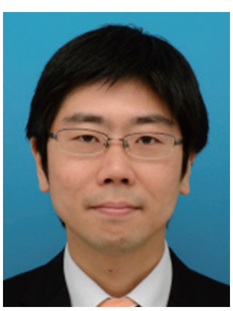
*3 Synchronization control: The voltage of an AC system repeats positive and negative values periodically. The role of synchronization control is to match the timing of this repetition between systems.

Toru Tanaka
Senior Research Engineer, Supervisor, Energy Network Technology Group, Zero Environment Impact Research Project, NTT Space Environment and Energy Laboratories.

He received a B.E. and M.E. in quantum science and energy engineering from Tohoku University, Miyagi, in 1996 and 1998. He joined NTT Integrated Information and Energy Systems Laboratories in 1998, where he was engaged in research on the evaluation of DC power supply system stability and voltage fluctuations. He also developed HVDC power supply systems for telecommunication buildings and datacenters. From 2009 to 2012, he was a manager at NTT FACILITIES, where he developed power supply systems and smart community. He is currently researching energy networks. He received the 2003 and 2009 Shibusawa Award of the Japan Electric Association. He is Professional Engineer, Japan (Electrical & Electronics Engineering).

Hiroya Minami
Senior Research Engineer, Energy Network Technology Group, Zero Environmental Impact Research Project, NTT Space Environment and Energy Laboratories.

He received a B.E. and M.E. from Seikei University, Tokyo, in 1994 and 1996. He joined NTT in 1996 and has been engaged in research on traffic technologies of communications systems, ubiquitous systems, and service delivery platforms. He received the Young Engineer's Award from the Institute of Electronics, Information and Communication Engineers (IEICE) in 2003. He is a member of IEICE.



Toshimitsu Tanaka
Senior Research Engineer, Energy Network Technology Group, Zero Environmental Impact Research Project, NTT Space Environment and Energy Laboratories.

He received a B.E., M.S., and Ph.D. in electronic engineering from Chiba University in 2001, 2004 and 2007. He joined NTT in 2007, where he has mainly been engaged in R&D of DC microgrid systems. He received the Young Researcher's Award from IEICE in 2006. He is a member of IEICE.

Naomichi Nakamura
Senior Research Engineer, Energy Network Technology Group, Zero Environmental Impact Research Project, NTT Space Environment and Energy Laboratories.

He received a B.E. in physics from Nihon University, Tokyo, in 2004 and an M.E. in nanoscience and nanoengineering from Waseda University, Tokyo, in 2006. He joined NTT in 2006 and studied electromagnetic compatibility technology for telecommunication. He has been researching and developing methods of lightning protection and grounding for telecommunication systems.

Toshihiro Hayashi
Senior Research Engineer, Energy Network Technology Group, Zero Environmental Impact Research Project, NTT Space Environment and Energy Laboratories.

He received a B.E. and M.E. in geosystem engineering from the University of Tokyo in 2004 and 2006. He joined NTT in 2006, and his research interests are energy control technologies and optimization techniques.

Masaki Kozai
Senior Research Engineer, Energy Network Technology Group, Zero Environmental Impact Research Project, NTT Space Environment and Energy Laboratories.

He received a Ph.D. in engineering from Tokyo Institute of Technology in 2010 and joined NTT the same year. His research interests are energy demand forecast and energy control technologies.

Yuji Higuchi
Research Engineer, Energy Network Technology Group, Zero Environmental Impact Research Project, NTT Space Environment and Energy Laboratories.

He received a B.E. and M.E. in electrical engineering at Shinshu University, Nagano, in 2007 and 2009. He joined NTT FACILITIES in 2009 and engaged in the maintenance of power systems for telecommunication facilities. He subsequently joined NTT Space Environment and Energy Laboratories and is currently researching electrical safety of DC microgrid.

Naoki Hanaoka
Research Engineer, Energy Network Technology Group, Zero Environmental Impact Research Project, NTT Space Environment and Energy Laboratories.

He received a B.S. in physics from Shinshu University, Nagano, in 2010 and M.S. in particle and astrophysical science from Nagoya University, Aichi, in 2012. He joined NTT in 2012 and studied 380 V power supply systems. From 2015 to 2019, he was a researcher at NTT FACILITIES, where he researched circuit analysis and evaluation of 380 VDC equipment. He is currently researching the electrical safety of DC microgrids. He is a member of IEICE and the Institute of Electrical Engineers of Japan.

Miho Iwamoto
Researcher, Energy Network Technology Group, Zero Environmental Impact Research Project, NTT Space Environment and Energy Laboratories.
She received an M.S. in physical chemistry of soft matters from Kyushu University, Fukuoka, in 2019 and joined NTT Space Environment and Energy Laboratories the same year. Her research interests are electrical energy demand forecast technologies and energy optimization techniques.

ESG Management Science and Technology for a Sustainable and Inclusive Society

Yuriko Tanaka, Xiaoxi Zhang, and Machiko Shinozuka

Abstract

We introduce ESG (environmental, social, and governance) Management Science and Technology for achieving a sustainable and inclusive society with respect to recent climate changes and problems related to human rights. We also analyze the relationship between the global environment and socio-economic systems to predict the future and identify long-term corporate risks as well as opportunities for corporations to generate new revenue and enhance their corporate value.

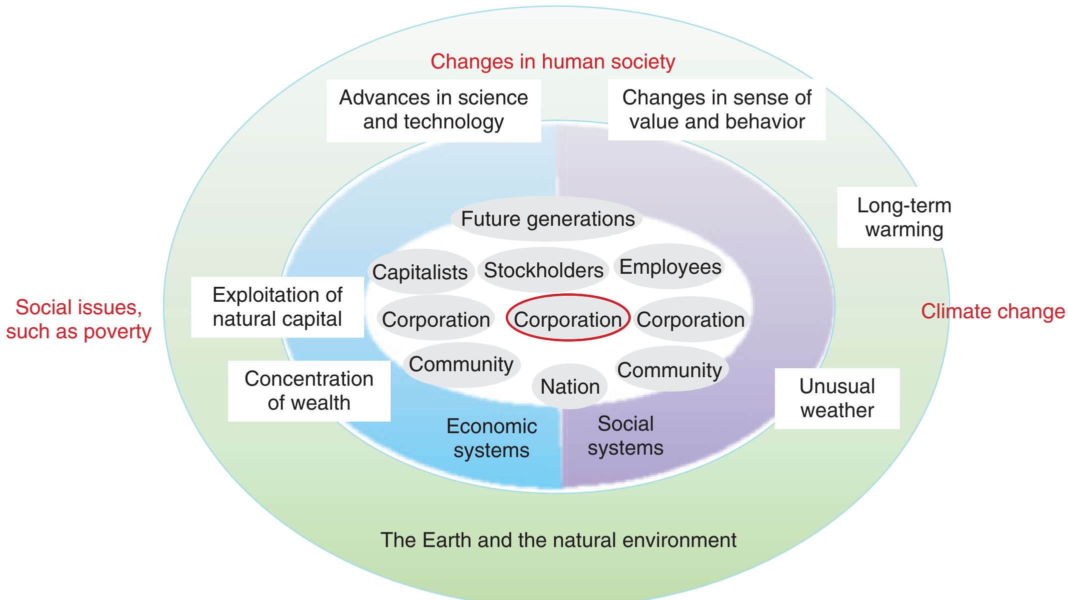
Keywords: ESG, future prediction, corporate value

1. Overview of ESG Management Science and Technology

Increasing attention has been paid to the Sustainable Development Goals adopted by the United Nations and how to respond to problems caused by changes in the natural environment (including climate change), poverty, and other social problems. Amid the global COVID-19 pandemic, we are faced with the need to re-examine how society and the economy operate. Solving these problems requires an approach that integrates environmental, social, and economic aspects and identifies correlations and causal relations among them [1]. As shown in **Fig. 1**, which presents a global view, the Earth and humans are closely and intricately related, as evidenced by climate change and social problems, such as poverty, caused by the concentration of wealth particularly in capitalist societies and the exploitation of natural capital*1. These problems could result in an unprecedented crisis in 5 to 10 years [2]. Due to changes in demographics and economic growth, social changes through science and technology and changes in people's values and behavior, the future is not necessarily an extension of the present. Corporate activities are also impacting the environment and society. Business strategies and actions developed from a long-term perspective are critical for ensuring a sustainable business environment. Therefore, corporations are attaching importance not only to their financial information but also their non-financial information, such as environmental, social, and governance (ESG) information. However, they still fall short of evaluating and verifying the impact of their ESG strategies and actions.

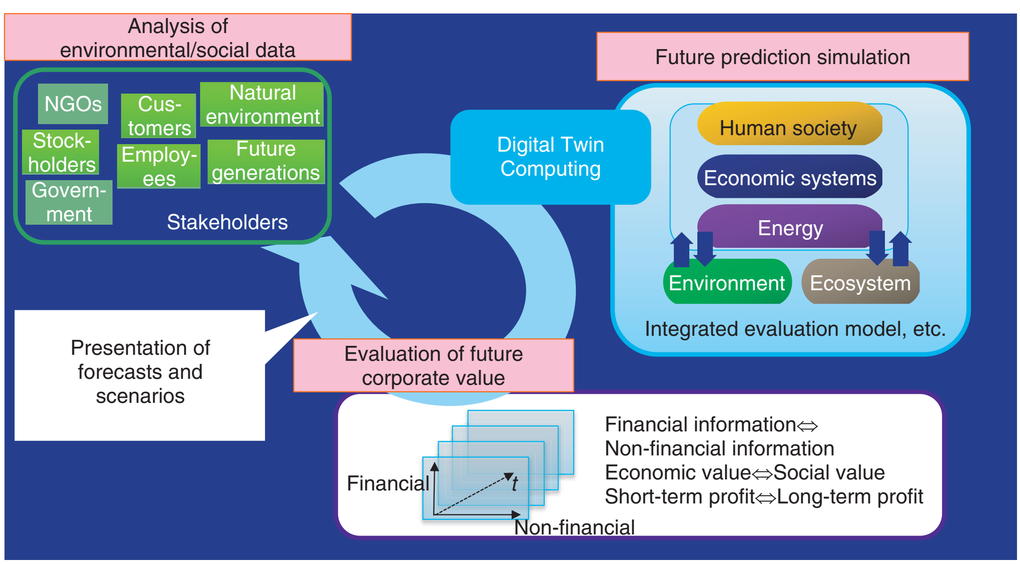
An overview of the ESG Management Science and Technology we are developing is shown in **Fig. 2**. Future prediction simulation uses environmental and social information as input data. Such data include the sense of value and situations of individual stakeholders in a corporation and is an important element in formulating an ESG strategy. Such simulation will use a model that represents causal relations among various environmental and social events, such as U.S. presidential elections, decarbonization strategies, disasters, and corporate performance. We will develop simulation systems as part of global-scale Digital Twin Computing (DTC) [3] and combine these systems with existing integrated evaluation models and new models to predict the future. We will evaluate the prediction results to make further predictions by

*1 Natural capital: A capital produced by nature, such as forest, soil, water, atmospheric air, and natural resources.



Note: Created by the authors based on References [1] and [2]

Fig. 1. Challenges and changes in the global environment and socio-economic systems.



NGO: non-governmental organization

Fig. 2. Overview of ESG Management Science and Technology.

using DTC and identify ways to achieve future transformation. We aim to indicate forecasts and future scenarios that will help corporations formulate their ESG strategies with a clear picture of their future. For this purpose, we will undertake research and development of future evaluation methods that will help enhance corporate value and reinforce the concept of corporate value from viewpoints that involve non-financial information, social value, and long-term profit. We intend to evaluate corporate well-being*2

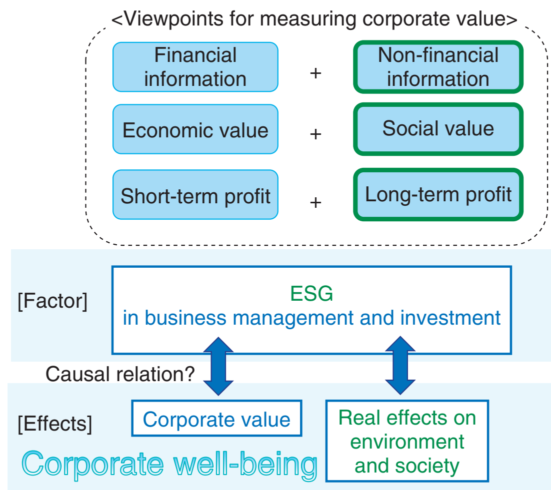


Fig. 3. Corporate value and ESG.

by clarifying the causal relations between factors in corporate actions and their effects on the environment and society (**Fig. 3**). In the next section, we describe future-prediction technology focusing on ESG for enabling future prediction simulation.

2. Future-prediction technology focused on ESG

One of the potential approaches to making a future prediction is to first predict social changes at the country level, then, on the basis of the previous prediction, predict changes that can affect corporate management. To predict social changes at the country level, our ESG Management Science Group began to collaborate with National Institute for Environmental Studies and four other research organizations*3 from fiscal year 2020. Taking climate change and the aging population, coupled with the declining birthrate faced by Japan, into consideration, we are developing several future visions that reflect various aspects of Japanese society and technology for predicting social, economic, and environmental changes quantitatively. One of the important visions we are developing is "a human-centered society that balances economic advancement with the resolution of social problems by a system that highly integrates cyberspace and physical space," as stated in the government's Society 5.0 [4] document. By determining changes in the economy, the environment, and people's lives before they occur, we will formulate NTT's ESG management strategy to maximize positive effects on society and the global environment while avoiding as many negative effects as possible. By reflecting predicted macroscopic social, economic, and environmental changes in NTT's management strategy, we can formulate an even more proactive strategy.

With the aim of predicting what the future will look like with information and communication technology (ICT) including the Innovative Optical and Wireless Network (IOWN)*4, the following section describes prediction technology focused on production and consumption.

3. Predicting the impact of the environment and economy on society

First, we introduce the prediction method from the viewpoint of production. It goes without saying that ICT boosts the economy by improving productivity and substituting human labor. Though it has a negative environmental effect because the use of ICT devices produces environmental loads (such as greenhouse gas emissions through electric power consumption), improved efficiency in production and consumption leads to dematerialization and a reduction in the use of raw materials, which lower environmental

*2 Well-being: A state of being well physically, mentally, and socially, or a concept related to spiritual richness or satisfaction.

*3 This study is supported by the Environmental Research and Technology Development Fund of the Environmental Restoration and Conservation Agency of Japan (JPMEERF20201002).

*4 IOWN: The concept of a next-generation communication infrastructure being pursued by NTT with the aim of commercial implementation around 2030.

Table 1. Evaluated ICT and direct effects of their introduction.

Evaluated ICT	BAU	Case 1	Case 2	Case 3	Direct effects of their introduction
Farming robots/ self-driving tractors	—	○	◎	●	Substitution for human labor Improved productivity
Plant factories/sensors	—	—	◎	●	Stable production
Food-distribution platform	—	—	—	●	Reduced transport distance (local production for local consumption), reduction in food waste

Note: ○, ◎, and ● indicate that the penetration level is respectively low, medium, and high.

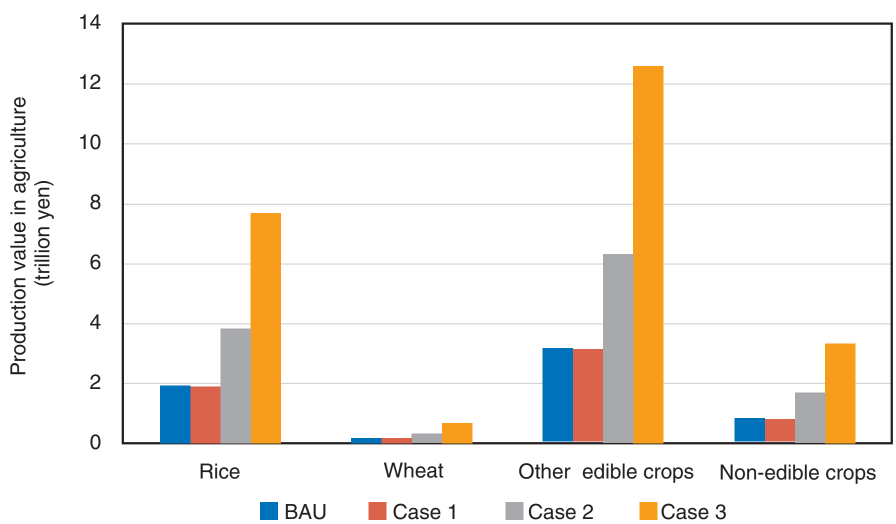


Fig. 4. Production value in each case (2050).

loads. This method simulates the macroscopic economic state (production and consumption), energy consumption, and greenhouse gas emissions of a future scenario using a computable general equilibrium model [5] based on Japan's input-output table [6]. First, we simulate the state in a baseline scenario on the basis of basic pre-conditions, such as the changes in population and gross domestic product (GDP) growth ratio. We then consider the direct effects of ICT penetration in industries (reduction in the use of raw materials, reduction in movement, improvements in productivity, etc.). We reflect these effects into the model and simulate the macroscopic economic state, energy consumption, and greenhouse gas emissions in the ICT-accelerated scenario.

The effects of introducing several types of ICT in agriculture up to 2050 are described as an example. **Table 1** shows the ICT we are focusing on, its penetration levels, and the direct effects of its introduction. We conducted calculations for four cases. In the baseline scenario (BAU), the penetration of ICT is assumed at current levels. To evaluate the effects of introducing further ICT, we considered three cases in which the penetration of farming robots/self-driving tractors, plant factories, and food-distribution platforms is set at different levels (low, medium, and high). **Figures 4** and **5** show the simulation results on the effects (change in production value and greenhouse gas emissions) due to the introduction of ICT. In Case 1, in which the ICT-penetration level is low, the production value in the agriculture sector is almost the same as that in BAU, while the greenhouse gas emissions slightly decrease. In Cases 2 and 3, in which the ICT penetration level is higher, production increases, boosting the country's food self-sufficiency, but the greenhouse gas emissions are also likely to

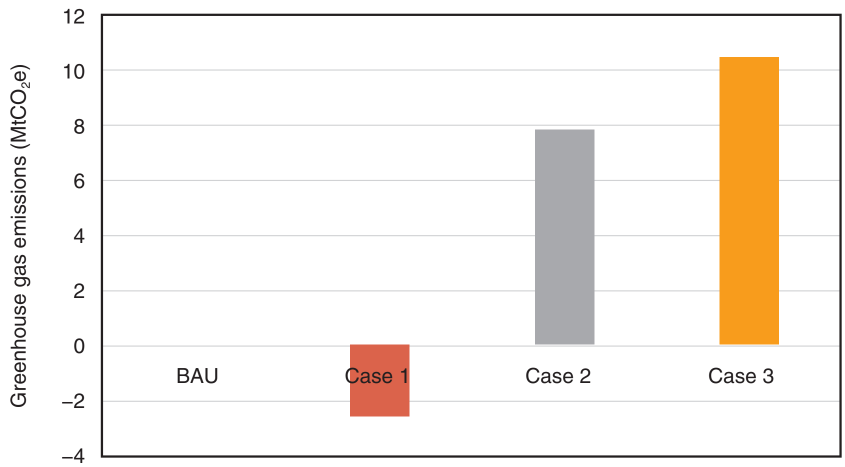


Fig. 5. Difference in greenhouse gas emissions of each case in comparison to BAU in 2050.

increase.

We will apply this analysis and prediction to a wider range of industries and not only evaluate greenhouse gas emissions and GDP but also use DTC to evaluate other indicators, such as resources, land use, and water utilization in an integrated manner and on a global scale.

4. Predicting environmental changes caused by changes in people's lifestyles

We now focus on the behavior of consumers. The use of ICT brings about changes in people's lifestyles and affects the production activities of industries and environmental loads. For example, when teleworking enables people to work at home, the use of private cars and public transportation systems will decrease, reducing environmental loads. On the other hand, the use of lighting and home appliances at home increases electric power consumption, generating environmental loads. Since commuting time is saved, time for new activities, such as hobbies, will increase. Therefore, the use of ICT can reduce environmental loads through reductions in travel time but can also increase them through changes in people's activities that result from changes in their locations and reduction in commuting time.

As an example of using the prediction of social changes caused by lifestyle changes, the following describes the analysis of how the penetration of ICT services, such as teleworking, online shopping, and online education, into consumers' lives affects environmental loads. We focus on how people use their 24 hours. On the basis of statistical data and survey reports, we specifically consider how ICT penetration changes time-usage patterns of consumers. When people switch from commuting to the office to working at home, they increase the time they spend on cooking and leisure activities. Taking changes in their activity locations and the use of ICT tools for reading and learning into consideration, we calculate the duration of their activities and the amount of greenhouse gas emissions per unit of time, as shown in **Table 2**. We calculate the environmental loads in terms of greenhouse gas emissions using the life-cycle assessment method [7]. The amounts of energy and physical material consumed are calculated from the details and durations of activities. We analyze the contribution of each ICT usage (component) to changes in greenhouse gas emissions after ICT penetration and identify those components that are critical in accelerating the decrease of emissions or in slowing the increase of emissions. Since the environmental loads arising from human activities are affected by social conditions, such as lifestyle and the types of electric power sources, it is necessary to reflect in the analysis the relations between such social conditions and the effects of using ICT. We pay attention to the negative effects of ICT penetration, such as people's weariness from working at home, in creating options that will lead to corporate actions to resolve social problems, thereby helping to build a better society.

As part of DTC initiatives, NTT aims to create a future in which a harmonious relationship can be established among the Earth, society, and individuals

Table 2. Examples of impact of ICT penetration.

Activity	Changes after ICT penetration	
	Activity duration	Greenhouse gas (GHG) emissions per unit time (GHG intensity)
Commuting	Decreases as a result of telework	Since commuting methods remain unchanged, the GHG intensity remains unchanged.
Shopping	Travel time is reduced	The GHG intensity increases because electronic devices consume electric power.
Hobbies	Increases as a result of reduction in commuting	Since hobbies remain unchanged, the GHG intensity remains unchanged.
…		

[3]. To achieve it, we are enhancing the purpose of life and the richness of the spirit of the individual expressed as well-being, in a future in which the diversity, opportunities, and possibilities of individuals are expanded and the complexity of the social structure and global uncertainty increase through technologies for exploring the shape of a future society and deriving an inclusive equilibrium solution between the Earth and socio-economic systems.

5. Conclusion

Looking forward, we will build a firm technical foundation for future prediction on the basis of the technologies mentioned above and develop a method for evaluating corporate value and corporate well-being. We will predict a future society in which social structures will become increasingly complex and the uncertainty on a global scale will increase. We will identify the impact of ICT on climate change and other problems and reflect the results in corporate ESG strategies so that corporations can proactively solve the problems identified. Through these efforts, we aim to achieve a sustainable global environment and sustainable and inclusive human society as well as enhance corporate value.

References

[1] Annual Report on the Environment, the Sound Material-Cycle Society and Biodiversity in Japan, https://www.env.go.jp/en/wpaper/index.html

[2] K. Saito, "'The Capital' in Anthropocene," Shueisha, 2020 (in Japanese).

[3] NTT press release, "NTT Announces New R&D Projects of Digital Twin Computing," Nov. 13, 2020. https://group.ntt/en/newsrelease/2020/11/13/201113c.html

[4] Cabinet Office, Government of Japan, Society 5.0, https://www8.cao.go.jp/cstp/english/society5_0/index.html

[5] National Institute for Environmental Studies, "Asia-Pacific Integrated Model 2: Economic Model," NIES Research Booklet, Vol. 74, p. 9, 2019 (in Japanese). http://www.nies.go.jp/kanko/kankyogi/74/column4.html

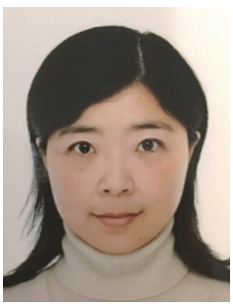
[6] Ministry of Internal Affairs and Communications, Input-Output Tables for Japan, https://www.soumu.go.jp/english/dgpp_ss/data/io/index.htm

[7] Japan Environmental Management Association for Industry, "Method to Develop Environmentally Friendly Products and Services: Life Cycle Assessment," 2004 (in Japanese). https://www.meti.go.jp/policy/recycle/main/3r_policy/policy/pdf/text_2_3_a.pdf

Yuriko Tanaka

Senior Research Engineer, Supervisor, ESG Management Science Group, Resilient Environmental Adaptation Research Project, NTT Space Environment and Energy Laboratories.

She received a B.S. and M.S. in physics from Keio University, Kanagawa, in 1992 and 1994. Since joining NTT in 1994, she has been engaged in research on micromachining and sensing and assessment of environmental impact. She is a member of the Institute of Electronics, and Communication Engineers (IEICE) of Japan.



Xiaoxi Zhang

Senior Research Engineer, ESG Management Science Group, Resilient Environmental Adaptation Research Project, NTT Space Environment and Energy Laboratories.

She received a B.S. and M.S. in social engineering from Tokyo Institute of Technology in 2007 and 2009. Since joining NTT in 2009, she has been engaged in research on risk-based management of telecommunication infrastructures and assessment of the environmental impact of ICT use. She currently specializes in environmental and social future prediction simulations. She won TTC (the Telecommunication Technology Committee) Distinguished Service award in 2020. She is a member of IEICE.

Machiko Shinozuka

Research Engineer, ESG Management Science Group, Resilient Environmental Adaptation Research Project, NTT Space Environment and Energy Laboratories.

She received a B.S. and M.S. in medical engineering from Keio University, Kanagawa, in 2013 and 2015. Since joining NTT in 2015, she has been engaged in research on assessment of the environmental impact of ICT use. She currently specializes in environmental and social future prediction simulations in terms of lifestyle. She is a member of IEICE.

Proactive Environment Adaptation Technology for Living Safely and Securely

Jun Kato

Abstract

Changes in the Earth's environment are expected to have a significant impact on our social life. In this article, environmental adaptation technologies (technology to develop a platform for collecting and analyzing all types of information on the Earth, meteorological forecasting/control technology, lightning control technology, and electromagnetic barrier technology) for predicting various effects of changes in the Earth's environment, responding to such effects proactively, and achieving a resilient society by enabling humans to adapt to such changes are introduced.

Keywords: resilience, weather prediction, cosmic rays

1. Introduction

The frequency of extreme weather[*1] has increased around the world [1]. In Japan, heavy rains and typhoons are common extreme-weather events but are difficult to observe and predict, causing severe damage. For this reason, highly accurate weather forecasting is important. Weather-forecasting technology has made significant progress from technology based on the experience and subjectivity of forecasting engineers to observation technology such as weather radar and numerical analysis using supercomputers. However, typhoon predictions, especially regarding intensity, are still done using satellite photographs.

Meteorological observations are carried out on a regular basis using an observation and forecasting system that uses observation data from land and sea on a global scale as well as from space. Since it takes only about 15 minutes from cumulonimbus formation to maturity and fluctuation occurs rapidly within a limited area of several square kilometers [2], observations, such as with satellites and AMeDAS (Automatic Meteorological Data Acquisition System), are not sufficient to respond to such extreme weather.

The rise in sea-surface temperature due to global warming and the meandering of mid-latitude westerlies increase the water vapor supply to typhoons [3]. Such climate change is caused by human activities as well as natural climate change of the Earth over the long term [4]. Examining, understanding, and diagnosing the state of the Earth's climate is crucial to the long-term prediction of climate change and the implementation of policies to curb the effects of anthropogenic causes. Wide-area observations are needed to assess the state of the Earth's climate. Such observations can be carried out using satellites, but there is a problem regarding observation accuracy (vertical components of the atmosphere, observation below the sea surface, etc.).

Therefore, we are investigating the technologies described in this article for making high-precision predictions on changes in the global environment, such as extreme weather and climate change, and making the impact less severe by implementing countermeasures in advance.

*1 Extreme weather: A phenomenon that exceeds a specific index, such as extremely high or low temperatures or heavy rain.

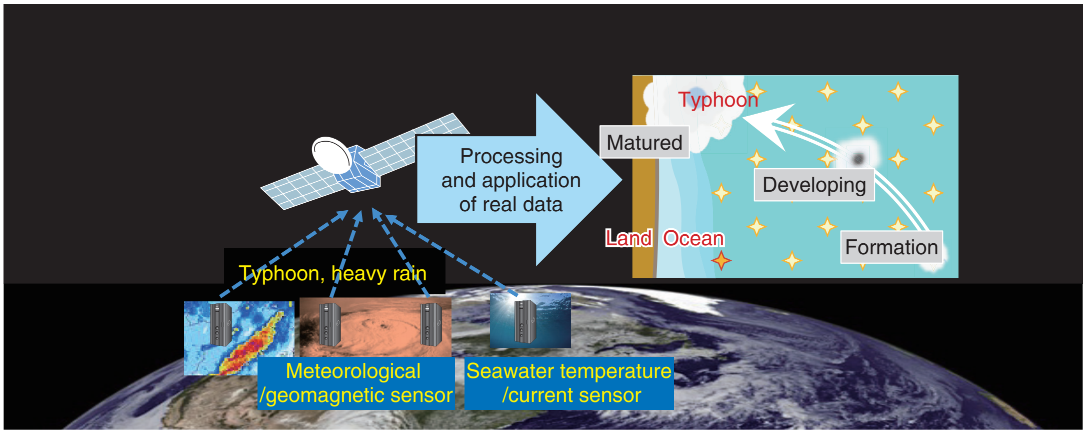


Fig. 1. Image of Earth-information analysis using satellite IoT platform.

2. Technology to develop a platform for collecting and analyzing all types of information on the Earth

We are conducting studies on predicting weather and disasters in real time and with high accuracy by making extensive use of information from areas that have not been extensively observed such as the sea surface, underwater, and mountains. NTT's proposal of "In-orbit demonstration of 920 MHz band satellite Internet of Things (IoT) platform utilizing satellite multiple-input and multiple-output (MIMO) technology" was selected as an innovative satellite-technology demonstration theme by the Japan Aerospace Exploration Agency (JAXA) in May 2020 [5]. In this demonstration theme, we are currently investigating a system to cover areas where information cannot be collected using terrestrial communication infrastructure.

This system is a new sensor-network system that simultaneously acquires information from various IoT sensors on the ground with satellites over 550 km above the Earth then bundles, transmits, and analyzes it on the ground.

With this system, IoT sensors can be installed at desired positions to enable detailed meteorological observations for data acquisition and data assimilation[*2], which will enable predicting extreme weather that changes drastically, such as local heavy rains and typhoons (**Fig. 1**).

3. Meteorological forecasting and control technology

We will collect meteorological information by using the basic technology of Earth information analysis, construct a digital twin[*3] of meteorological phenomena of the whole Earth from the data, and enable the simulation of meteorological prediction and meteorological control on a digital twin.

In meteorological forecasting, we will investigate how to enable high-precision meteorological observation. In particular, we are designing a system for observing meteorological data and measuring data related to typhoons from the ocean and air. We will also study typhoon weather models in collaboration with universities.

We now discuss typhoons and lightning as examples of weather control. Regarding typhoon control, we are studying technologies such as for lowering the temperature of the nearby sea by exchanging water masses in the deep sea and shallow water to weaken the force of a typhoon and a technology for converting the energy of a typhoon into electricity (**Fig. 2**).

Regarding lightning control, we are developing a technology that guides lightning strikes to a safe

*2 Data assimilation: This is mainly done in Earth science to improve the reproducibility of numerical models. Simply put, it involves inputting actual observation data into a model to obtain more realistic results.

*3 Digital twin: A technology that reproduces various data collected from the real world on a computer as if they were twins. It is possible to conduct physical simulations that are as close to reality as possible from the enormous amount of data collected, which is an effective means for further improving the manufacturing process and services of products.

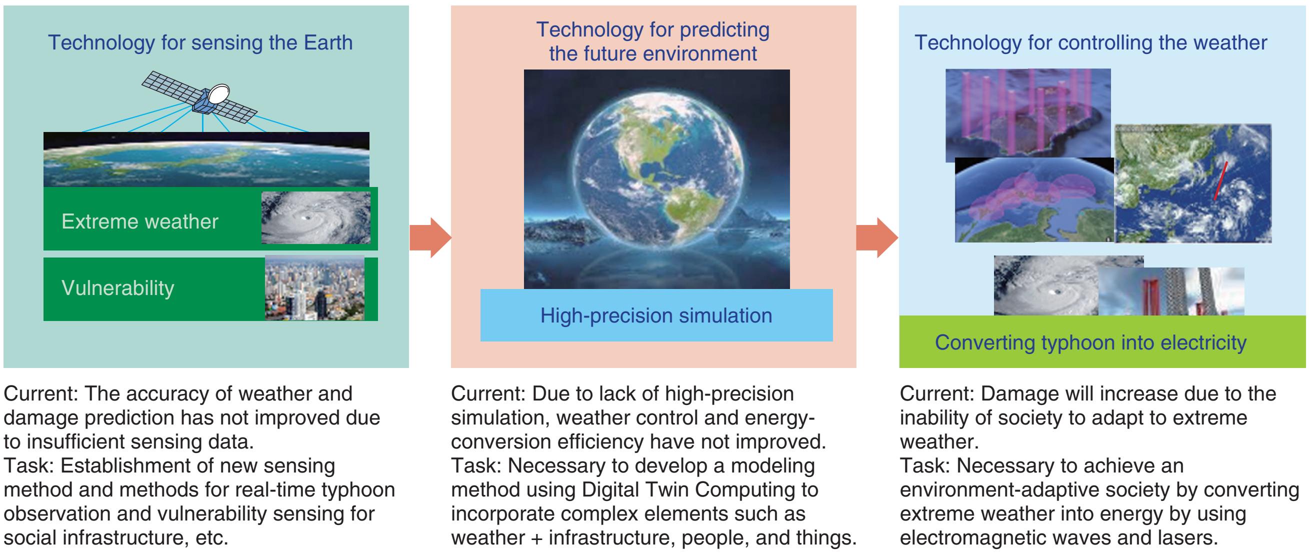


Fig. 2. Overview of weather prediction and control technology.

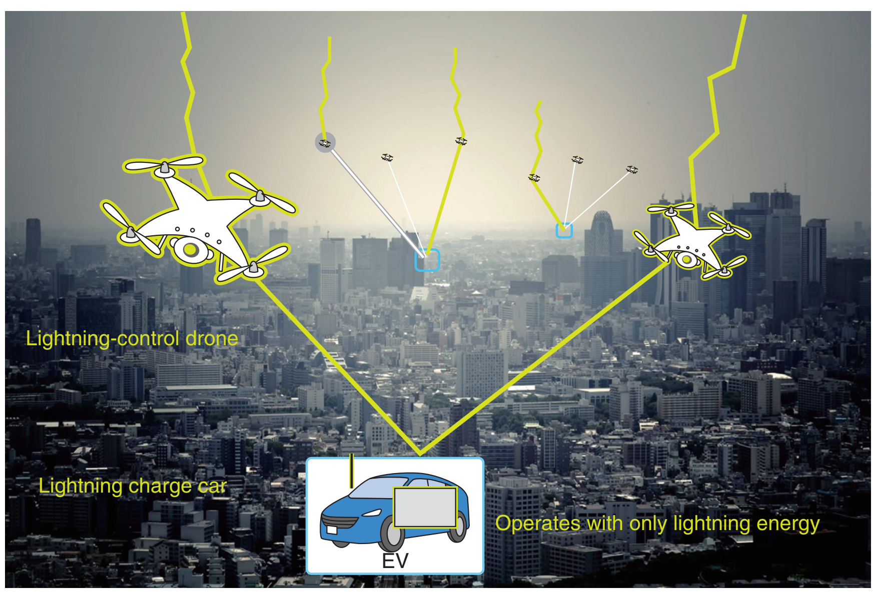
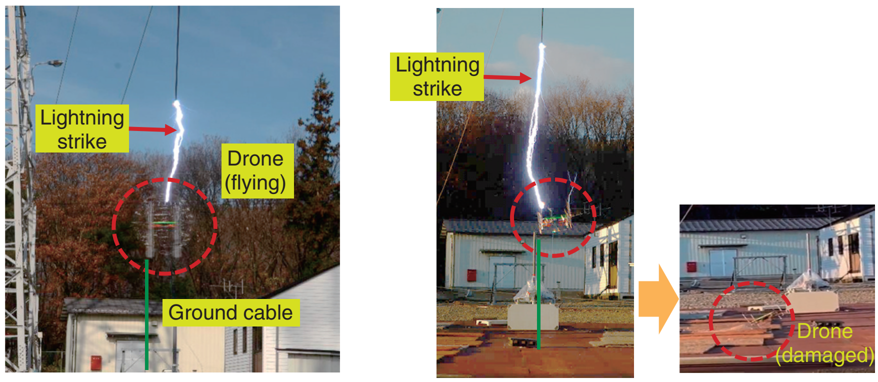


Fig. 3. Image of lightning control and lightning charging system using drone.

place using an air vehicle, such as a drone, with functionality to maintain flight even if it is struck by lightning, as shown in **Fig. 3**. **Figure 4** shows photographs of a drone with a grid-like Faraday cage*4 attached to it at the moment of a lightning strike that continued to fly and of the same model without the Faraday cage, which lost control after being struck by lightning and crashed. This confirms that the drone with the Faraday cage had high lightning resistance. We will also consider methods, such as that illustrated in Fig. 3, for collecting and using lightning energy and construct

*4 Faraday cage: A space surrounded by conductors, or a conductor cage or vessel used to create such a space. Since electric lines of force cannot enter the space surrounded by conductors, the external electric field is blocked and all the internal potentials are equal. It is also called a Faraday shield.



With cage (no damage)   Without cage (damaged after lightning strike)

Fig. 4. Drone lightning-strike performance test (effectiveness of Faraday cage).

a lightning-control system for charging electric vehicles (EVs) that operate autonomously using only lightning energy to achieve a safe and secure society.

4. Electromagnetic barrier technology

The Proactive Environmental Adaptation Technology Group is also engaged in research and development for technologies that will innovate the future of society and the environment from a space perspective. For humans to advance into space, create living spaces, and live for a long time in space, the impact of powerful cosmic rays[*5] from the sun and other stars on the human body and precision equipment must be reduced. Therefore, we are investigating the evaluation of cosmic rays and the development of barrier technology to reduce their impact.

The impact of cosmic rays on the ground is mainly derived from neutrons, but in space, protons are the main source. Since protons have an electric charge, they can form an electromagnetic barrier (**Fig. 5**) that blocks and refracts cosmic rays with strong magnetic and electric fields.

Verification in space is required to study this technology, but it is not easy to transport experimental materials into space. Therefore, we are developing a technology for designing electromagnetic barriers in virtual space by digitally twinning spacecraft, space stations, and lunar bases in cyberspace. To do this, we will first conduct simple experiments and simulations using a proton accelerator.

If this research progresses, not only will we be able to live in space for a long time but manned planetary exploration and lunar bases will no longer be dreams. It will also be possible to build an ultra-high security and highly reliable datacenter in outer space.

5. Conclusion

We are developing an IoT network platform using satellite MIMO to carry out more detailed weather observations to make highly precise predictions and take countermeasures regarding extreme weather and climate change, which are expected to have a greater impact in the future. We will develop a weather-prediction technology that uses analysis data from digital twins and work on achieving the goal of prediction/control of extreme weather. We will also study electromagnetic barriers that block and refract cosmic rays and create an environment where people can safely and securely live and work in space.

*5 Cosmic rays: High-energy radiation that travels through space. The main component of cosmic rays is protons, which originate from the sun and other stars. There is concern about the effects on electronic devices and living organisms due to long-term cosmic ray exposure.

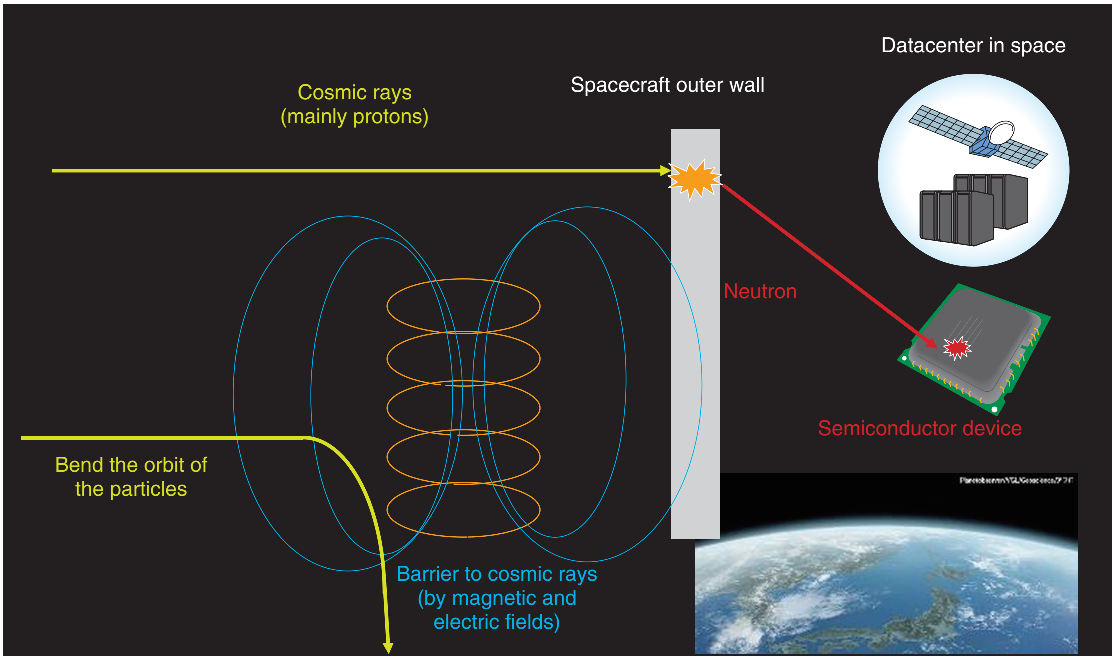


Fig. 5. Electromagnetic barrier system in space.

References

[1] T. Toyoda, "Extreme Weather and Observation/Prediction Technology," Forecast and Response to Extreme Weather, pp. 5–15, 2019 (in Japanese).
[2] E. Nakakita, H. Sato, and K. Yamaguchi, "Studies on Formation Mechanism of Vertical Vortex Tube inside Cumulonimbus Cloud for Accuracy Improvement of Guerrilla-heavy Rainfall Prediction," DPRI Annuals, Vol. 60, No. B, pp. 539–558, 2017 (in Japanese).
[3] S. C. Herring, N. Christidis, A. Hoell, J. P. Kossin, C. J. Schreck III, and P. A. Stott, "Explaining Extreme Events of 2016 from a Climate Perspective," Special Supplement to the Bulletin of the American Meteorological Society, Vol. 99, No. 1, pp. S1–S157, 2018.
[4] The Intergovernmental Panel on Climate Change (IPCC): "Climate Change 2007: The Physical Science Basis," Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, 2007.
[5] NTT press release issued on May 29, 2020 (in Japanese), https://www.ntt.co.jp/news2020/2005/200529a.html
[6] Press release issued by NTT, Nagoya University, and Hokkaido University, "Neutron Energy Dependence of Semiconductor Soft Errors Was Successfully Measured for the First Time," Nov. 25, 2020. https://group.ntt/en/newsrelease/2020/11/25/201125a.html

Jun Kato

Project Manager, NTT Space Environment and Energy Laboratories.

He received a B.E. from Shizuoka University in 1992 and joined NTT the same year. He is currently engaged in research and development of proactive environmental adaptation technologies.

The Future Pioneered by Device Technology for a Sustainable Society

Masato Tomizawa and Akira Okada

Abstract

The research and development NTT is conducting to create a sustainable society, specifically regarding human health and aging infrastructure, is outlined in the following Feature Articles in this issue. After the trends toward solving social issues in Japan and overseas are briefly described, the direction of smart-healthcare and infrastructure-maintenance technologies—which use device technology cultivated by NTT laboratories—is discussed. Research results and cutting-edge technologies that are about to be put into practical use and be used for prevention and maintenance by grasping and estimating the conditions of people and infrastructure are also introduced.

Keywords: healthcare, infrastructure maintenance, sustainability

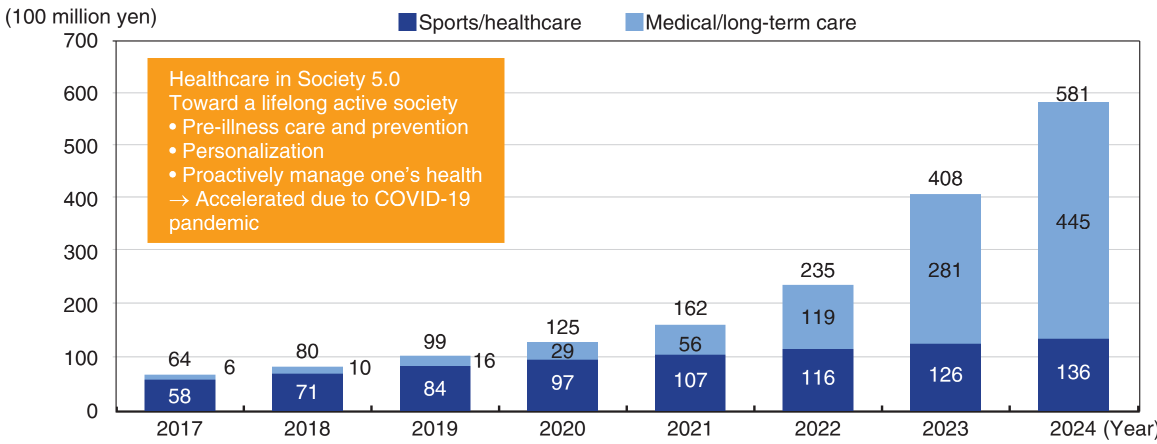
1. Challenges facing creation of a sustainable society

Problems, such as declining birthrates and aging populations, global warming, energy problems, and food crises, are becoming apparent across the world, and it is said that 2030 will be the turning point for the continuous economic growth that humankind has enjoyed as civilizations have developed. The Sustainable Development Goals (SDGs) were established by the United Nations with the aim of creating a sustainable society [1], and in Japan, efforts toward creating a people-centered super-smart society called "Society 5.0" have been positioned as important issues [2]. Under such circumstances, we have entered an era of reorganization of the economic and geopolitical world order, and how to revise the information society has become a major issue. To address such issues, it is necessary to develop technologies to promote continuous business while understanding the needs of society and expanding the horizons of the entire social system. In other words, simultaneously achieving business continuity and solutions to social issues is the key to the creation of a truly sustainable society.

We believe that people-centered efforts will be a major first step when addressing the above issues. If we want to think in a people-centric manner, we should focus on two aspects: (i) the health of individuals and healthcare provided for them and (ii) the environment surrounding them. We believe that developing technology that takes into account people and their environment will significantly contribute to solving social issues while achieving business continuity.

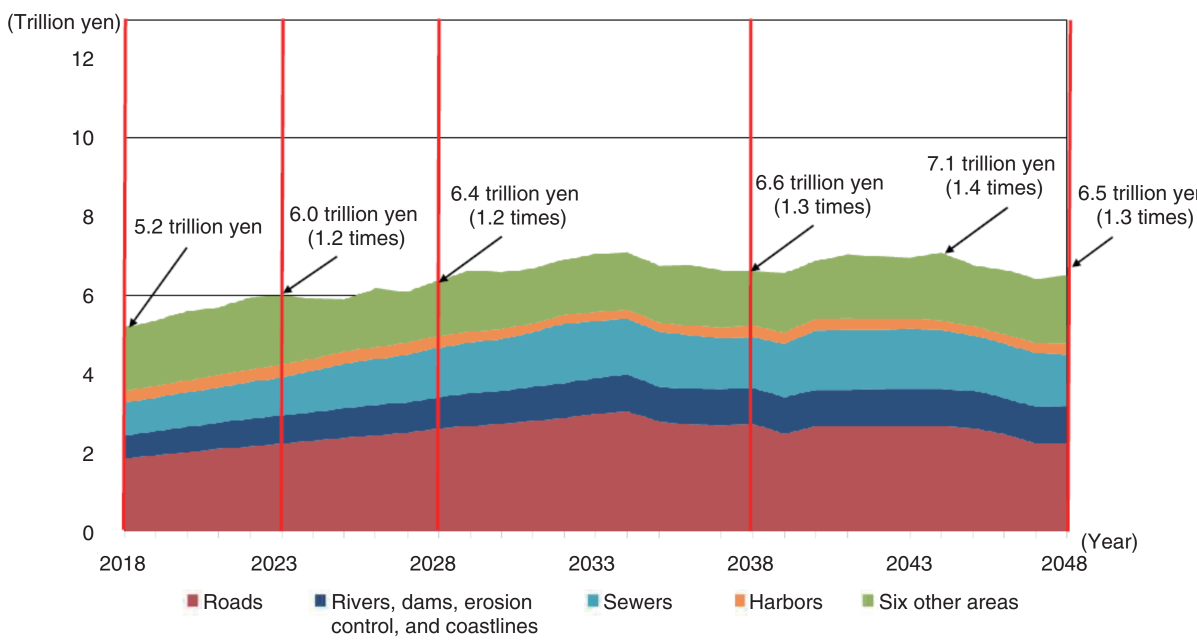
Regarding human health, the economic effect of achieving a lifelong active society is 33 trillion yen, and the health-technology market is worth over 50 billion yen [3] (**Fig. 1**). It is thought that the time will come when we will take the initiative in managing our own health, such as early intervention through daily monitoring and pre-illness care and prevention through personalized guidance. The above awareness of issues has been pointed out for some time; however, the need for digital transformation (DX) of health is increasing at a rapid pace due to the recent spread of infectious diseases.

Regarding environment-friendly technology, how to efficiently maintain infrastructure equipment, the most-basic element of the information society, needs to be addressed. The cost of infrastructure maintenance and renewal in Japan is estimated to be enormous, 5 to 7 trillion yen per year [4] (**Fig. 2**). Infrastructure maintenance is an extremely difficult technical area because infrastructure is used for a long



Source: Nomura Research Institute, materials for the 273rd NRI Media Forum (issued on December 6, 2018).
The graph is created by NTT utilizing data from Nomura Research Institute.

Fig. 1. Trends in domestic market size of healthcare technology.



*Since the estimated value is a value with a width, the graph is created using the maximum value.

Source: Ministry of Land, Infrastructure, Transport and Tourism, "Estimation of Future Maintenance and Renewal Costs of Social Capital in Fields under the Jurisdiction of the Ministry of Land, Infrastructure, Transport and Tourism," 2018 (in Japanese).

Fig. 2. Changes in infrastructure maintenance and renewal costs.

time in various environments, and it is necessary to evaluate and elucidate physical phenomena in units of ten-years. Infrastructure maintenance currently involves a large amount of manual work; therefore, DX conversion including automation of inspection is required by using the power of technology. Against this background and to create a sustainable society, NTT is focusing on research and development (R&D)

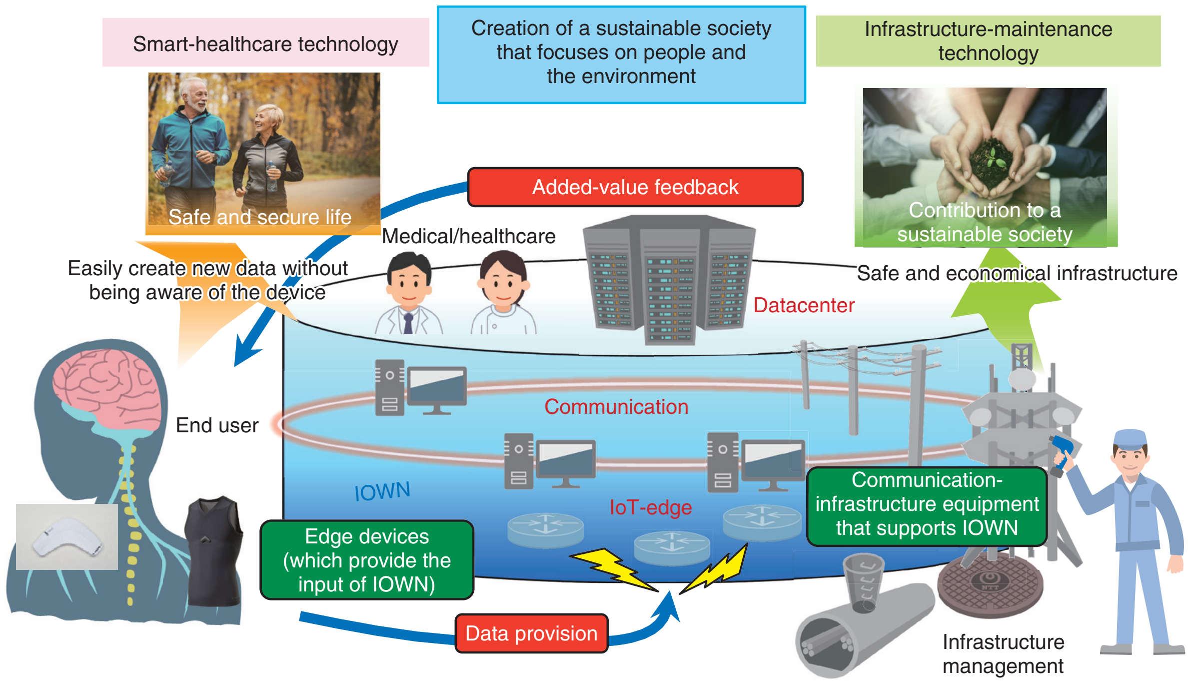


Fig. 3. Smart-healthcare and infrastructure-maintenance technologies for a sustainable society.

of smart-healthcare and infrastructure-maintenance technologies (**Fig. 3**).

2. Direction of smart-healthcare and infrastructure-maintenance technologies

2.1 Smart-healthcare technology

To support people's health and provide healthcare to them on a daily basis, it is necessary to (i) acquire the information necessary of their daily lives without them being aware the devices being used to collect such information and (ii) present the appropriate information in accordance with the circumstances concerning each person. Accordingly, it is necessary to develop devices that naturally blend into as well as enrich our lives. Portable devices and smartwatches for measuring heartbeats and pulse have been commercialized, and their usefulness in various situations is beginning to be recognized. From the perspective of addressing social issues and creating a market, the situation is on the verge of great change. Such devices have begun to evolve from their utilization at the personal-fitness level to true healthcare in the form of medical applications. NTT has developed low-power multi-sensor data-processing and high-precision sensing technologies. In addition to conventional electrocardiographic measurement and acceleration sensors, we have put into practical use a wearable, compact low-power transmitter with a built-in temperature and humidity sensor as our first wearable device [5]. By using this device, it is possible to estimate fluctuations in body temperature and body load, and that information will make it possible to develop high-value-added services by obtaining body information that was previously unknown in real time. We are also researching and developing photoacoustic-sensing and molecular-labeling technologies that enable non-invasive, highly selective, and highly sensitive monitoring. Targeting previously unmeasurable vital-sign information and biomarkers in relation to lifestyle-related and chronic diseases, for which the number of patients is increasing yearly, we are aiming for a simpler biosensor device that does not require the collection of samples such as saliva and blood.

2.2 Infrastructure-maintenance technology

Infrastructure facilities, which are used for long periods of time (several decades) in a variety of harsh environments, are supported by a large amount of

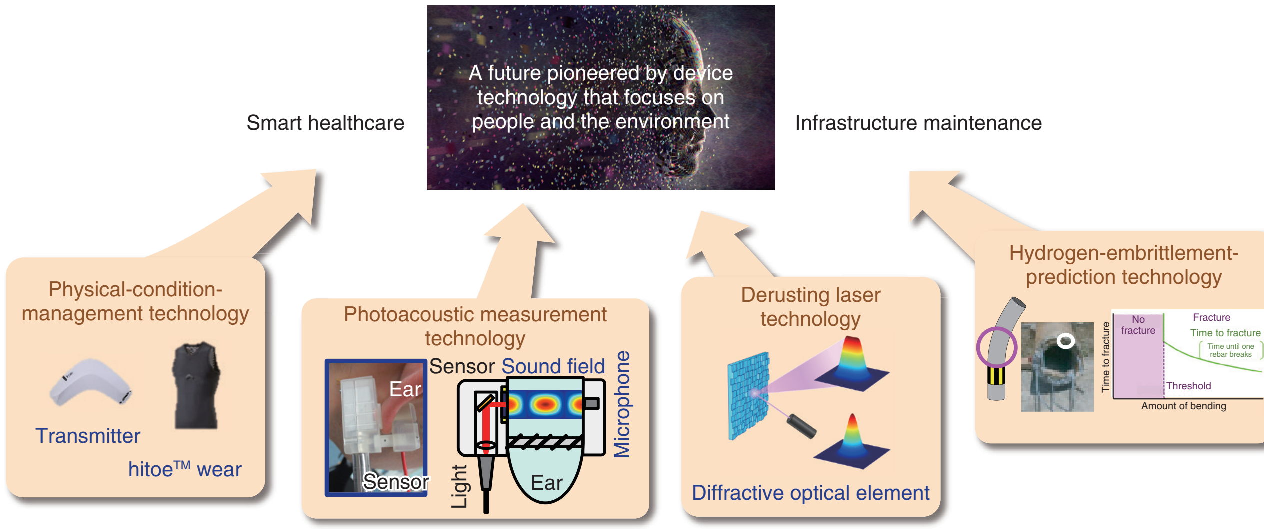


Fig. 4. Technology NTT is developing that is focused on people and the environment.

labor and experience, and the development of technologies that contribute to efficient work is still insufficient. Moreover, many unknowns, such as the degree of deterioration of the materials that make up the infrastructure over a period of ten years, must be considered. It will be paramount to achieve sustainable conservation of infrastructure that is both safe and economical. Infrastructure maintenance mainly consists of four steps: (i) maintenance planning, (ii) inspection, (iii) diagnosis, and (iv) repair and reinforcement. For more efficient and safer infrastructure maintenance, it is important to plan in advance as precisely as possible and streamline manual repair work.

Infrastructure facilities are mainly made of steel and concrete, so it is no exaggeration to say that infrastructure maintenance is the maintenance of steel and concrete. Accordingly, from the viewpoint of preventive maintenance of infrastructure, NTT is focusing on steel and concrete poles and researching and developing technologies that contribute to making rust removal more efficient and estimating deterioration, which are extremely difficult challenges to address with current technologies. It is important to remove rust from telecommunication towers and other steel infrastructure facilities as they age. By using the diffractive-optical-element technology developed by NTT and combining it with a high-power laser, the weight of a rust remover is expected to decrease by several times compared to commercial products, significantly improving work efficiency.

The degradation of reinforcing bars (rebars) in concrete poles is caused by hydrogen embrittlement, but the details of this phenomenon are still unknown. NTT is promoting R&D to establish hydrogen-embrittlement-prediction technology using core technologies such as electrochemistry and materials.

3. Topics and composition of the Feature Articles

The following Feature Articles in this issue focus on smart-healthcare and infrastructure-maintenance technologies that are close to practical application and are medium- to long-term, and the following four technologies are introduced as the latest research results (**Fig. 4**).

3.1 Physical-condition-management technology using wearable biological and environmental-sensor technology

NTT has commercialized wearable biological and environmental-sensor technology that can acquire and transmit not only biological data (such as heart rate and electrocardiograms) but also environmental data (such as temperature and humidity underneath clothing) by using the functional fabric hitoe™* as electrodes. This technology enables efficient signal processing of data from three sensors (electrocardiogram, acceleration, and temperature/humidity), which result in a low-power, compact wearable device. It will make it possible to comfortably and easily obtain biological information and personal environmental information from various daily activities. For example, it will enable the development of smart-healthcare applications such as those to counter heat stroke. A method based on this technology was developed that involves workers in hot environments wearing sensors to manage their physical conditions. This makes it possible to understand real-time physical information that was previously unavailable. Its effectiveness and practicality were verified at a network-construction site [6].

3.2 Non-invasive biological-information sensing using photoacoustic-measurement technology

A technology for non-invasive sensing of biological information without damaging the body—by using a photoacoustic method for measuring ultrasonic waves generated when a specific light is irradiated onto biological components in the body—is introduced. Compared with other methods such as optical coherence tomography and ultrasonography, photoacoustic technology is superior in measurement depth and spatial resolution as well as the potential in responding to various biological components. It is therefore expected to enable monitoring of various biological components related to lifestyle-related diseases. Since a non-invasive method enables continuous measurement of biological data, it is expected to be used in medical and healthcare applications to monitor biological data that change daily. To establish the technology for such a biological-sensing device, we are constructing a biophysical model of the penetration of a probe into the skin and its effect on biological mechanisms. We are also pursuing R&D on measuring biological components on the basis of the correlation between biological mechanisms and electrical and optical parameters concerning the regions from the surface of the skin to the interior of the body [7].

3.3 Compact and lightweight rust remover incorporating a high-power laser device that uses a diffractive optical element

Infrastructure facilities made of steel, such as communication towers, are subject to aging due to rusting. The first step in maintaining a steel tower is to remove the rust, and the second step is to paint the tower to protect the surface. To maintain the performance of coating and increase the durability of the steel tower, the surface condition of the underlying steel is important, and the key is how to effectively remove the rust. Rust is removed by irradiating a high-power laser beam onto the steel surface. By combining NTT's optical device technology with a compact and lightweight diffractive optical element, it is possible to fabricate a rust remover that is several times lighter than other products on the market for controlling the laser profile and efficiently removing rust. At current work sites, metal brushes are used to remove rust in narrow spaces; however, using the developed technology is expected to reduce work load and shorten work time [8].

3.4 Hydrogen-embrittlement-prediction technology for rebars of concrete poles

A technology for predicting hydrogen embrittlement, which is a degradation phenomenon of steel rebars in concrete poles will enable safer and more economical maintenance and management of concrete poles, which are one of the key infrastructure facilities that support telecommunications services. Concrete is strong in compression but weak in tension; thus, tensile stress is applied to the internal rebars so that compressive stress can be applied to the concrete. However, steel rebars subjected to tension undergo deterioration called hydrogen embrittlement, which can lead to facility failure. However, such rebars cannot be visually checked, so it is difficult to determine the deterioration status of concrete poles, which poses a challenge for maintenance. From the viewpoint of preventive maintenance, by (i) establishing evaluation methods (such as conducting an accelerated hydrogen-embrittlement test and evaluating hydrogen amount), (ii) using analysis methods such as statistical data analysis, and (iii) elucidating and modeling the hydrogen-embrittlement mechanism, we are working on a formula for estimating hydrogen embrittlement [9].

4. Future developments

We will accelerate the practical development of the smart-healthcare and infrastructure-maintenance

* hitoe™: A functional fabric developed by Toray and NTT. It is fabricated by specially coating nanofiber fabric, which is the most-advanced fiber material, with a highly conductive resin. It has excellent durability and can detect biosignals with high sensitivity even though it is a non-metallic material. Having hitoe adhere to the skin surface makes it possible to obtain biological data, such as heart rate, electrocardiograms, and sleep data, estimated from R-wave intervals. Using nanofibers makes it possible to acquire more-sensitive measurements of biological signals in close contact with a person's body (e.g., through clothing and hats) because the nanofibers are durable enough to be washed at home and have an increased degree of adhesion to the skin.

technologies introduced in this article. We will also promote R&D on challenging themes from a medium-to-long-term perspective to contribute to creating a sustainable society that focuses on people and the environment.

References

[1] Website of the United Nations, Sustainable Development Goals, https://www.un.org/sustainabledevelopment/
[2] Website of Cabinet Office, Government of Japan, Society 5.0, https://www8.cao.go.jp/cstp/english/society5_0/index.html
[3] Nomura Research Institute, materials for the 273rd NRI Media Forum, Dec. 2018.
[4] Ministry of Land, Infrastructure, Transport and Tourism, "Estimation of Future Maintenance and Renewal Costs of Social Capital in Fields under the Jurisdiction of the Ministry of Land, Infrastructure, Transport and Tourism," 2018 (in Japanese). https://www.mlit.go.jp/sogoseisaku/maintenance/_pdf/research01_02_pdf02.pdf
[5] NTT press release issued on Nov. 8, 2019 (in Japanese). https://www.ntt.co.jp/news2019/1911/191108a.html
[6] K. Takagahara, Y. Hashimoto, K. Matsunaga, Y. Higuchi, N. Matsuura, K. Kuwabara, H. Togo, T. Kawahara, A. Hirata, H. Tanaka, and T. Miyazawa, "Physical-condition Management Technology for Creating More Comfortable Work Sites," NTT Technical Review, Vol. 19, No. 6, pp. 48–54, June 2021. https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202106fa7.html
[7] Y. Tanaka, T. Tajima, and M. Seyama, "Non-invasive Biological-information Sensing Using Photoacoustic Measurement Technology," NTT Technical Review, Vol. 19, No. 6, pp. 55–60, June 2021. https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202106fa8.html
[8] S. Kawamura, T. Sakamoto, M. Ueno, and S. Oka, "Derusting Technology Using High-power Laser Device," NTT Technical Review, Vol. 19, No. 6, pp. 61–65, June 2021. https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202106fa9.html
[9] T. Kamisho, R. Ishii, and M. Tsuda, "Technology for Predicting Hydrogen Embrittlement in Reinforcing Bars of Concrete Poles," NTT Technical Review, Vol. 19, No. 6, pp. 66–70, June 2021. https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202106fa10.html

Masato Tomizawa

Vice President, Head of NTT Device Innovation Center.

He received an M.S. and Ph.D. in applied physics from Waseda University, Tokyo, in 1992 and 2000. From 2003 to 2004, he was a visiting scientist at Massachusetts Institute of Technology, USA. He has been engaged in R&D of high-speed optical transmission systems. Since 2009, he has been a project leader of the 100G Center-of-Excellence (CoE) Consortium consisting of several manufacturing companies and is responsible for the development and marketing strategies of 100G coherent digital signal processors. In 2013, he received the Minister's Award of the Ministry of Internal Affairs and Communications of Japan from the Telecommunication Technology Committee for his contributions and leadership of the consortium in the 100G digital coherent CoE project. In 2015 and 2016, he received Fellow-grade memberships from the Institute of Electronics, Information and Communication Engineers (IEICE) and the Optical Society (OSA), respectively.

Akira Okada

Vice President, Head of NTT Device Technology Laboratories.

He received a B.S. and M.S. in physics in 1988 and 1990, and a Ph.D. in materials science in 1993 from Keio University. He joined NTT in 1993 and conducted research on polymer-based waveguide devices, full-mesh wavelength division multiplexing networks, optical packet switching, and optical modules for access networks. From October 1997 to October 1998, he was a visiting scholar at Stanford University, CA, USA. He is a member of the Institute of Electrical and Electronics Engineers (IEEE), IEICE, and the Japan Society of Applied Physics (JSAP).

Physical-condition Management Technology for Creating More Comfortable Work Sites

Kazuhiko Takagahara, Yuki Hashimoto, Kenichi Matsunaga, Yuichi Higuchi, Nobuaki Matsuura, Kei Kuwabara, Hiroyoshi Togo, Takashi Kawahara, Akimasa Hirata, Hideto Tanaka, and Taiki Miyazawa

Abstract

Physical-condition management is becoming more important to improve the safety of work sites, such as preventing heat stroke caused by intense heat. We at NTT Device Innovation Center have developed a physical-condition management technology for creating more comfortable work sites by using the wearable-device sensors and data-analysis technology we have developed thus far, and the knowledge of thermal and exercise physiology in collaboration with specialists. This article introduces the problems with physical-condition management, how our technology can solve these problems, and the results from verifying our technology at an actual work site.

Keywords: wearable sensor, physical-condition management, heat countermeasures

1. Introduction

The number of emergency transports and deaths due to heat stroke has increased, and reducing them has become a major social issue in Japan. According to a survey by the Fire and Disaster Management Agency, 64,770 people were transported by emergency due to heat stroke from June 1st to October 4th, 2020. According to the Ministry of Health, Labor and Welfare (MHLW), there were 829 casualties (death and leave of absence 4 days or more) due to heat stroke in the workplace in 2019, of which 25 died. MHLW has published guidelines and manuals for heat-stroke prevention measures in the workplace [1]. We at NTT Device Innovation Center have been engaged in research and development of physical-condition management technology using wearable biological/environmental sensors to solve such social issues and create more comfortable work sites.

2. Technical problems

We developed our physical-condition management technology to make work sites more comfortable from two aspects: real-time control of the risk of poor physical condition due to heat and reduction of accident risk by short- and medium-term operation management.

Figure 1 shows a schematic of the cause of poor physical condition due to activities in a hot environment [2]. When the body temperature rises due to exercise in normal environments, the heat is dissipated to the outside air due to sweating and increase in skin temperature, regulating body temperature. However, in a hot environment, it is difficult for heat to dissipate to the outside air. If the water and salt lost due to sweating are not sufficiently replenished, blood flow will also be impaired and heat will easily accumulate in the body, causing poor physical condition.

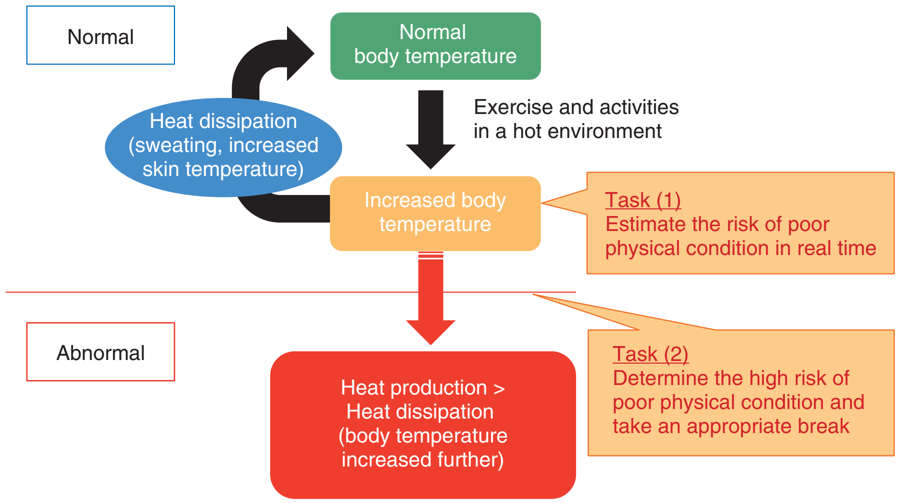


Fig. 1. Cause of poor physical condition in a hot environment.

We have found two requirements to mitigate such conditions. One is that it is necessary to estimate the risk of poor physical condition for each individual in real time because the environment, such as outside temperature and humidity at the work site, and the intensity of work and exercise vary from person to person and change from moment to moment. The other is that it is necessary to determine the high risk of poor physical condition from the estimation results to properly encourage breaks and water intake before poor physical condition occurs.

To reduce accident risk by short- and medium-term operation management, we applied the acute chronic workload ratio (ACWR), which is attracting attention as being effective in reducing the risk of injury and poor physical condition of athletes, to workers. The ratio of short-term work load of about one week to long-term work load of about one month is defined as the ACWR. The risk of injury increases if the ACWR is too high or too low, so daily operation is managed so that the ACWR is in the low risk area. One of the problems is quantifying the work load caused by daily work.

To solve these problems, we developed a wearable sensor for acquiring biological/environmental information and a sensor-data-analysis technology based on thermal and exercise physiology.

3. Key technologies

3.1 Wearable biological/environmental sensor

To estimate the risk of poor physical condition for each worker in real time, it is necessary to acquire various biological and environmental information without interfering with work, and we believe wearable sensors are effective for this purpose.

Figure 2 shows our wearable biological/environmental sensor. It consists of a transmitter (TX02), which is commercialized by NTT TechnoCross based on the wearable biological/environmental sensor technology researched and developed at NTT Device Innovation Center [4], a hitoe™*1 shirt, hitoe belt from Toray Industries, Inc., or C3fit IN-pulse*2 shirt from GOLDWIN INC. **Figure 3** shows a schematic of data acquisition. The user wears the garment as underwear so that the hitoe electrode is in direct contact with the skin, and the TX02 is attached to the garment via the connector. The weak bioelectric signal generated from heart beats is acquired from the hitoe electrode, input to the TX02 via the connector, and recorded as electrocardiographic data by the bioelectric signal sensor. In addition to the bioelectric signal sensor, the TX02 has a built-in temperature/humidity sensor and acceleration/angular velocity sensor. Therefore, it is possible to measure data on an electrocardiogram, temperature and humidity inside clothes, and acceleration and angular velocity of the upper body. Various features such as heart rate, heart-rate interval, number of steps, and upper body tilt, are

*1 hitoe™: The functional fabric hitoe is a fiber material jointly developed by Toray Industries, Inc. and Nippon Telegraph and Telephone Corporation, and is a trademark of the two companies.
*2 C3fit IN-pulse: A clothing line that monitors physiological information using hitoe offered by GOLDWIN INC.

Fig. 2. Wearable biological/environmental sensor.

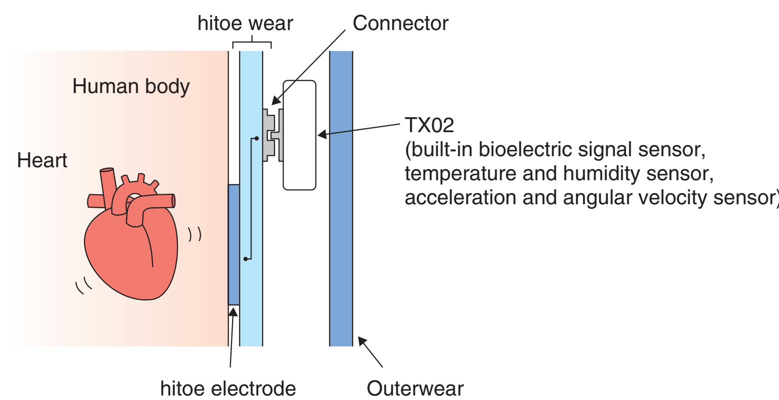


Fig. 3. Schematic of data acquisition.

also analyzed from the measured data.

3.2 Core-temperature-fluctuation estimation

Body-core temperature[*3], heart rate, and subjective symptoms of dizziness and nausea are listed as indicators of poor physical condition in hot environments [5]. Conventionally, the body-core temperature is measured by inserting a thermometer into the esophagus or rectum, which requires specialized skills, and is difficult to measure it in real time during activities such as work and exercise.

Therefore, we developed a technology for estimating core-temperature fluctuations in real time during activity through joint research with Nagoya Institute of Technology. With this technology, body-temperature fluctuation is estimated by inputting the information acquired from the wearable sensor into a newly constructed calculation model. The overview of this model is shown in **Fig. 4**. The human body is divided into a core layer and skin layer, and the heat exchange between each layer and the outside air is formulated. The formula uses an algorithm developed by Nagoya Institute of Technology that takes into account factors such as heat production from human activities, thermoregulatory function due to sweating etc., and clothing. Heart rate, temperature/humidity inside clothes, and personal information (age, height, weight, gender, clothes, etc.) are input to this model to calculate fluctuations in core temperature. With this model, it has become possible to calculate core-temperature fluctuations in real time even with the processing power of smartphones.

To confirm the usefulness of this estimation technology, we conducted a joint clinical experiment[*4] with NTT, Yokohama National University, Shigakkan University, and Nagoya Institute of Technology. This

*3 Body-core temperature: Temperature inside the head or trunk.
*4 Shigakkan University Research Ethics Review Committee No. 124.

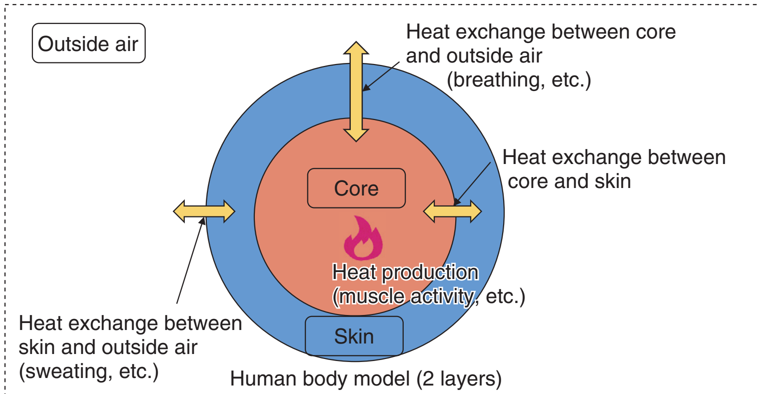


Fig. 4. Calculation model of core-temperature fluctuation.

experiment was conducted in the artificial weather room of Shigakkan University to simultaneously estimate body-temperature fluctuations using this technology and with a rectal thermometer. We confirmed that the estimation accuracy of our technology was sufficient to determine the risk of poor physical condition.

3.3 Determine risk of poor physical condition

Indicator criteria and algorithms are required to determine the high risk of poor physical condition for each worker. On the basis of the knowledge obtained from the joint experiment and from thermal physiology, we set criteria for three indicators: heart rate, estimated core-temperature fluctuation, and subjective information. We also constructed an algorithm that determines the overall risk of poor physical condition from the state of the three indicators and issues an alert in the case of high risk.

3.4 Work-load estimation

To quantify the workload caused by daily work, it was conventionally necessary to obtain the rate of perceived exertion from questionnaires as soon as possible after the work. We developed a technique to estimate the rate of perceived exertion through heart-rate analysis based on exercise physiology without using a questionnaire and confirmed its effectiveness with the cooperation of the Waseda University Rugby Club [6].

4. Verification in the workplace

To verify the usefulness of our physical-condition-management technology at work sites, we conducted a verification experiment*5 targeting construction workers in the Tokyo, Kanagawa, and Hokkaido regions from August to September 2020 with the cooperation of NTT EAST. **Figure 5** shows a schematic diagram of this experiment. We implemented our core-temperature-fluctuation-estimation technology, algorithm for determining the risk of poor-physical condition, and work-load-estimation technique as smartphone applications and built a demo system that remotely monitors the physical condition of each worker wearing wearable biological/environmental sensors via the cloud (this demo system is not for medical use). Alerts were sent to workers who were determined to be at high risk.

To confirm the usefulness of the core-temperature-fluctuation-estimation technology and work-load-estimation technique at the work site, we evaluated the relationship between the subjective information (warm/cold feeling, rate of perceived exertion) obtained from the workers and the estimation results. We confirmed that there is a correlation between the estimated core-temperature fluctuation and warm/cold feeling and between the estimated work load and the rate of perceived exertion. These results indicate the possibility of visualizing the subjectivity of workers without using questionnaires and the usefulness of core-temperature fluctuation estimation and work-load estimation based on wearable biological/environmental sensor data.

Risk cases were comprehensively detected during the verification by the three indicators and the algorithm for determining the risk of poor physical condition.

*5 The Japanese Society for Wellbeing Science and Assistive Ethics Review Committee No. 286.

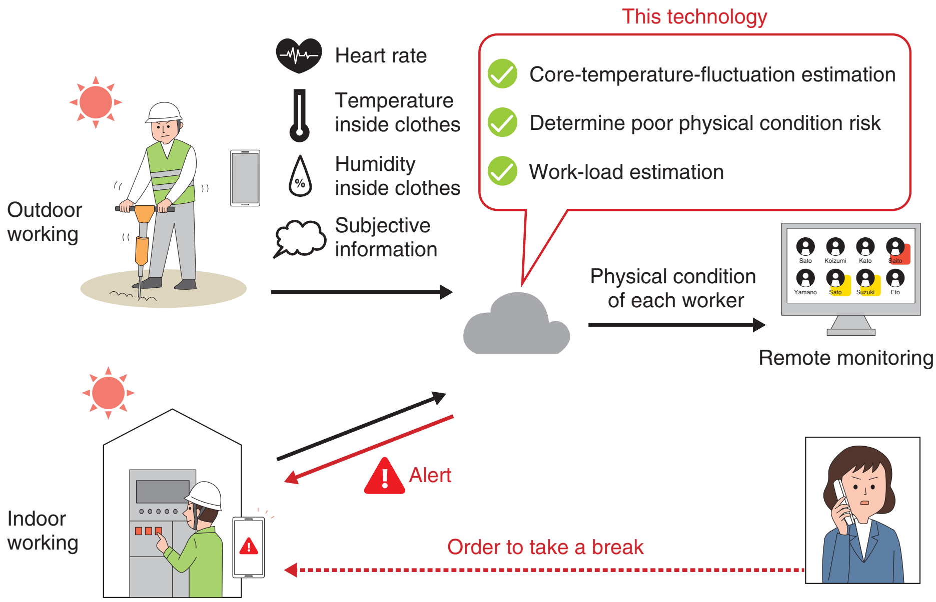


Fig. 5. Schematic of verification experiment at the work site.

Alerts were sent to remotely monitoring managers and workers. Since no serious cases of poor physical condition, such as heat stroke, occurred during this verification experiment, we consider our technology useful.

5. Summary

To make work sites more comfortable, we developed a physical-condition-management technology that involves wearable sensors and verified it at a work site. We will continue to deepen our knowledge by introducing our technology at more work sites and promote further improvements.

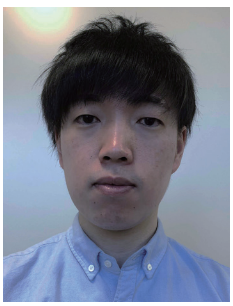
References

[1] Ministry of Health, Labor and Welfare, "Heat Stroke Prevention Measures in Workplace" (in Japanese), https://www.mhlw.go.jp/stf/seisakunitsuite/bunya/0000116133.html
[2] Ministry of the Environment, Heat Illness Prevention Information, Heat illness prevention/countermeasures, https://www.wbgt.env.go.jp/en/doc_prevention.php
[3] T. J. Gabbett, "The Training-injury Paradox: Should Athletes Be Training Smarter and Harder?", Br. J. Sports Med., Vol. 50, No. 5, pp. 273–280, 2016.
[4] Focus on the News: "Development of Low-power and Compact Wearable Sensor for Measuring Electrocardiographic, Acceleration, Temperature/Humidity Data for Use in Smart Healthcare," NTT Technical Journal, Vol. 32, No. 3, pp. 57–58, 2020 (in Japanese).
[5] American Conference of Governmental Industrial Hygienists, "Threshold Limit Values and Biological Exposure Indices," 2019.
[6] Focus on the News: "Development of Technology for Supporting Scientific Training in Sports and Demonstration of the Feasibility for Rugby Players," NTT Technical Journal, Vol. 32, No. 7, pp. 60–62, 2020 (in Japanese).

Kazuhiko Takagahara

Senior Research Engineer, NTT Device Innovation Center.

He received a B.S. in mechanical engineering and M.S. in information science and technology from the University of Tokyo in 2006 and 2008. He joined NTT Microsystem Integration Laboratories in 2008, where he has been engaged in research and development (R&D) of optical and wireless telecommunication devices and vital sensing devices. He is a member of the Japan Society of Applied Physics.



Yuki Hashimoto

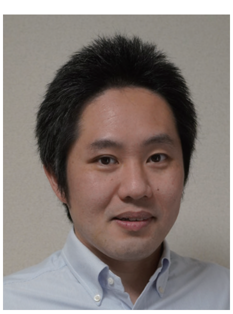
Engineer, NTT Device Innovation Center.

He received a B.E., M.E., and Ph.D. in engineering from Tokyo Institute of Technology in 2014, 2016, and 2018. He joined NTT Device Innovation Center in 2018 and is currently researching wearable healthcare devices for management of heat stress. He is a member of the Japan Society of Mechanical Engineers and the Institute of Electrical Engineers of Japan.

Kenichi Matsunaga

Research Engineer, NTT Device Innovation Center.

He received an M.E. in electronics from Tokyo Institute of Technology in 2010 and joined NTT Microsystem Integration Laboratories the same year, where he studied low-power complementary metal oxide semiconductor (CMOS) circuits design for wireless sensor nodes. Since 2015, he has been with NTT Device Innovation Center, where he is currently developing Internet of Things devices. His research interests include CMOS circuits and sensor networks. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) and the Institute of Electrical and Electronics Engineers (IEEE).



Yuichi Higuchi

Manager, Digital Twin Business Department, NTT TechnoCross Corporation.

He received a B.E. and M.E. from Kyoto University in 2006 and 2008. He joined NTT Microsystem Integration Laboratories in 2008, where he was engaged in R&D of optical telecommunication devices and vital sensing devices. In 2020, he moved to NTT TechnoCross, where he is currently in charge of the healthcare service development. He is a member of IEICE and the Japan Society for Precision Engineering.

Nobuaki Matsuura

Senior Research Engineer, NTT Device Innovation Center.

He received a B.S. in applied physics and M.E. in energy science from Tokyo Institute of Technology in 1990 and 1992. He joined NTT in 1992 and has been conducting research on optical interconnection technology. He is a member of IEICE.

Kei Kuwabara

Senior Research Engineer, Project Planning Section, NTT Device Innovation Center.

He received a B.E. and M.E. in electronics engineering from Keio University, Kanagawa, in 2002 and 2004. He joined NTT Microsystem Integration Laboratories in 2004 and studied micro electro-mechanical systems for wireless and optical networks. Since 2013, he has been engaged in R&D of wearable devices for healthcare, such as wearable blood-flow sensors and hitoe, and in 2015, was responsible for promoting open collaboration of hitoe in the R&D planning department. He is currently in charge of promoting R&D of NTT Device Innovation Center. He is a member of IEEE and IEICE.

Hiroyoshi Togo

Senior Research Engineer, Supervisor, NTT Device Innovation Center.

He received an M.Sc. and Ph.D. in applied physics and electronic engineering from the University of Tsukuba, Ibaraki, in 1996 and 2010. He joined NTT Musashino Opto-electronics Laboratories in 1996. Until 2001, he was involved in the development of the thermo-capillary waveguide-based optical switch and from 2001 to 2002 endeavored to commercialize it for NTT Electronics. From 2003 to 2015, he developed ultrawideband impulse radio systems using photonic techniques and millimeter-wave tomography with electro-optic probing at NTT Device Technology Laboratories. Since 2016, he has been leading a wearable-device development project to contribute to smart healthcare at NTT Device Innovation Center. He is a senior member of the IEEE Photonics, Antenna and Propagation, and Microwave Theory and Techniques Society, and IEICE of Japan. He was a finance director of the Council of Technical Committee Representatives and a director of the Technical Committee on Photonics-applied Electromagnetic Measurement in the IEICE Communications Society. He is also an expert member of the Technical Committee on Microwave Photonics in the IEICE Electronics Society and an expert member of the Japan Electronics and Information Technology Industries Association wearable electronics standardization. He received the 2006 Asia Pacific Microwave Photonics Conference AP-MWP Award, the 2010 European Conference on Antenna and Propagation Award, and The Japan Wood Research Society Best Paper Award 2013.

Takashi Kawahara

Research Professor, NTT.

He graduated Medical School, the University of Tokyo in 1976. After his medical internship, he specialized in cardiology and worked at the Hospital, the University of Tokyo. He became lecturer at the Department of Physical Education and Sport Sciences, College of Arts and Sciences, the University of Tokyo in 1985, associate professor in 1989. He became director of Sport Medicine, Japan Institute of Sport Sciences in 2001, general director of Japan Institute of Sport Sciences in 2014, and retired in 2017. He joined NTT as research professor in 2019. His main research areas were prevention of disorders caused by sport (such as heat stroke, overtraining syndrome, anemia) and hypoxic training. He participated in the Olympic Games six times as the Japanese delegation doctor. He is currently vice president of the Japan Association for University Athletics and Sport, chairman of Sport Medicine and Science Commission, Japan Sport Association.

Akimasa Hirata

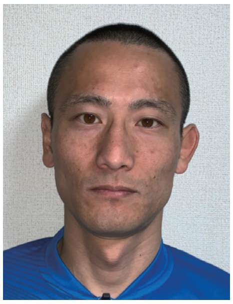
Professor and Research Director, Nagoya Institute of Technology.

He received a B.E., M.E., and Ph.D. in communications engineering from Osaka University in 1996, 1998, and 2000. From 1999 to 2001, he was a research fellow of the Japan Society for the Promotion of Science (JSPS) and a visiting research scientist at the University of Victoria, Canada, in 2000. In 2001, he joined the Department of Communications Engineering, Osaka University, as an assistant professor. In 2004, he joined the Department of Computer Science and Engineering, Nagoya Institute of Technology as an associate professor where he is currently a full professor. His research interests include electromagnetic safety, risk management system for heat-related illness, methods in neuroscience, antennas, and related computational techniques. He is an editorial board member of Physics in Medicine and Biology, a member of the main commission and a chair of project group of International Commission on Non-Ionizing Radiation Protection, a member of administrative committee and a subcommittee (EMF Dosimetry Modeling) chair of IEEE International Committee on Electromagnetic Safety, and an expert of the World Health Organization. He received several awards including Young Scientists' Prize (2006) and Prizes for Science and Technology (Research Category 2011, Public Understanding Promotion Category 2014, 2020) by the Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science, and Technology, Japan, and IEEE EMC-S Technical Achievement Award (2015), and the Japan Academy Medal and JSPS Prize (2018). He is a fellow of IEEE, Institute of Physics, and IEICE.

Hideto Tanaka

Professor, Graduate School of Education, Yokohama National University.

He received a Bachelors of Health and Sports Science and an M.A. in health education from the University of Tsukuba, Ibaraki, in 1981 and 1983 and a Ph.D. in medical science from Osaka University in 1988. He has been an assistant at the School of Medicine, Osaka University since 1983, conducting research on thermal physiology, especially thermoregulation during exercise. He then became a lecturer at the Faculty of Education, Yokohama National University in 1990, associate professor in 1991, and professor in 2004. From 1994 to 1995, he was appointed as a visiting researcher at the Faculty of Psychology, University of Delaware, USA. His research areas are exercise physiology and environmental physiology, with a focus on thermal physiology. His current main research themes are thermoregulation during exercise, the living environment and thermoregulatory function, and prevention of heat stroke. In 2002, he received the 5th Chichibunomiya Memorial Sports Medicine and Science Encouragement Award for "Study of Heat Stroke Prevention (Principal Investigator: Dr. Kawahara)." His main academic societies are the Japanese Society of Physical Fitness and Medicine, the Japan Society of Exercise Physiology, the Japanese Society of Biometeorology, and the Physiological Society of Japan.



Taiki Miyazawa

Associate Professor, Department of Health and Sports Science, Faculty of Wellness, Shigakkan University.

He received a B.E. in mechanical engineering from Osaka City University in 2004, M.E. in physics system of machine from the Graduate School of Engineering, Osaka City University, in 2006, and Ph.D. in medical science from the Graduate School of Medicine, Osaka City University, in 2010. He was a postdoctoral fellow with the University of Toyo, Saitama, from 2010 to 2012, the National Institute of Advanced Industrial Science and Technology, Ibaraki, from 2012 to 2013, and Kyorin University, Tokyo, from 2013 to 2015. He is currently an associate professor with Shigakkan University, Aichi. His current research interests include body-temperature regulation and cerebral blood-flow regulation during exercise.

Non-invasive Biological-information Sensing Using Photoacoustic Measurement Technology

Yujiro Tanaka, Takuro Tajima, and Michiko Seyama

Abstract

Biological-information sensing technology for simplifying the measurement of blood components without drawing blood has been attracting attention. NTT has been researching and developing biological-information sensing using photoacoustic measurement technology that combines the ability of light to selectively measure specific biological components and the ability of sound (ultrasound) to propagate through the human body. In this article, we introduce non-invasive biological-information sensing technology using photoacoustic measurement technology with the aim of collecting various types of information from within the body.

Keywords photoacoustic, non-invasive, sensor

1. Advances in biological-information sensing through non-invasive measurement technologies

Recent progress in information and communications technology (ICT) and growing awareness of health management has made personalized healthcare services that use biological information obtained from wearable devices increasingly popular. Information that is monitored during an individual's daily life shows promise for application to systems that promote behavior modification or use healthcare-oriented big data (**Fig. 1**). However, biological information obtained from current wearable devices consists mostly of data such as amount of activity, heart rate, respiration, body temperature, and blood pressure obtained from physical sensors. Consequently, when one is not feeling well, for example, such biological information cannot be used to describe the cause or suggest a countermeasure even if one's state can be objectively presented. It would therefore be desirable if wearable devices could also provide biochemical information such as data on blood components. The current method of obtaining such information is to draw blood at a hospital or medical clinic and analyze that sample using various types of test equipment on an item-by-item basis. Alternatively, to obtain blood-component information from wearable devices, it would be necessary to establish technology that could easily obtain data in a continuous and non-invasive manner without harming the body. In this regard, biological imaging technology using the photoacoustic effect has recently been investigated as a non-invasive biological sensing technique. This is a powerful technique for learning about the body's interior by combining two key features: the ability of light to measure biological components selectively and the ability of sound to propagate well through the body. In other words, the strongpoint of photoacoustic measurement technology is the ability to make measurements deep into the body that light cannot easily penetrate. There is a great need to look inside the human body at healthcare facilities, and this is currently done through the use of diagnostic imaging equipment such as X-ray computed tomography, magnetic resonance imaging, and positron emission tomography. In contrast to such diagnostic imaging equipment, photoacoustic equipment consisting of a light source and microphone has the advantage of being simple and portable with little burden placed on the user. We have been researching and developing

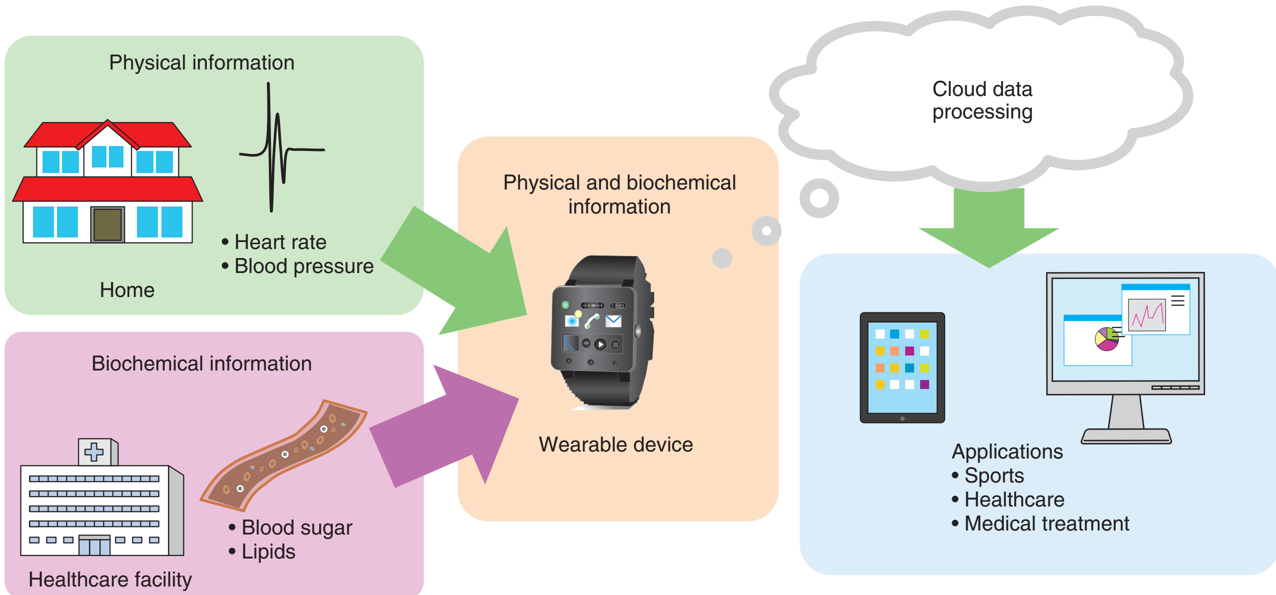


Fig. 1. Advances in biological-information sensing through non-invasive measurement technologies.

the application of the photoacoustic effect to biochemical information measurements from the viewpoint of establishing technology that enables measurements to be conducted anytime and anywhere. In this article, we first provide a basic description of the principle behind the photoacoustic effect then introduce the current state of photoacoustic research at NTT.

2. Measurements using the photoacoustic effect

The photoacoustic effect was discovered in 1880 by Alexander Graham Bell, the inventor of the telephone, as a phenomenon in which the intermittent irradiation of a substance with light generates sound. In 1965, Mark Leonidovitch Veingerov proposed the application of the photoacoustic effect to the analysis of gaseous components at concentrations on the ppm (parts per million) level (one-ten-thousandth of 1%), since then, techniques have been established for using the photoacoustic effect to analyze chemical structures on a molecular level.

We describe the photoacoustic effect in easy-to-understand terms. As shown in **Fig. 2(a)**, the absorption of light by matter is followed by the conversion of that optical energy to heat and the thermal expansion of that substance due to this thermal energy. If such optical irradiation should be applied in an intermittent manner, thermal expansion will occur repeatedly giving rise to elastic waves, that is, sound (ultrasonic waves). These are called photoacoustic waves.

Recent advances in ICT have also led to amazing benefits from a variety of devices and technologies such as light sources and optical switches that can generate optical pulses with high temporal controllability, acoustic technologies that can detect sound with high sensitivity, and electronics technologies that can perform diverse signal processing. Such devices and technologies have been applied in a wide range of fields including material analysis, gas analysis, and imaging. In biological measurements using the photoacoustic effect, the amount of light absorbed by the target substance within the body is converted to ultrasonic waves that propagate well through the body, and the concentration of that substance is estimated by detecting those waves as photoacoustic waves. Substances have optical colors (wavelengths) that are easy to absorb due to individual characteristics. This feature can be used to learn about biological components and their distribution in the human body. For example, as shown in **Fig. 2(b)**, blood cells, lipids, and glucose/proteins absorb light well in the 500-nm (visible light), 1000-nm (near-infrared light), and 1500-nm (near-infrared light) regions, respectively. Making use of this property, information on biological components can be obtained by irradiating the body with various colors and measuring how much of that light is absorbed. It is well known that more than

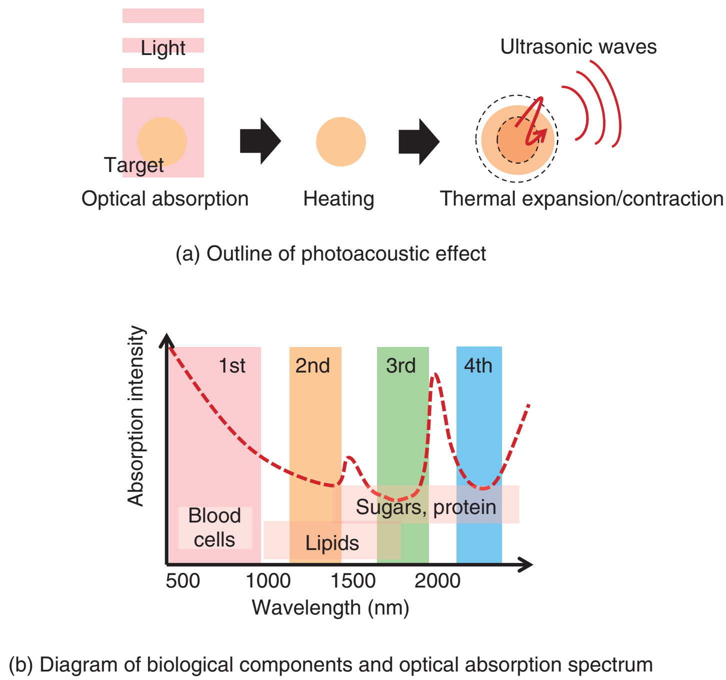


Fig. 2. Relationship between light and matter.

half of a living body is composed of water, which also has the property of absorbing light. Consequently, when using light to conduct measurements, it is generally necessary to select optical wavelengths that are not greatly absorbed by water. This is because no wavelength absorption by water makes it easier for light to enter the body without attenuation. This range of optical wavelengths is called the “optical window.” At the same time, there are limits to the depth at which light can penetrate the body for conducting measurements, and it is extremely difficult to determine by what path and in what way light is absorbed as it passes through our bodies intricately composed of diverse components. Despite this problem, photoacoustic measurements are conducted to detect the amount of absorbed light by converting it to ultrasonic waves that propagate well through the body, which means that the effects of reflection in the body can be suppressed. It is also possible to investigate the interior of the body in a non-invasive manner by measuring not only the intensity of photoacoustic waves (sound pressure) from light absorption by the target substance but also their propagation time and frequency characteristics.

3. Non-invasive approaches for measuring biological components using the photoacoustic effect

There are two approaches for measuring biological components in a non-invasive manner using the photoacoustic effect. One involves irradiating the body with a light pulse of extremely short duration (pulse width: several nanoseconds), having the target substance absorb that light, and measuring both the time taken for the generated photoacoustic wave to return and the position of the component absorbing the light on the basis of the sound pressure of that wave. With this approach, a photoacoustic wave is obtained as shown in **Fig. 3(a)**, and the depth of the target substance is determined from the time spent by the sound propagating through the body and its speed. A demonstration of three-dimensional imaging of the letter “N” embedded in material simulating the human body is shown in **Fig. 3(b)**. The second approach, as shown in **Fig. 3(c)**, involves irradiating the body with light that is periodically turned ON/OFF, letting the photoacoustic wave generated from the target substance reflect any number of times to generate a standing wave, and measuring the concentration of the target from the sound pressure of that wave.

The former approach can be used to obtain

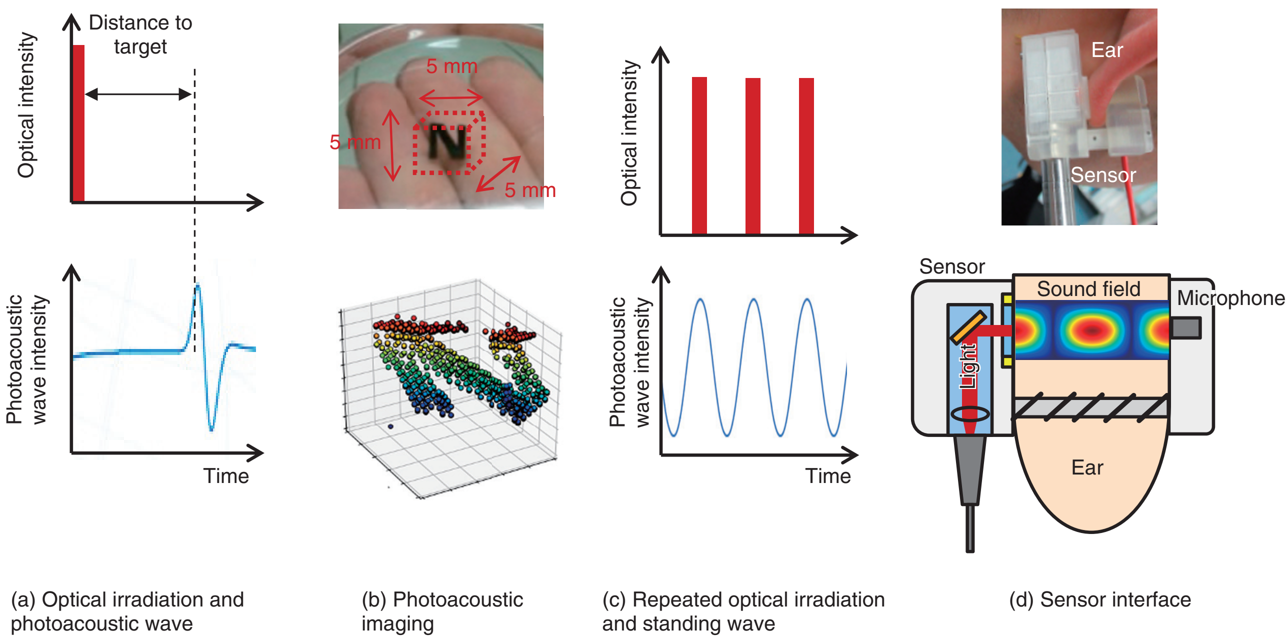


Fig. 3. Biological measurements using the photoacoustic effect.

information on a substance and its position. For example, knowing that many fine blood vessels form near cancer cells that require a considerable amount of nutrition to survive, much applied research has been conducted on imaging that situation. Such research, however, generally requires equipment that is large and expensive. Another problem is that signals that include information on biological components are weak and easily affected by noise.

The latter approach, while not able to obtain positional information of the target substance, can obtain a relatively large signal-to-noise ratio with just a low-intensity, inexpensive light source and one microphone, which makes it advantageous for measuring component concentrations or downsizing equipment. However, component measurements cannot provide clear contours such as those of blood vessels obtained by imaging. Since irradiated light is absorbed in a graduated manner in accordance with that component's concentration, the propagation waveform of the photoacoustic wave can collapse. To solve this problem, NTT proposed a sensor structure that confines the sound wave to reflect the photoacoustic wave many times. To give an example, a person's earlobe can be sandwiched by a clip with an irradiating light source on one side and a microphone embedded on the other side. A method for generating a standing wave and obtaining a strong signal by reflecting a photoacoustic wave many times between a light-irradiating surface and a sound-receiving surface is shown in **Fig. 3(d)**. Although the frequency of the photoacoustic wave is determined by the frequency of the irradiating light, selection of that frequency is important. This is because low frequencies are easily affected by human voices or everyday sounds (up to several tens of kilohertz), while high frequencies (up to several megahertz) suffer from significant attenuation within the body. As a result, researchers at NTT conduct measurements using photoacoustic waves in a frequency band (several hundred kilohertz) between those frequencies.

4. Application example: biological measurements

Finally, we introduce an example of applying the photoacoustic effect to the measurement of biological components. The sensor used in this example was one that sandwiches the earlobe as in the clip introduced above. We asked a healthy person to drink a beverage containing a large amount of glucose and measured subsequent change in the concentration of glucose in that person's interstitial fluid [1, 2]. Glucose concentration in interstitial fluid differs from that in the blood (so-called blood-sugar level) in that it indicates the concentration of glucose in interstitial fluid exuded

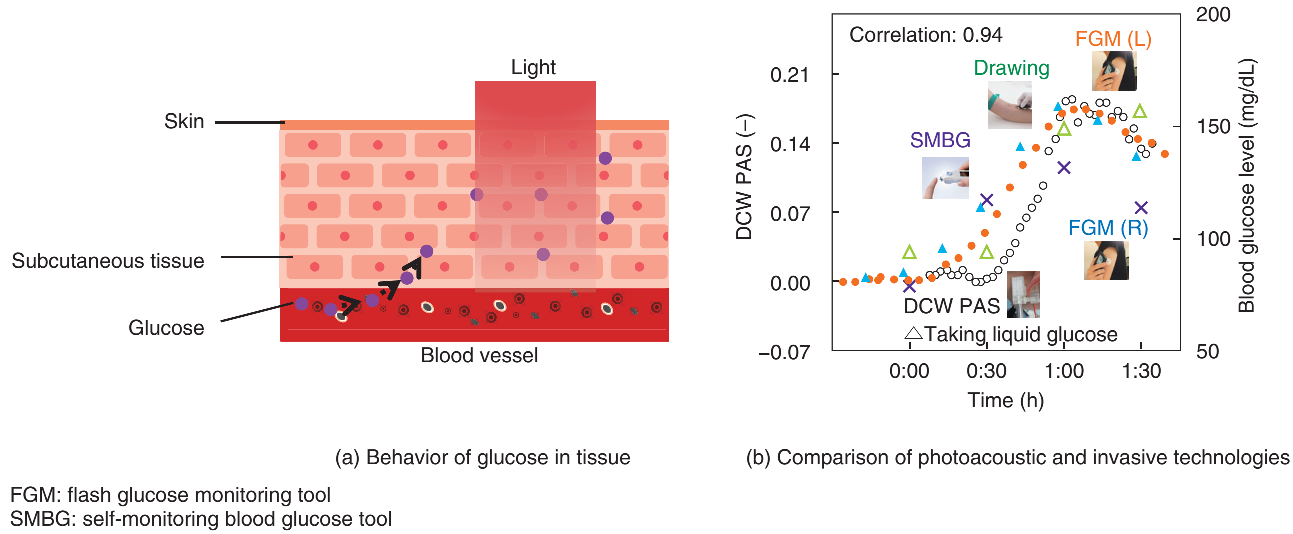


Fig. 4. Example application for measuring blood-sugar level.

from blood vessels and supplied to cells, as shown in **Fig. 4(a)**. It is known that the glucose concentration in interstitial fluid changes in nearly the same manner as the blood-sugar level. A comparison of measured values by using photoacoustic measurement technology with those by using various types of invasive blood-sugar-level sensors is shown in **Fig. 4(b)**. The blue plot represents values from differential continuous-wave photoacoustic spectroscopy ("DCW PAS" in the figure), and the other plots represent values measured by drawing blood and carrying out an intravenous procedure, i.e., invasively. With the invasive technologies, the blood-sugar level increased by about 60 mg/dl 15–30 min after drinking the glucose beverage and began to decrease gradually one hour later. These results indicate that the photoacoustic method could enable measurements that conform well to this 60-mg/dl change in the blood-sugar level. By matching a target substance with an appropriate optical wavelength, this technology holds promise for application to a variety of biological components of great interest such as cholesterol, neutral fats, and other types of lipids.

5. Future work

This article introduced the potential of biological-information sensing using the photoacoustic effect and its application to technology for measuring biological components. Up to now, biochemical-information sensing has not been a target of continuous monitoring in everyday life, but if it can be made practical, we can expect it to be applied in a variety of ways. It could be used, for example, as a technology supporting online diagnostics, which have become increasingly popular during the COVID-19 pandemic. To achieve such continuous monitoring in everyday life, device size and usability will be important factors in addition to non-invasive features. Going forward, we will take up the research and development of technology that uses photoacoustic measurements to enable high accuracy analysis regardless of gas, liquid, or solid targets and that enables the continuous monitoring of biochemical information such as biological and respiratory components in everyday life.

References

[1] Y. Tanaka, T. Tajima, M. Seyama, and K. Waki, "Differential Continuous Wave Photoacoustic Spectroscopy for Non-invasive Glucose Monitoring," IEEE Sensors Journal, Vol. 20, No. 8, pp. 4453–4458, 2020.

[2] Y. Tanaka, T. Tajima, and M. Seyama, "Acoustic Modal Analysis of Resonant Photoacoustic Spectroscopy with Dual-wavelength Differential Detection for Noninvasive Glucose Monitoring," IEEE Sens. Lett., Vol. 1, No. 3, 3500704, 2017.

Yujiro Tanaka
Researcher, NTT Device Technology Laboratories and NTT Bio-Medical Informatics Research Center.
He received a B.S. and M.S. in engineering from Tohoku University, Miyagi, in 2011 and 2013. He joined NTT Microsystem Integration Laboratories in 2013. He has been with NTT Device Technology Laboratories and NTT Bio-Medical Informatics Research Center, where he is currently engaged in photoacoustic technology for biosensing. He is a member of the Japan Society of Applied Physics (JSAP).

Takuro Tajima
Senior Research Engineer, NTT Device Technology Laboratories.
He received a B.S. and M.E. from the University of Tokyo in 2000 and 2002, and a Ph.D. from Tokyo Institute of Technology in 2017. In 2002, he joined NTT Telecommunication Energy Laboratories, where he has been engaged in the research and development of laser photoacoustic spectroscopy for biomedical sensing, sub-terahertz antenna-in-packages for ultrafast wireless communication, and broadband dielectric spectroscopic system using photonic integration technologies. His current research involves multi-modal biomedical analysis using microwave, terahertz-wave, optics, and ultrasonics. He is a member of the Institute of Electronics, Information and Communication Engineers.

Michiko Seyama
Senior Research Engineer, Supervisor, NTT Device Technology Laboratories and NTT Bio-Medical Informatics Research Center.
She received a B.S., M.E., and Ph.D. from Waseda University, Tokyo, in 1995, 1997, and 2004. In 1997, she joined NTT and worked on an odor sensing system based on a plasma-polymerized organic film for environmental contamination and biogas and a one-dimensional-surface plasmon resonance biosensor combined with a microfluidic device for on-site immunological sensing. Her current interest is the development of biosensing platforms for blood components and blood coagulation, including both invasive and non-invasive technologies. She is a member of JSAP, the Electrochemical Society of Japan, and the American Chemical Society.

Derusting Technology Using High-power Laser Device

Sohan Kawamura, Takashi Sakamoto, Masahiro Ueno, and Soichi Oka

Abstract

Rust removal in narrow spaces that are inaccessible to human hands or electric tools is a challenge in derusting operations essential in prolonging the life of steel towers and other communication infrastructure facilities supporting communication services. We are developing technologies for efficient derusting using high-power laser devices developed by NTT. In this article, we introduce a compact and lightweight derusting technology incorporating a high-power laser device called a diffractive optical element.

Keywords: high-power laser, derusting, diffractive optical elements

1. Issues surrounding derusting technologies for communication infrastructure facilities

Steel towers and other communication infrastructure facilities are important in safely and securely providing communication services essential in modern life. Exposure to sunlight and weather elements deteriorates the strength of these facilities, which are not easy to replace. Therefore, they need to undergo regular inspection and repair to enable continued use over a long period. There are approximately 20,000 of these steel towers, including small ones, owned by the NTT Group across Japan. Most were built during the high-economic-growth period in the 1960s and 1970s and are now in an advanced state of deterioration; thus, costs and human resources needed for their inspection and repair have increased yearly. Reducing costs and labor is, therefore, critical in making future inspection and repair sustainable. NTT is currently developing various painting materials to control rusting, as well as technologies to test paint deterioration, predict corrosion of steel products, and remove rust.

Prolonging the life of steel towers requires methods of controlling rusting as well as removing rust. Electric tools and metallic brushes are usually used in derusting, but it is difficult to remove rust from narrow spaces or around bolts. Sand blasting, a method with which sand particles are propelled at high speed onto surfaces, is one such method but is difficult to use because removing the sand takes time. Derusting tools using high-power lasers have, therefore, drawn attention. Commercially available rust removers using high-power lasers, however, have large and heavy handheld laser-emission heads, making it difficult to use by workers who have to climb steel towers to carry out derusting. We, therefore, developed an affordable, light-weight diffractive optical element (DOE) for a compact, lightweight, and field-friendly rust remover we are developing.

2. Technology of DOEs used in high-power lasers

A DOE is a device that applies holographic techniques for phase modulation of incident light in substrate microstructures. It enables the transforming of the incident laser-beam into any desired shape, as shown in **Fig. 1**. This characteristic is exploited in metal and resin processing.

Figure 2 is a schematic diagram of the DOE we developed for high-power laser processing. To prevent the increase in temperature due to the absorption of laser light and the damage it causes, we used a silicon carbide substrate, which has high thermal conductivity, and designed a reflection-type device,

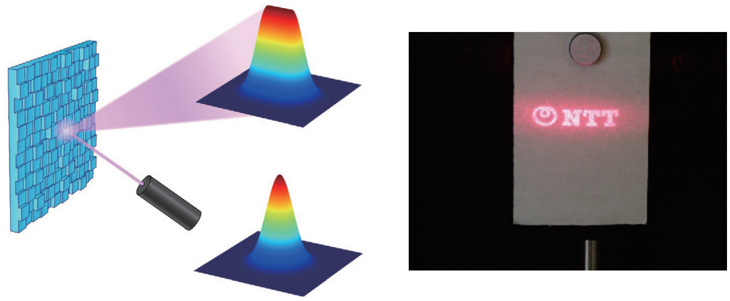


Fig. 1. Example of laser-beam shaping using a DOE.

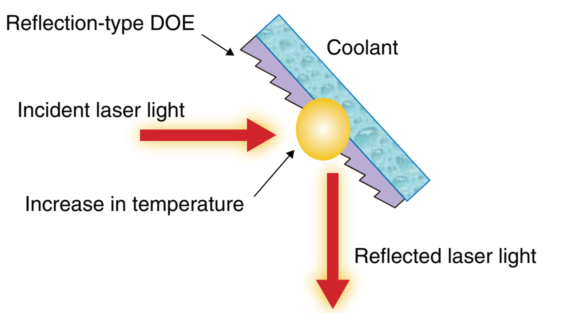


Fig. 2. Schematic diagram of a 10-kW reflection-type DOE for processing.

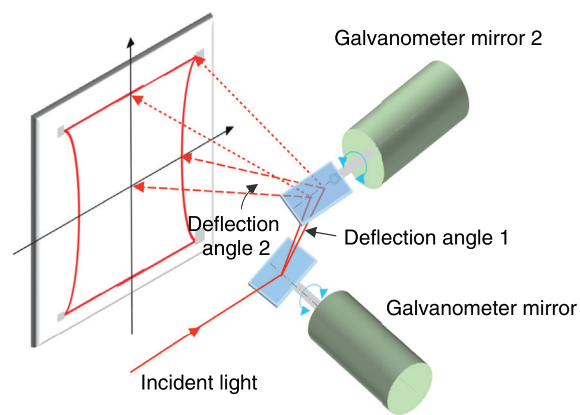


Fig. 3. Example of a beam-scanning method using galvanometer mirrors.

which is easier to cool, making it possible to carry out laser processing at 10 kW [1]. This DOE is not only light at only a few grams but also simple in structure. We used this DOE to develop the compact and light-weight rust remover described below.

3. Rust remover that NTT is developing

As shown in **Fig. 3**, in commercially available rust removers using lasers, laser-beam scanning is carried out either one-dimensionally or two-dimensionally using a mirror and motor to enable workers to remove rust over a fixed surface area without moving their hands. The handheld laser-emission head, however, is large and weighs several kilograms, making it burdensome for the worker and difficult to use on steel towers. To address these issues, we developed the method shown in **Fig. 4** for shaping light into a thin straight line using our DOE and carrying out manual scanning without the need for a motor. Derusting, therefore, can be carried out with the same efficiency as with the conventional method.

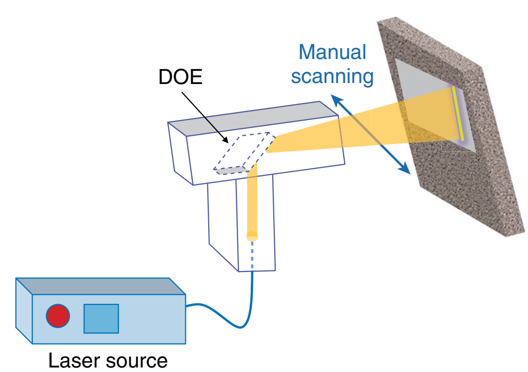


Fig. 4. Conceptual drawing of derusting laser using a DOE.

4. Towards affordable DOEs

As mentioned above, we used silicon carbide for DOEs in high-power lasers, but it is an expensive

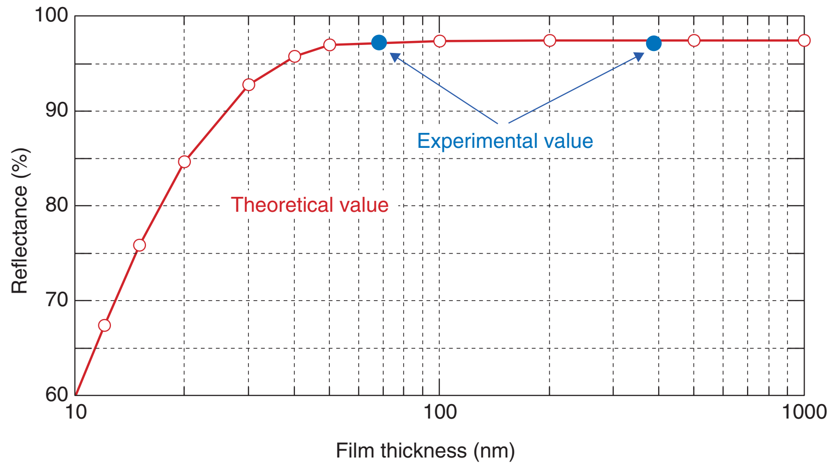


Fig. 5. Correlation between thickness and reflectance of gold film.

material. Due to the high likelihood that a DOE would become dirty or damaged during derusting, it is preferable to use more inexpensive DOEs. We, therefore, devised methods of replacing silicon carbide with less expensive materials to promote the use of rust removers that use DOEs.

Silicon is a material for which micro-processing techniques are well established in the semiconductor industry. Aside from its relatively low cost, it is also easily available, making it an ideal substitute as an inexpensive material. However, due to absorption of light at a wavelength of 1.07 μm used in rust removal, there is risk of damage due to increase in temperature. Although reflectance can be increased by applying a metal film on the surface to minimize light absorption, a thicker coating would result in the rounding of the corners of the DOE surface's microstructure, leading to errors in laser-beam shapes. In other words, it is critical to find the right metal with the proper thickness to achieve sufficient reflectance while reducing laser-beam-shape errors.

We, therefore, considered gold, which has high reflectance and high thermal conductivity, as a coating material and calculated and measured the relationship between its film thickness and reflectance. As shown in **Fig. 5**, reflectance reaches its peak at 50-nm thickness. Therefore, we determined the optimum thickness that results in sufficiently low laser-beam-shape error at around 50 nm. We were able to achieve laser processing at 10 kW, which far exceeds the power needed for rust removal. This demonstrates that costs can be feasibly reduced by using silicon as the diffraction grating material [2].

5. Development of a compact and easy-to-use rust remover

Figure 6 shows a prototype of the laser-emission head of the rust remover we are developing. By using our DOE, we demonstrated the possibility of fabricating a laser-emission head that weighs only 500 g, which is not possible with commercially available devices. The laser head is as small as a conventional electric tool, and being light and easy to use, it has potential for widespread use in derusting. **Figure 7** shows the results of an experiment to remove rust from narrow spaces that are difficult to reach with electric tools. Since laser light is used, there are no vibrations and restrictions in applicability inherent with electric tools, reducing the burden on workers.

These results indicate that using our DOE eliminates the need for motors, which are a limiting factor in the size and weight of commercially available devices, demonstrating the feasibility of using compact and lightweight rust removers for steel-tower cleaning.

6. Future prospects

As mentioned in the introduction, prolonging the life of steel towers and other communication infrastructure facilities requires technologies for rust removal and for maintaining surface conditions that prevent paint from peeling off.

The conditions needed in the irradiation of laser light affect surface conditions and the strength of paint adhesion. Therefore, research on the surface

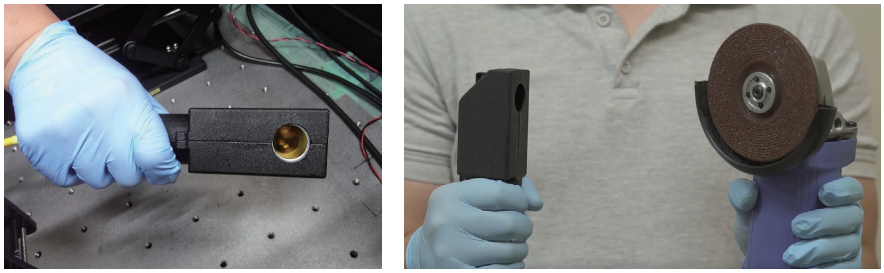


Fig. 6. Conventional electric tool (far right) and prototype of the laser-emission head of the rust remover we are developing (left).

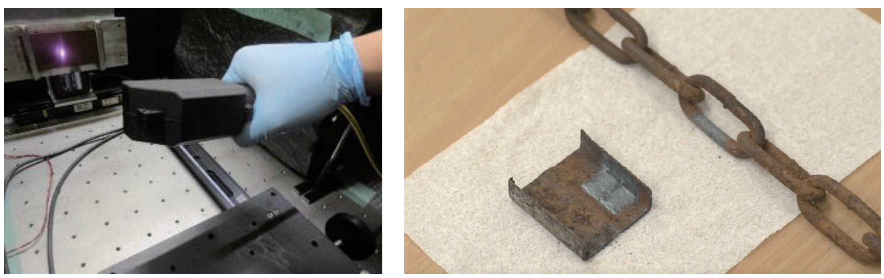


Fig. 7. Example of derusting experiment using our prototype laser-emission head of the rust remover we are developing.

conditions after rust removal using laser and on-paint adhesion are crucial in prolonging the life of communication infrastructures. Going forward, we will continue to conduct research on these areas to create new value by developing rust removers that contribute to improving paint adhesion and are easy to use in the field.

7. Conclusion

In this article, we introduced the derusting technology we are developing to contribute to a sustainable society. We were able to reduce the cost of a device by replacing the silicon carbide of our DOE with silicon. We also resolved the problems associated with the size and weight of commercially available devices and demonstrated the feasibility of an affordable, compact, lightweight, and user-friendly rust remover. Going forward, we will conduct research on surface conditions to improve paint adhesion and create new value in infrastructure maintenance.

References

[1] Y. Akage, T. Imai, S. Kawamura, S. Oka, Y. Fujitani, and T. Okuda, "Development of Beam Shaping Device for 10-kW-class Laser Processing," 94th Japan Laser Processing Society Conference, Online, Nov. 2020 (in Japanese).

[2] S. Kawamura, S. Toyota, and S. Oka, "Reflection-type Diffractive Optical Element Employing SiC and Si for Application to High Power Laser Material Processing," Proc. of SPIE, Vol. 11273, San Francisco, CA, USA, Mar. 2020.

Sohan Kawamura
Engineer, Smart Maintenance and Management Technology Development Project, Health & Environmental-Sensing Device Project, NTT Device Innovation Center.

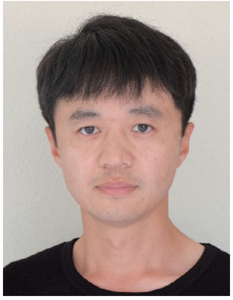
He received a B.E., M.E., and Ph.D. in engineering science from Hokkaido University in 2004, 2006, and 2009. At Hokkaido University, he studied on-single crystal growth and scintillation properties of Ce-doped gadolinium pyrosilicate. He joined the Advanced Opto-electronics Device Research Group in NTT Photonics Laboratories in 2009, where he studied on-crystal growth of electro-optic materials, nonlinear optical devices, and diffractive optical elements for high-power laser machining.

Takashi Sakamoto
Senior Research Engineer, Smart Maintenance and Management Technology Development Project, Health & Environmental-Sensing Device Project, NTT Device Innovation Center.

He received a B.A. and M.S. (multidisciplinary sciences) from the University of Tokyo in 1994 and 1996 and a Ph.D. in engineering from Tohoku University, Miyagi, in 2008. He joined NTT in 1996, where he researched optical packet switching, wavelength conversion, scanning nonlinear dielectric microscopy, and the development of high-speed optical scanning devices with potassium tantalate niobate crystals. He is now investigating rust removal from metal surfaces with laser irradiation. He is an associate member of the Institute of Electrical and Electronics Engineers.

Masahiro Ueno
Senior Research Engineer, Health & Environmental-Sensing Device Project, NTT Device Innovation Center.

He received a B.E. and M.E. in electrical engineering from Chiba University in 1987 and 1989 and a Ph.D. from Tokyo University of Science in 2010. He joined NTT Applied Electronics Laboratories in 1989 and studied mass storage systems using optical disks, disaster tolerant storage systems, holographic storage systems, ion flow printers, three-dimensional imaging systems, cloud computing systems, and optical coherence tomography systems from 1989 to 2018. He was also active in developing small computer system interface specifications. He is currently studying LiDAR (light detection and ranging) systems and diffractive optical elements at NTT Device Innovation Center. He is a member of the Institute of Electronics, Information and Communication Engineers.



Soichi Oka
Senior Research Engineer, Supervisor, NTT Device Innovation Center.

He received a B.E. in environmental information and an M.E. and Ph.D. in media and governance from Keio University, Kanagawa, in 1996, 1998, and 2001. From 2002 to 2003, he was engaged in research and development of evanescent microwave imaging at Wright Patterson Air Force Research Laboratories and the University of Cincinnati in Ohio, USA. Since joining NTT in 2004, he has been researching and developing civil engineering technologies.

Technology for Predicting Hydrogen Embrittlement in Reinforcing Bars of Concrete Poles

Takuya Kamisho, Ryuta Ishii, and Masayuki Tsuda

Abstract

A concrete pole, which is an important part of the communication infrastructure supporting communication services, requires significant maintenance costs to ensure its safety. If hydrogen embrittlement, a phenomenon by which reinforcing bars in concrete poles deteriorate, could be accurately predicted, it would be possible to maintain and manage concrete poles more safely and economically. A technology for predicting hydrogen embrittlement in reinforcing bars inside concrete poles that involves using an accelerated-hydrogen-embrittlement test and statistical data analysis is introduced.

Keywords: hydrogen embrittlement, deterioration prediction, concrete pole

1. Maintenance of concrete poles

A concrete pole is an important part of the communication infrastructure supporting communication services in Japan. If a concrete pole breaks, it may lead to property damage or personal injury; accordingly, all concrete poles are systematically maintained and managed so that they do not deteriorate. Maintaining concrete poles in this manner incurs a huge cost, so an economical maintenance technology that also ensures safety is required.

Pre-stressed concrete is used to suppress cracks in concrete poles. Such concrete is formed by applying tensile stress to the reinforcing bars (rebars) in advance. This shrinks the rebars and applies compressive stress to the concrete, which suppresses crack generation. Rebars used in pre-stressed concrete do not exhibit any problems under normal usage conditions. However, a deterioration phenomenon called hydrogen embrittlement can progress when various adverse conditions are combined [1–3]. Since the strength of concrete poles is secured by the internal rebars, deterioration of the rebars could lead to breakage of the concrete poles. If hydrogen embrittlement of rebars in concrete poles could be accurately predicted, inspections and repairs based on the predicted risk of deterioration would be possible; as a result, concrete poles could be maintained and managed more safely and economically. Given this possibility, we are pursuing research and development to establish a technology for predicting hydrogen embrittlement of rebars in concrete poles.

2. Hydrogen-embrittlement-prediction technology

Hydrogen embrittlement is a phenomenon in which atomic hydrogen (i.e., individual hydrogen atoms) penetrates a metallic material under tensile stress, reducing its strength and causing cracks and fractures in the material. It is sometimes called delayed fracture because the metallic material breaks after a certain period after hydrogen invades it under a constant load. Since the rebars used in pre-stressed concrete are constantly subjected to tensile stress, hydrogen embrittlement due to intrusion of hydrogen is a constant risk. The interior of concrete is normally an alkaline environment, so corrosion of rebars rarely occurs; however, when cracks occur in concrete, the concrete around the cracks are neutralized by carbon dioxide in the air, and rainwater that has penetrated the concrete via the cracks can corrode the rebars.

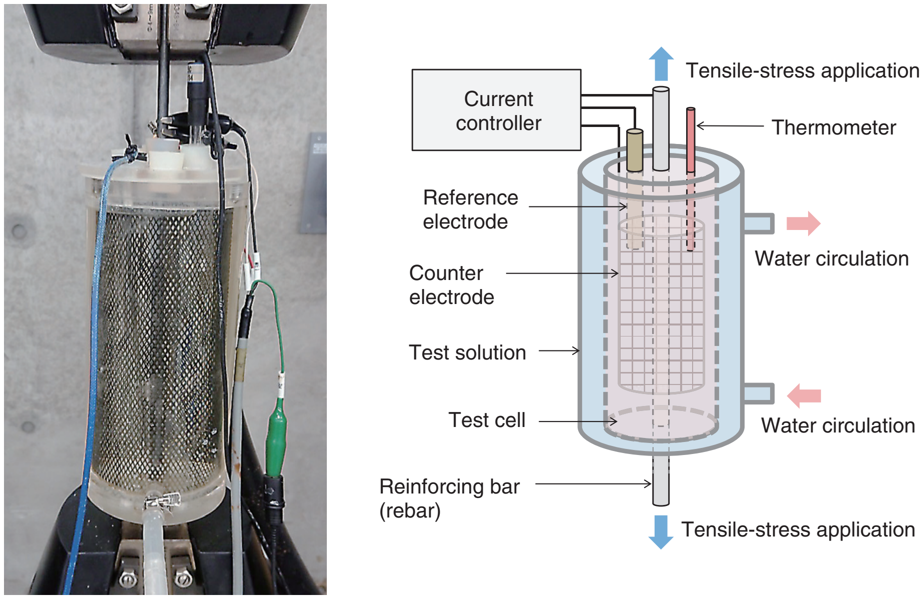


Fig. 1. External appearance and schematic of accelerated-hydrogen-embrittlement test.

When rebars corrode in this manner, hydrogen is generated, penetrating the rebars and causing hydrogen embrittlement. Therefore, the environmental factors that cause hydrogen embrittlement of rebars in prestressed-concrete are being investigated.

The mechanism of hydrogen embrittlement remains unclear. It is therefore considered difficult to predict hydrogen embrittlement by using a deductive method based on the hydrogen-embrittlement mechanism. By conducting tests to reproduce hydrogen embrittlement in a neutralized concrete environment and investigating the behavior of hydrogen embrittlement, we are attempting to predict hydrogen embrittlement by using an inductive method based on data analysis. In the future, it will be possible to make predictions with deductive methods by deepening our understanding of the hydrogen-embrittlement mechanism; in other words, we are aiming for a virtuous cycle in which the prediction accuracy of an inductive method is further improved using the results from a deductive method.

When reproducing hydrogen embrittlement, it is assumed it takes a long time to occur in an actual environment. To shorten that time, we are using an accelerated test that increases hydrogen concentration in a rebar to quickly cause fracture by hydrogen embrittlement. The external appearance and a schematic diagram of the accelerated-hydrogen-embrittlement test are shown in **Fig. 1**. In the test, hydrogen embrittlement in a neutralized concrete environment is simulated as follows: (i) a rebar is immersed in a weak-alkaline test solution inside a test cell (to reproduce a neutralized concrete environment); (ii) a tensile tester is used to apply a pre-determined tensile stress to the rebar (to reproduce the pre-stress applied to the rebar); and (iii) an electric current is passed through the rebar to generate hydrogen by electrolysis of water (to reproduce hydrogen generation due to corrosion). Since the amount of hydrogen generated can be controlled by adjusting the magnitude of the electric current, the hydrogen concentration in the rebar is increased by generating a sufficiently larger amount of hydrogen than that in an actual environment, accelerating hydrogen embrittlement. By conducting the accelerated-hydrogen-embrittlement test to determine the relationship between hydrogen concentration and fracture time/probability and extrapolating that relationship to the hydrogen concentration in an actual environment, we are attempting to predict hydrogen embrittlement in an actual environment.

3. Estimating time to fracture and fracture probability by conducting the accelerated-hydrogen-embrittlement test

Hydrogen embrittlement of rebars is known to vary greatly in time to fracture even under uniform environmental conditions. For general regression analysis,

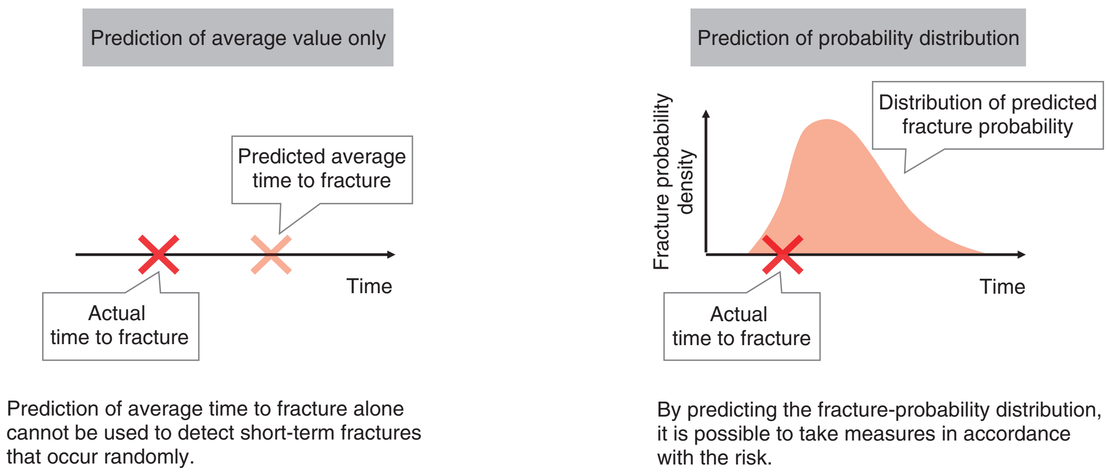


Fig. 2. Results of predicting time to fracture (including probability distribution).

only the average time to fracture can be predicted, and predicting only this average cannot be done to detect short-term fracture that occurs randomly. If the probability distribution of time to fracture could be predicted, it would be possible to detect fractures with shorter times to fracture than the average in accordance with the risk fracture (**Fig. 2**). Accordingly, we are attempting to predict time to fracture (including its probability distribution) by using statistical modeling for a large amount of time-to-fracture data acquired from the accelerated-hydrogen-embrittlement test.

Two conclusions can be drawn from the results of the accelerated-hydrogen-embrittlement test: (i) the relationship between hydrogen concentration on the surface of a rebar and the average time to fracture can be approximated by an exponential function and (ii) the variation in time to fracture at uniform hydrogen concentration follows the Weibull distribution. By creating a statistical model from these results and using the maximum-likelihood method for the time-to-fracture data, the relationship between hydrogen concentration and the probability distribution of time to fracture can be estimated. The maximum-likelihood method is used to estimate the parameters of probability distributions other than normal distributions such as a Weibull distribution. Regarding the maximum-likelihood method, the parameters are estimated from the acquired data by searching for the parameters that maximize the infinite product (likelihood) of the probability density of the acquired data. Examples of time-to-fracture data obtained from the accelerated-hydrogen-embrittlement test, estimated average values only from regression analysis, and estimation results (including the probability distribution) obtained using statistical modeling are shown in **Fig. 3**. It is clear from these results that using statistical modeling makes it possible to estimate not only the average time to fracture but also its probability distribution.

When exposed to a certain environmental condition, some rebars fracture due to hydrogen embrittlement after a certain time and others do not no matter how much time passes, and the occurrence or non-occurrence of future fracture can be expressed as a fracture probability. When the tensile stress applied to a rebar or the hydrogen concentration on the surface of the rebar increases, the fracture probability increases. When the tensile stress or hydrogen concentration becomes sufficiently low, however, the fracture probability becomes almost zero. When considering the maintenance of concrete poles, we must also consider the importance of the fracture probability of rebars due to hydrogen embrittlement.

It is understood from the results of the accelerated-hydrogen-embrittlement test that the relationship between hydrogen concentration on the surface of a rebar and fracture probability can be approximated with a sigmoid curve. It thus follows that the relationship between hydrogen concentration and fracture probability can be estimated using logistic regression analysis, which is a means of estimating the probability of an event occurring when a binary variable (namely, whether a certain event occurs) is taken as the objective variable. A logistic function is used in logistic regression analysis as a regression model,

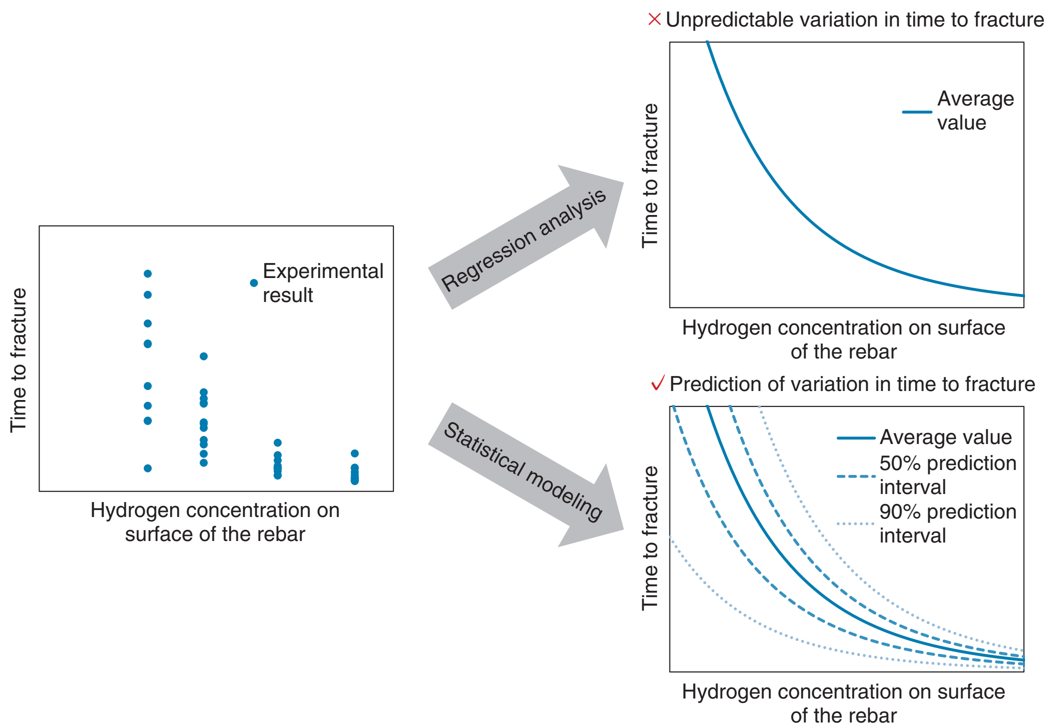


Fig. 3. Estimating the probability distribution of time to fracture by using statistical modeling.

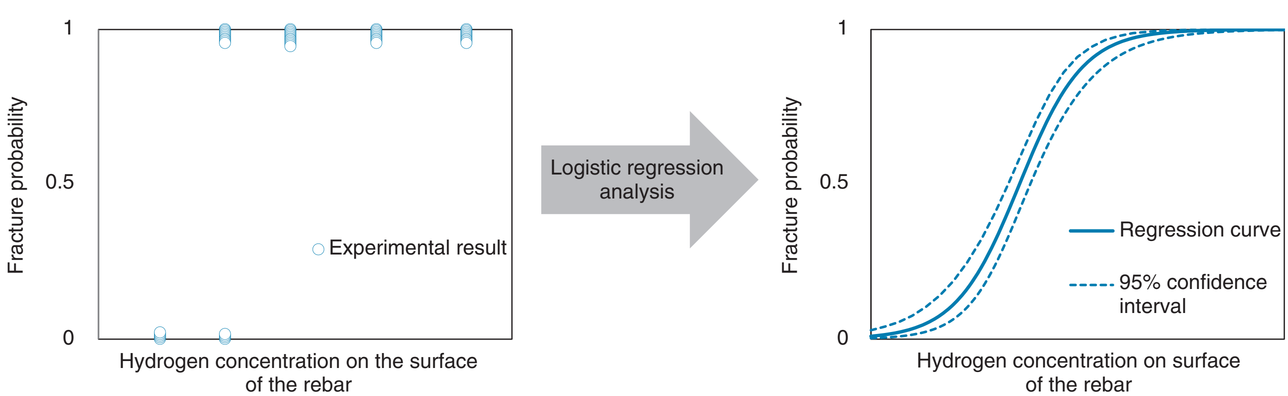


Fig. 4. Experimental results of fracture occurrence or non-occurrence from accelerated-hydrogen-embrittlement test and estimated fracture probability.

and the parameters of the logistic function are estimated using the maximum-likelihood method.

We conducted the accelerated-hydrogen-embrittlement test under variable tensile stress, hydrogen concentration on the surface of a rebar, and temperature and estimated the fracture probability from the acquired data on occurrence or non-occurrence of fracture. The relationship between hydrogen concentration on the surface of a rebar and fracture probability when tensile stress and temperature were fixed is shown in **Fig. 4**. In this analysis, the case in which the rebar fractures during the accelerated-hydrogen-embrittlement test is defined as “1” and that in which it does not fracture is defined as “0,” and the regression curve of fracture probability and the 95%-confidence intervals are estimated from logistic regression analysis. Therefore, the relationship between hydrogen concentration on a rebar surface and future fracture probability can be estimated from the fracture occurrence or non-occurrence data obtained from the accelerated-hydrogen-embrittlement test.

4. Future developments

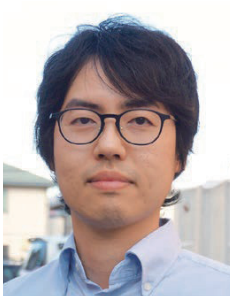
By extrapolating the relationship between hydrogen concentration, time to fracture, and fracture probability obtained from the accelerated-hydrogen-embrittlement test to include the hydrogen concentration in an actual environment, it will be possible to predict the time to fracture and fracture probability of rebars in concrete poles. The estimated surface-hydrogen concentration of rebars in a standard real environment will be used for extrapolation, and by constructing a new measurement system for detecting hydrogen that has entered a rebar, we plan to acquire the surface-hydrogen-concentration data for rebars that are required for estimation. To verify the prediction results, we also plan to continue research—in collaboration with universities—on modeling the hydrogen-embrittlement mechanism from the viewpoint of materials science.

References

[1] S. Matsuyama, "Delayed Fracture," pp. 45–48, The Nikkan Kogyo Shimbun, Tokyo, 1989.

[2] T. Shiraga and S. Mizoguchi, "Present State of Steel Bars for Prestressed Concrete as Civil Engineering and Construction Materials," Bulletin of the Iron and Steel Institute of Japan, Vol. 13, No. 9, pp. 611–615, 2008.

[3] M. Elices, A. Valiente, L. Caballero, M. Iordachescu, J. Fullea, J. Sanchez-Montero, and V. López-Serrano, "Failure Analysis of Prestressed Anchor Bars," Engineering Failure Analysis, Vol. 24, pp. 57–66, 2012.



Takuya Kamisho

Research Engineer, Advanced Infrastructure Maintenance Technology Research Group, NTT Device Technology Laboratories.

He received a B.S. and M.S. in meteorology from Hokkaido University in 2008 and 2010. He joined NTT Environment and Energy Research Laboratories in 2010. He has been with NTT Device Technology Laboratories since 2018, where he is currently working on developing prediction technology for hydrogen embrittlement.

Ryuta Ishii

Researcher, Advanced Infrastructure Maintenance Technology Research Group, NTT Device Technology Laboratories.

He received a B.S. and M.S. in condensed matter physics from Osaka University in 2012 and 2018. He joined NTT Device Technology Laboratories in 2018, where he is currently working on developing prediction technology for hydrogen embrittlement.

Masayuki Tsuda

Senior Research Engineer, Supervisor, and Group Leader, Advanced Infrastructure Maintenance Technology Research Group, NTT Device Technology Laboratories.

He received an M.E. and Ph.D. in mechanical engineering from Tokyo Institute of Technology in 1998 and 2005. He joined NTT Integrated Information and Energy Systems Laboratories in 1998, where he developed materials for lithium-ion batteries and environmental impact assessment of information and communication technology services. From 2013 to 2018, he worked at the NTT Environment Promotion Office. He was transferred to NTT Device Technology Laboratories in 2018, where he is currently working on developing technology to visualize infrastructure deterioration.

Security R&D Initiatives for Creating a Safe and Secure Society

Shinichi Hirata

Abstract

To talk about the future vision of security research and development (R&D) that NTT is working on, it is important to think not only about the problems in front of us but also about the future of society and security. This article introduces security R&D initiatives for the future.

Keywords: security, cyber attacks, data utilization

1. Introduction

The novel coronavirus has had varying impact on our society and lives. Various events, including the Olympic and Paralympic Games, were postponed due to the transition of social activities and lifestyles premised on the securing of social distance.

As the impact of the coronavirus has spread worldwide and the situation is expected to continue for a long time, the world's transformation (adoption of a new way of life and reconstrucion of social order in a post-coronavirus world) is being accelerated; accordingly, various efforts towards digitization and enhancement of connectivity to the Internet are rapidly advancing. The supply chain, which was based on conventional social activities, has become dysfunctional, and major changes are occurring not only at the individual level but also at the social-framework level.

Security and privacy concerns are spreading, and the damage caused by cyber attacks aimed at telework/telecommuniting, which is increasing rapidly, and attacks that take advantage of people's anxiety are becoming increasingly serious. Sufficient consideration must also be given to privacy in monitoring and behavior tracking to identify infected persons and those suspected of being infected for preventing the spread of coronavirus infection.

In the supply chain, wide-area attacks taking advantage of the rapid digitization and enhancemnet of connectivity are intensifying, and reconstruction of secure supply chains is necessary.

NTT is conducting research and development (R&D) on security to contribute to a safe and secure society. As the world changes drastically, it is important to think about the future of society and security to engage in security R&D looking ahead not only to the problems that are occurring in front of us but also to the future.

To create a safe and secure society, we will consider future visions, specifically the Smart World [1] 10 years from now, through changes in the social environment and development of technologies surrounding information and communication technology.

2. What will be the Smart World 10 years from now?

The society in which innovative technologies, such as artificial intelligence (AI), Internet of Things, robots, and big data, have penetrated is the fifth new society (Society 5.0 [2]) in the history of social development, following the development into an industrialized society due to the industrial revolution and into an information society due to the development of computer technology, and is expected to be a future ideal way (Smart World) to enrich lives.

In the Smart World, where cyberspace (virtual space) and the physical space (real space) are highly integrated by various innovative technologies, an enormous amount of data, such as sensor information

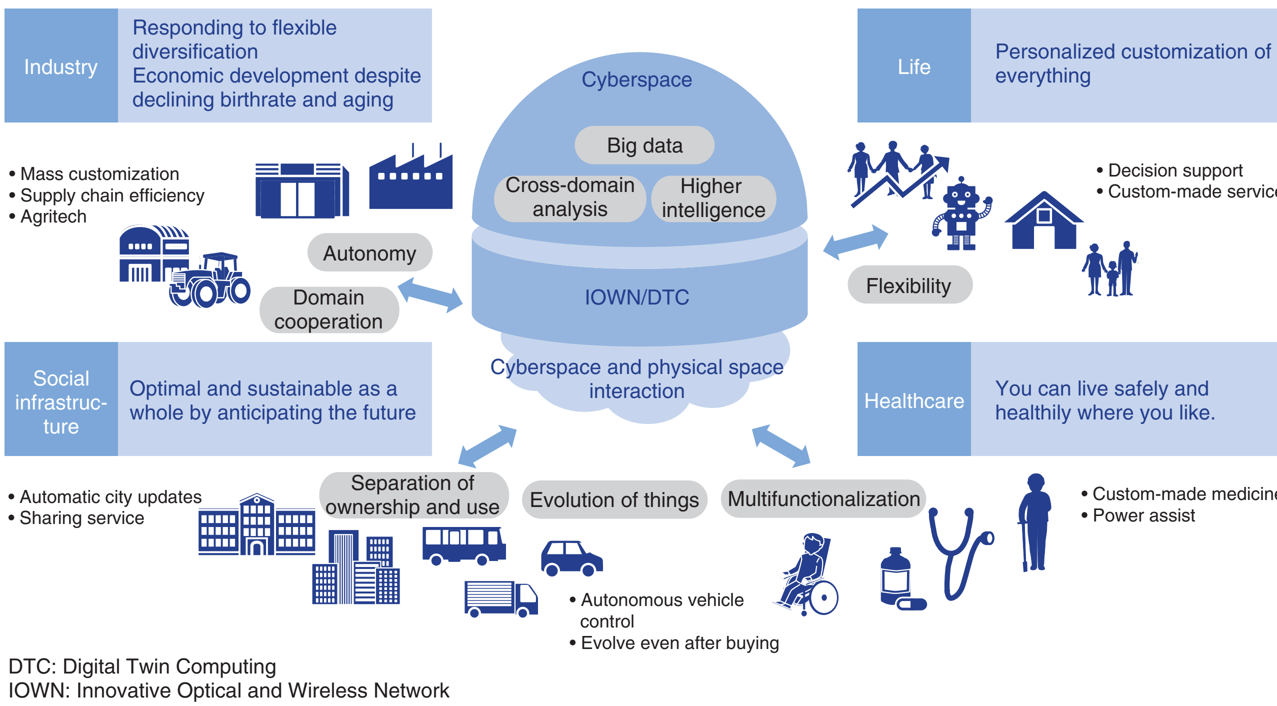


Fig. 1. The Smart World 10 years from now.

accumulated from physical space, is used for data analysis and prediction in highly intelligent cyberspace and fed back autonomously to the physical space. As a result, both the optimization of individual users and that of society as a whole will progress in various services and social infrastructures, and a society in which everyone can live safely and independently (a true Smart World) will be possible.

For example, when it comes to personal life and living, people will be able to enjoy ultimate customized services tailored to their individual circumstances. In terms of social infrastructures, AI predictions will enable us to take proactive measures to optimize the entire society and provide sustainable services. In terms of economy and industry, it will be possible to flexibly respond to diversification and develop the economy even in a society with a declining birthrate and aging population (**Fig. 1**).

There is also concern that the exposure to cyber attacks and the extent of such damage will intensify due to the increase in higher intelligence, autonomy, flexibility, and domain cooperation of technologies and infrastructures that support such an ideal world (**Fig. 2**). When analyzing or using huge amounts of data, privacy may not be sufficiently considered, unethical use may occur, or information may be unintentionally leaked.

The threat of malicious tampering with data-analysis algorithms is also becoming more real. In the past, it was difficult to tamper with a program that was created in accordance with a pre-designed algorithm without directly modifying or replacing it. However, in a situation in which AI has become widespread, there are risks of attacks that do not involve direct tampering, such as causing malfunctions in AI learning and AI decisions. Specifically, we can think of new attacks, such as an attack in which an attacker makes an intended decision by mixing illegal values into data learned by AI or an incorrect decision by crafting data recognized by AI or a new attack in which data that could violate privacy are illegally obtained by inferring data learned from AI operations.

Alteration of the algorithm can not only result in the intentional leakage of data but can also change the analysis results to malicious ones. Malicious analysis results are fed back into the physical space, which has a significant impact on various services and social infrastructures.

To achieve a true Smart World, it is necessary to consider that a new threat will be created by the advanced fusion of cyberspace and the physical space

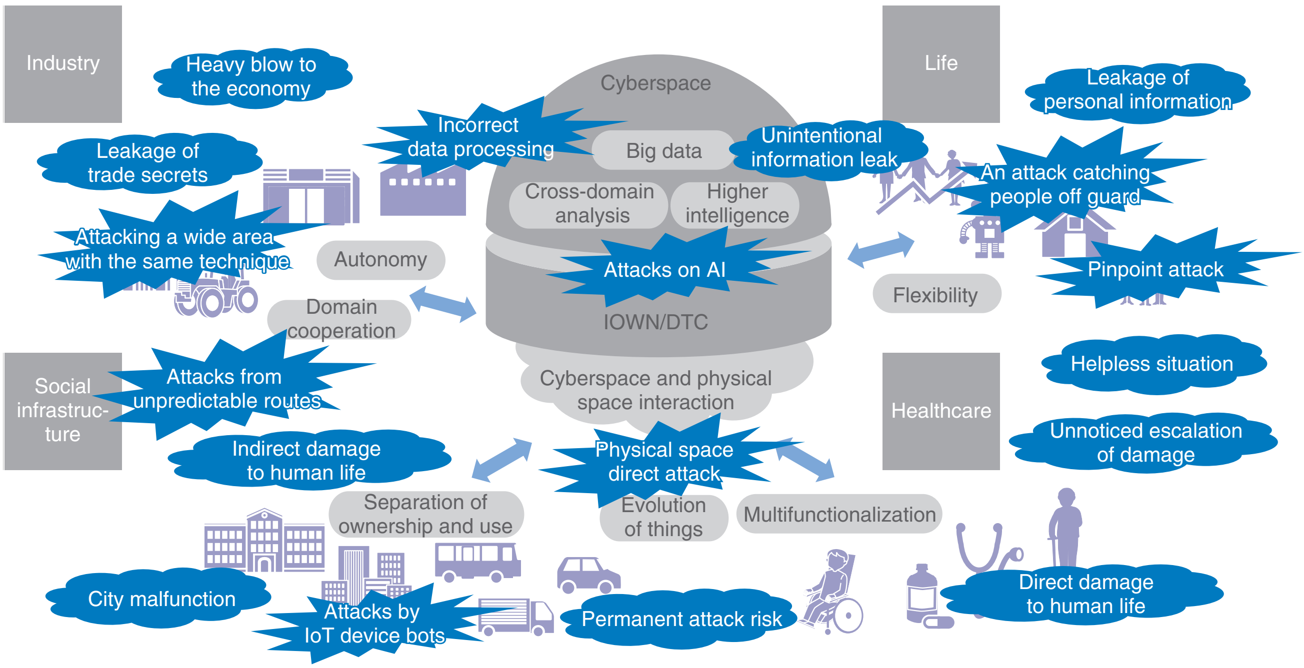


Fig. 2. Security threats in Smart World 10 years from now.

and focus on security R&D that can simultaneously improve convenience while resisting attacks that grow in size and sophistication.

3. Approach to security R&D from a long-term perspective

Security risk depends on the threat of an attack (in a broad sense involving people and society), vulnerability of the system, and size of the assets that must be protected (including not only information and money but also human life). As cyber attacks grow in size and sophistication and we become more exposed to various threats due to the advanced fusion of cyberspace and the physical space, security risks will increase dramatically.

There is a limit to how much a company can spend on security measures because it is expensive to strengthen security measures. It is difficult to implement countermeasures against all threats only by extending or simply enhancing existing security measures. Therefore, it is necessary to drastically improve defense and countermeasures against cyber attacks.

Security R&D from a long-term perspective must (1) focus on technologies that respond to new threats and protect the environment to support the creation of value in the Smart World; and (2) create technologies that change the situation in which attackers dominate, such as technologies that reduce the vulnerability risk to zero and that predict and proactively respond to attacks.

The NTT Group will strengthen its response systems to major sporting and cultural events, and the development of new fields (urban development, energy, and healthcare) on the basis of its medium-term management strategy will require the safe use of data and the security necessary to implement the Innovative Optical and Wireless Network (IOWN). Therefore, the following points will be important in security R&D (**Fig. 3**).

(1) Development and deployment of data distribution and utilization technologies that secure the value-creation process

Develop technology for flexible and safe sharing and analysis of data and capable of using data across fields to solve problems of data encirclement, privacy infringement, and illegal use of data [3].

(2) Development of technologies to solve operational-cost problems and minimize damage

Develop technology to autonomously and automatically respond to cyber attacks while responding to new threats so that humans will be able to focus on confirming responses and responding to new threats that require creativity, thereby strengthening their

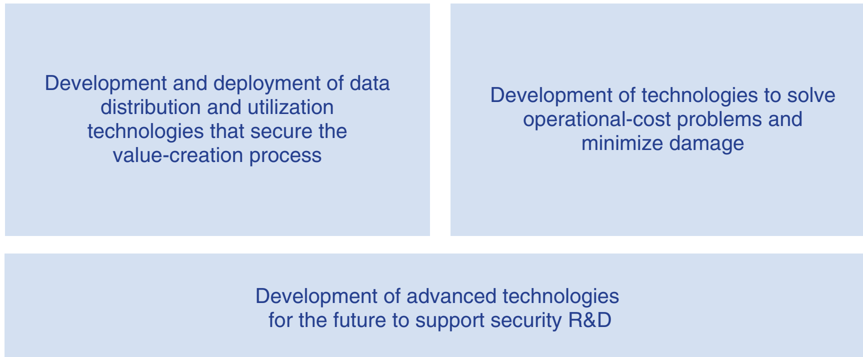


Fig. 3. Viewpoints required for security R&D.

comprehensive response capabilities [4].

(3) Development of advanced technologies for the future to support security R&D

As a security Center of Excellence, develop basic technologies for the future such as cryptography and information theory and quantum information security technology [5].

To sustain the safe and secure communication demanded by the NTT Group into the future, we will engage in R&D to meet the medium- and long-term objectives of safe data distribution and utilization and minimize damage including cutting-edge technologies for the future and those that make use of IOWN.

References

[1] NTT Technology Report for the Smart World, https://www.rd.ntt/e/techreport/

[2] Cabinet Office, Government of Japan, “Society 5.0,” https://www8.cao.go.jp/cstp/english/society5_0/index.html

[3] T. Washio, Y. Orime, T. Morita, K. Chida, K. Morimura, and Y. Oshima, “Data Sharing and Utilization Technologies for Safe and Secure Value-creation Processes,” NTT Technical Review, Vol. 19, No. 6, pp. 75–80, June 2021. https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202106fa12.html

[4] Y. Koga, Y. Nakajima, N. Chiba, J. Miyoshi, T. Koyama, H. Shito, and A. Miyajima, “Establishment and Development of Cybersecurity Technologies to Solve Problem of Increasing Operation Costs and to Minimize Damage,” NTT Technical Review, Vol. 19, No. 6, pp. 81–87, June 2021. https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202106fa13.html

[5] Y. Tokunaga, Y. Suzuki, S. Endo, R. Nishimaki, F. Kitagawa, and S. Tamechika, “Security Based on Quantum Information Technology and Data Protection of Quantum Information,” NTT Technical Review, Vol. 19, No. 6, pp. 88–93, June 2021. https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202106fa14.html

Shinichi Hirata

Vice President, Head of NTT Secure Platform Laboratories.

He received a B.S. from Hokkaido University in 1990 and joined NTT in the same year. He has been engaged in R&D of cryptography, smart card technology, and authentication systems.

Data Sharing and Utilization Technologies for Safe and Secure Value-creation Processes

Tomoaki Washio, Yoshinori Orime, Tetsushi Morita, Koji Chida, Kazuo Morimura, and Yoshihito Oshima

Abstract

To achieve Society 5.0, a vision of a future society that achieves both economic development and resolution of social issues, it is essential to use data across organizations and industries, but this is not as widespread as it should be. This article outlines the risks associated with data utilization and their causes and introduces a new paradigm of data sharing and the platform and key technologies to achieve it.

Keywords: data sharing, security, trust

1. Society 5.0 and cross-domain data sharing

The Japanese government proposed "Society 5.0," as a vision of the future society that achieves both economic development and resolution of social issues [1], and efforts to achieve it are actively being made. In Society 5.0, cyberspace and the physical space will be highly integrated, and by making full use of various data, it will become possible to understand the situation at that time, discover issues, predict the future, and derive optimal solutions, which will lead to economic development and solve social problems. In other words, the success of Society 5.0 depends on how much data across organizations and industries (i.e., cross-domain data sharing) can be used.

2. Barriers to cross-domain data sharing and its causes

However, cross-domain data sharing, especially the sharing of sensitive and rare data, has not progressed as much as expected. The largest barrier is the risk to both the data provider and data user.

Data providers take the risk that the data they provide may be leaked or used in an unexpected way, causing damage to themselves or others. Data users, on the other hand, take the risks associated with confidentiality management of the data provided and the risks associated with the legality of such data.

From another perspective, data users take the risk that the data they receive will not produce the desired results or value or may not meet the conditions imposed for receiving the data (for example, the payment for receiving the data). Data providers take the risk that the data they provide will create more value than expected (i.e, the payment they receive is undervalued) or may not fulfill the purpose of providing data for the data provider (for example, not receiving the obtained results from data utilization) when the expected results are not obtained.

The root cause of the above risks is that traditional methods of data sharing involve passing on or receiving the data. Data can create different values and problems depending on how the data are used; therefore, it is difficult to determine all values and problems beforehand. With all this uncertainty, cross-domain data sharing cannot be actively carried out.

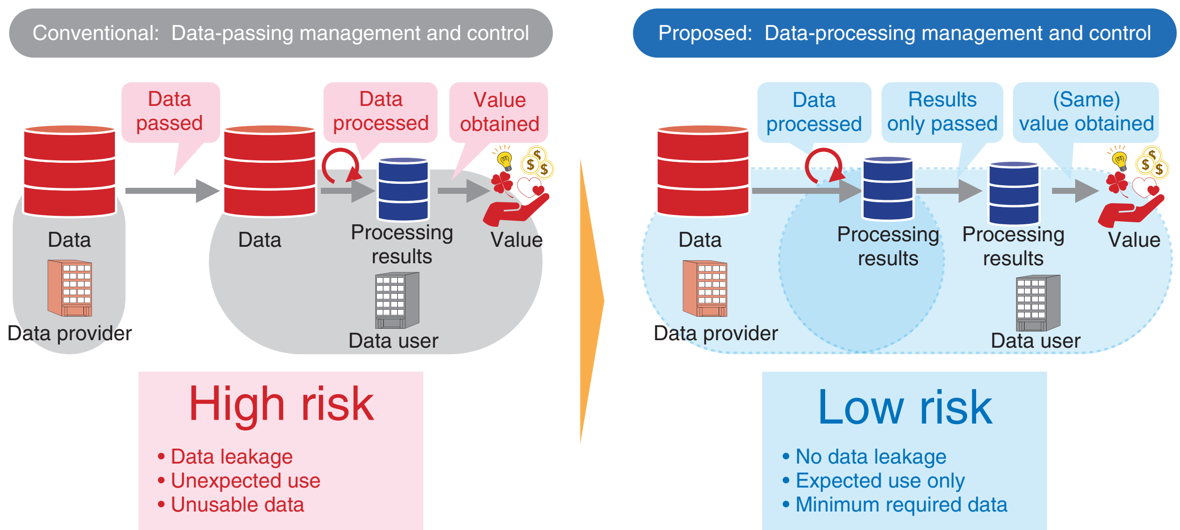


Fig. 1. Paradigm shift in data-sharing methods.

3. Toward a new paradigm of data-processing management and control

To solve this problem, it is necessary to shift from the conventional to a new paradigm of data-processing management and control. In this new paradigm, on the basis of the principle of data minimization, data users are only given the results of agreed processing (the processing data users request and the processing data providers approve) of the data, not the original data. By doing this, the value and problems that can arise from the use of those data are limited and predictable, and the risks mentioned above are greatly reduced (**Fig. 1**).

4. Overview of cross-domain data-sharing platform

Our goal is to create a trustworthy[*1] *cross-domain data-sharing platform* based on the above new paradigm so that all data providers and data users participating in the platform can share and use all data with confidence. The platform's three main requirements are (1) to be able to execute the necessary processing for the purpose while protecting the data, (2) to be able to control the processing of the data in accordance with the agreements and laws between the data provider and data user, and (3) to be transparent and accountable about the data handled and their processing (**Table 1**).

We believe the platform should consist of the following three mechanisms (**Fig. 2**):

(1) Data protection and utilization mechanism

- Executes various processes such as analysis or transformation required by the data user on the data while keeping the data (containing derived data[*2]) confidential.
- Ensures that only the processing permitted by the data-processing-authorization mechanism is executed as permitted and proves the facts of data processing, processing history for certain data, and origin of the derived data.

(2) Data-processing-authorization mechanism

- When a request for data processing is made to the data protection and utilization mechanism, it is determined whether to accept the request on the basis of the data usage policy[*3] specified by the data provider, agreement between the data provider and data user, and legality of the request.
- Prior to determining the above, the data provider,

*1 Trustworthy (platform): To earn the trust of data providers and data users, the platform should be able to demonstrate that it is doing exactly what data providers and data users expect it to do.

*2 Derived data: The result of processing data entrusted to the platform by the data provider. Includes the results of processing derived data.

*3 Data usage policy: The policy specifies what kind of data usage shall be permitted. The target of authorization is specified using the attributes of the target data and the requesting entity, how to use the data (method for processing), etc. Permitted/prohibited, or conditions to be satisfied to permit, are also specified to each target.

Table 1. Key requirements for cross-domain data-sharing platform.

Classification	Key requirements
Protect data storage and processing	Executes various analysis, transformation and other processing requested by data users while keeping the confidentiality and integrity of data at a high level.
	Also handles the results of data processing (derived data) as described above.
	Restricts platform operators from viewing or modifying data or derived data.
Managing and controlling data processing	Executes only data processing agreed between the data provider and data user.
	Depending on the target data, executes only processes that conform to laws (Personal Information Protection Law, etc.)
	Authorizes after confirming the propriety of data providers, data users, and target data involved in the requested data processing accurately and in detail.
Ensure transparency of data processing	Enables data users to confirm the characteristics and origin of data and derived data.
	Enables data providers and data users to confirm the fact and history of processing performed on data and derived data.
	Enables data providers and data users to confirm the operation of platforms regarding data storage and processing.

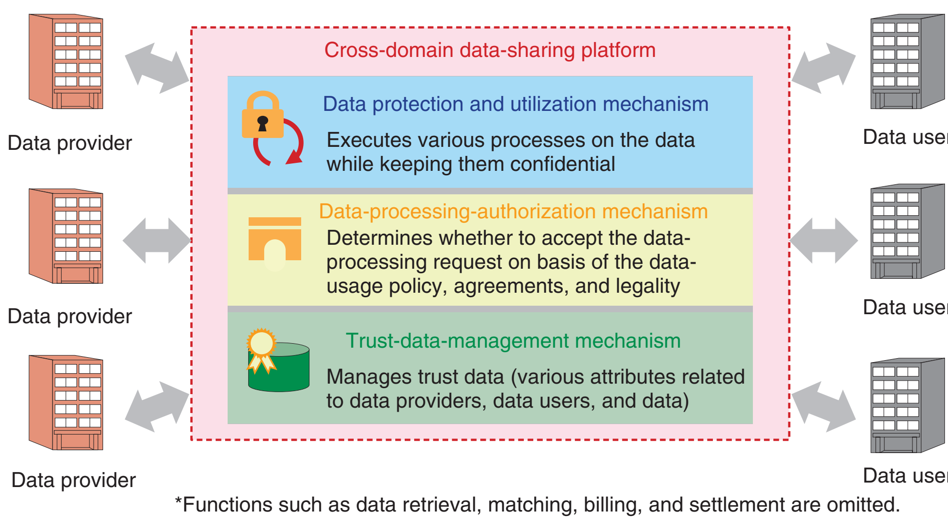


Fig. 2. Cross-domain data-sharing platform architecture.

data user, and target data are confirmed on the basis of accurate and detailed information on them from the trust-data-management mechanisms.

(3) Trust-data-management mechanism

- Manages various attributes related to data providers, data users, and target data (i.e., trust data) and provides them to the data-processing-authorization mechanism and those who need them.
- Manages information that proves the fact and history of data processing by the data protection and utilization mechanism and the origin of derived data as trust data as well and provides those trust data to those who need them.

5. Key technologies for cross-domain data sharing

The following is an overview of the key technologies for implementing the above mechanisms.

5.1 Secure computation

Secure computation is a technology that enables computation while keeping data encrypted. This enables secure use of sensitive data such as personal data or corporate trade secrets. It also should enable the analysis of such data to extract new value by increasing the types and amounts of data to be analyzed. In secure computation technology, not only safety but also performance and diversity of processing are important. NTT Secure Platform Laboratories developed a secure computation system with the world's fastest statistical processing [2]. We are currently developing secure computation artificial intelligence (AI) technology for executing learning and prediction processing in deep learning while keeping the input data and neural networks encrypted [3]. We are also working on increasing the speed of processing and expansion of the AI algorithms needed to process large amounts of data such as high-definition images.

5.2 Enhancing confidentiality and authenticity when data processing

Because cross-domain data sharing processes data in a variety of stakeholder computing environments, it is not easy to ensure data access control (ensuring confidentiality) or the authenticity of data-processing results. However, as mentioned above, cross-domain data-sharing platforms must meet these requirements to be trusted and widely used. Specifically, we believe the following two requirements are particularly important: (1) the data provider can check whether the provided data are being used only within the permitted operations and (2) the data user can check whether the data-processing results are correct as requested.

5.3 Attribute-based authorization

Because large amounts of data are registered continuously on the platform and it is not known in advance who is going to use the registered data, attribute-based authorization is effective for cross-domain data sharing. Regarding attribute-based authorization, data-usage policies are defined in the form of conditions for what kind of subject can use what kind of data using the attributes of the subject and data. When authorization decisions are made, the attribute values of the data users and target data are applied to the conditions and evaluated. For example, a data user's qualification (e.g., Information Security Management Systems Certification) is specified as a required attribute in the data-usage policy.

Attribute-based authorization is not a new concept, but there are technical challenges when applying it to cross-domain data sharing. To make authorization decisions that take legality into account, it is necessary to check and determine the existence or value of specified attributes in accordance with the characteristics of the data, regardless of the data-usage policy, as described later. To avoid making an incorrect authorization decision, it is necessary to strictly determine the existence of the attribute specified in the data-usage policy and its authenticity (whether it has been certified by a third-party organization, etc.). It is also necessary to have flexibility in authorization decisions, such as conditionally allowing data usage in addition to permitting or prohibiting it. For example, the requested data may not be used as is but may be used after being anonymized. We believe that making flexible authorization decisions while coordinating the requirements of both data providers and data users will contribute to expanding data-sharing opportunities (**Fig. 3**).

5.4 Trust-data management

The trust-data-management mechanism collects and manages attributes of platform users (qualifications, achievements, reputation, etc.) and attributes of data processed on the platform (data characteristics such as type, items, collection method, origin, and processing history). It then provides them to the data-processing-authorization mechanism, data providers, and data users as "trust data" that can be relied on when users and data are confirmed (**Fig. 4**).

Because trust data are the basis of trust, it is necessary to be able to verify that such data have been guaranteed by various entities regarding the data's authenticity and correctness. However, trust data may be confidential; thus, it is necessary to appropriately determine when, to whom, and to what extent to disclose trust data. It is also required for the data to be available whenever needed. We will develop trust-data-management technologies and mechanisms that meet these various requirements.

5.5 Implementing legal requirements for trust data and authorization decisions

Data providers and data users must also consider the legality of the data they share. It is difficult for data users to understand how the data were obtained and might not notice that illegally obtained data were included. The Act on the Protection of Personal Information prohibits the use of data that constitute personal information outside the scope of the purpose of use indicated to the person at the time of acquisition and the provision of such data to third parties without the person's consent.

To reduce the burden of legal compliance, we are studying a method of assigning attribute data that

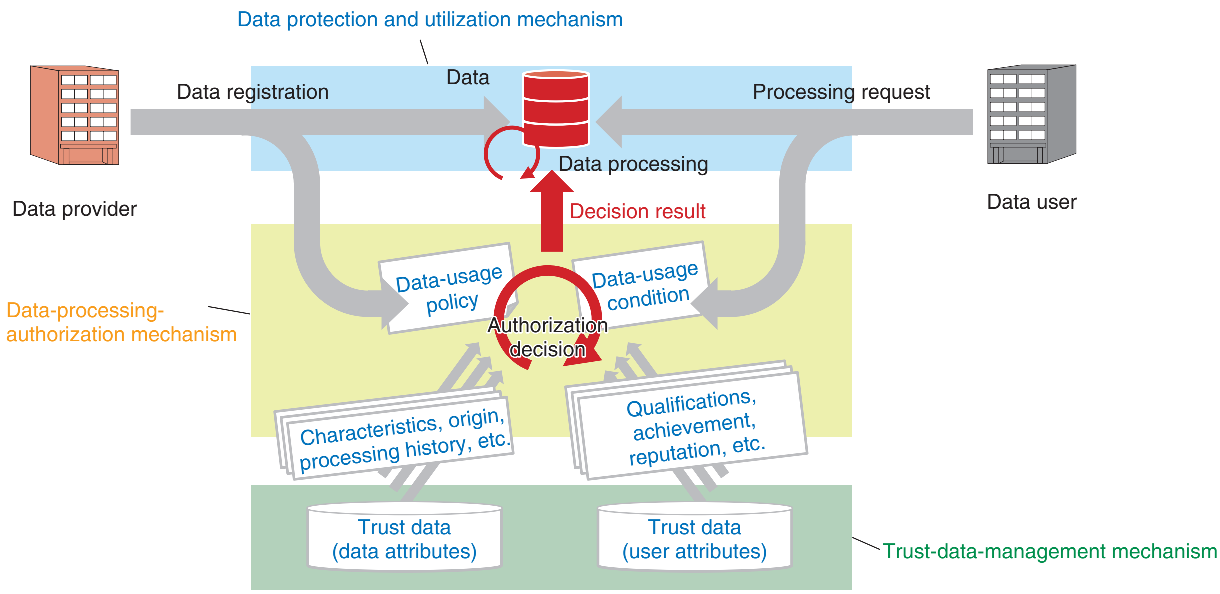


Fig. 3. Attribute-based authorization.

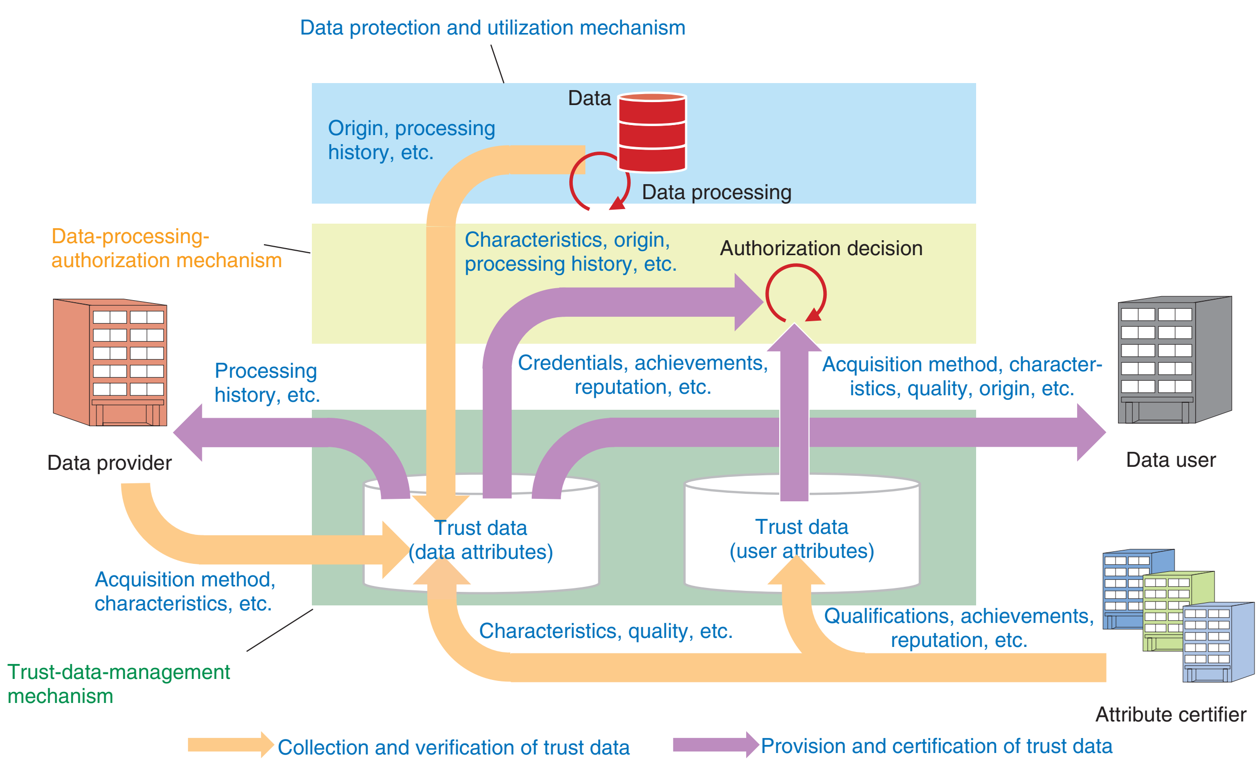


Fig. 4. Flow of trust data.

implements legal requirements together with data, managing the data as trust data, and checking the data when making authorization decisions.

6. For the future

We believe that a trustworthy cross-domain data-sharing platform will accelerate collaboration and co-creation among the same or different industries, which were previously difficult, and enable the creation of new value and resolution of major social issues such as those regarding food, health, and the environment.

To achieve this, we will accelerate not only research and development of key technologies but also proof of concept in cooperation with partners aiming at cross-domain data sharing, international standardization, and activities to foster social acceptability.

References

[1] Cabinet Office, Government of Japan, "Society 5.0," https://www8.cao.go.jp/cstp/english/society5_0/index.html

[2] NTT press release, "Trial Service of Secure Computation System San-Shi®," Aug. 8, 2018. https://www.ntt.co.jp/news2018/1808e/180808a.html

[3] NTT press release "Secure Computation for a Typical Training Algorithm of a Deep Neural Network," Sept. 2, 2019. https://www.ntt.co.jp/news2019/1909e/190902a.html

Tomoaki Washio

Senior Research Engineer, NTT Secure Platform Laboratories.

He received a B.E. and M.E. in systems and information engineering from Hokkaido University in 2000 and 2002. Since joining NTT in 2002, he has been engaged in research and development (R&D) of authentication systems and secure data-sharing technologies.

Koji Chida

Senior Research Engineer, Supervisor, NTT Secure Platform Laboratories.

He received a B.S. and M.S., and Dr.Eng. from Waseda University, Tokyo, in 1998, 2000, and 2006. Since 2000, he has been engaged in research on cryptography and privacy-enhancing technologies at NTT. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) and Information Processing Society of Japan (IPSJ). He received the IPSJ Best Paper Award in 2012.

Yoshinori Orime

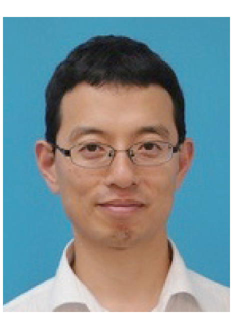
Senior Research Engineer, NTT Secure Platform Laboratories.

He received a B.E. in computer science from Saitama University in 1998 and joined NTT the same year. Since 2020, he has been engaged in research on incorporating legal and social requirements into technical requirements.

Kazuo Morimura

Senior Research Engineer, Supervisor, NTT Secure Platform Laboratories.

He received a B.A. from Aichi University of Education in 1993 and M.E. from Nara Institute of Science and Technology in 1996. He joined NTT in 1996 and is currently conducting R&D on data protection technologies centered on cryptography.



Tetsushi Morita

Senior Research Engineer, Supervisor, NTT Secure Platform Laboratories.

He received a B.E. and M.E. from Kyoto University in 1996 and 1998 and a Ph.D. in engineering from University of Tsukuba, Ibaraki, in 2010. Since joining NTT Software Laboratories in 1998, until 2012, he was engaged in research on information retrieval and personalization systems. His current research interests include secure data-sharing technologies.

Yoshihito Oshima

Executive Research Engineer, Supervisor, NTT Secure Platform Laboratories.

He received a B.E. and M.E. in electrical engineering from Hokkaido University in 1994 and 1996. He joined NTT in 1996 and is currently conducting R&D on secure data-sharing technologies. He is a member of IPSJ.

Establishment and Development of Cybersecurity Technologies to Solve Problem of Increasing Operation Costs and to Minimize Damage

Yuzo Koga, Yoshiaki Nakajima, Naoko Chiba, Jun Miyoshi, Takaaki Koyama, Hidehiro Shito, and Asami Miyajima

Abstract

While responding to new cybersecurity threats such as cyber attacks, we will radically improve the efficiency of security operations by developing technologies for autonomous and automated security measures. Such technologies will enable operators to concentrate on countermeasures against advanced threats that cannot be handled mechanically and enhance overall security-response capabilities.

Keywords: cybersecurity, security operation, security measures

1. Background

Cyber attacks are increasing yearly and becoming more complicated and sophisticated. In particular, there has been a significant increase in cyber attacks that directly target humans, which has dramatically increased the cost of cybersecurity measures for enterprises.

When users have diverse requirements and enterprises need to cope with long tail customers, a variety of applications should be provided through a combination of servers and software on ultrahigh-speed optical communication networks connecting various communication equipment, terminals, and devices. In such a situation, the efficiency of security measures to handle each cyber attack is too low, which can be a factor hindering the digital transformation and business-value creation of enterprises.

2. Goal of our research and development

We are conducting research and development (R&D) on technologies for automatically and proactively implementing security measures against cyber attacks and various vulnerabilities that are targets of them.

Through such technologies, we will provide an information and communication technology (ICT) environment capable of preventing damage caused by cyber attacks and resolving the shortage of human resources in security operations that restrict enterprise management, enabling users to use services with peace of mind. This environment eliminates the need for enterprises to respond to security vulnerabilities each time (whack-a-mole game), after an incident (cat-and-mouse game), or respond to business loss due to damage (**Fig. 1**).

By reducing the total cost of security operations, we will enable enterprises to focus on development and operations and support them in creating business values in short cycles in a Smart World of smart factories, buildings, mobility, etc. (**Fig. 2**).

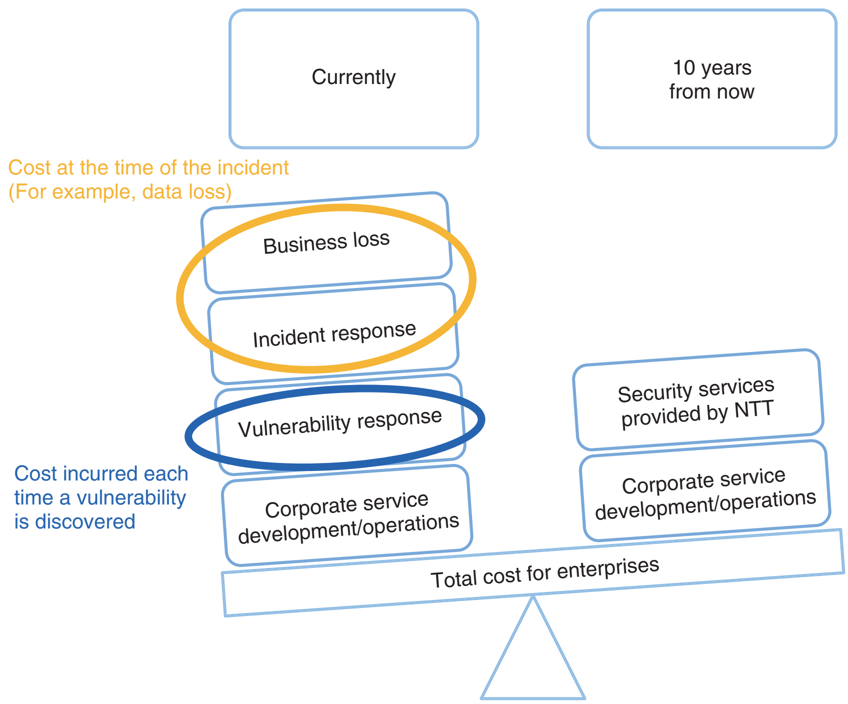


Fig. 1. Total cost reduction of security operations.

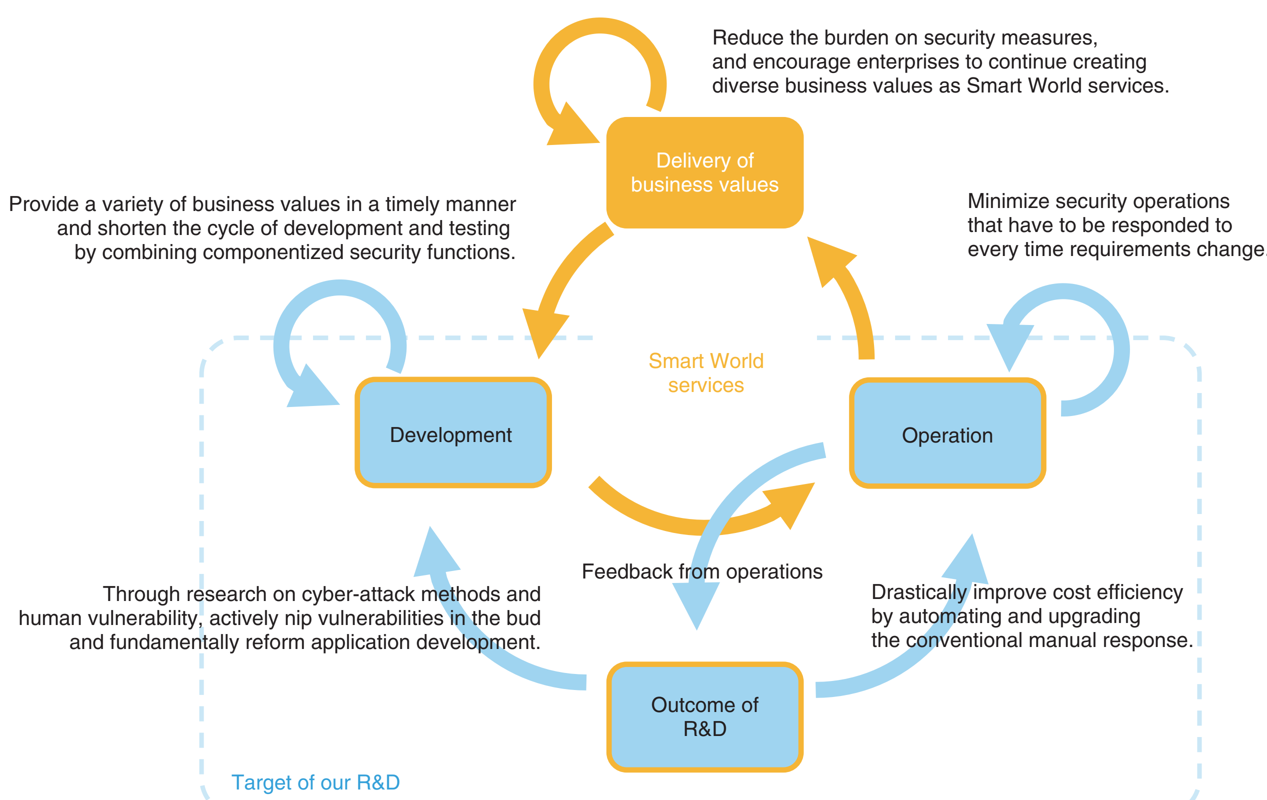


Fig. 2. Purpose of our R&D.

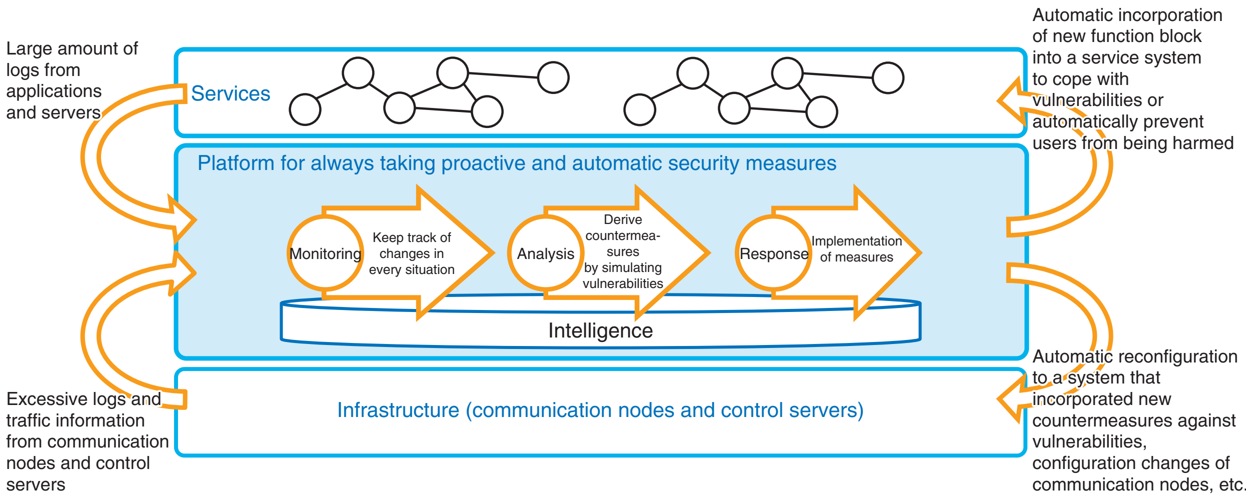


Fig. 3. Platform as a result of our R&D.

3. Platform as a result of our R&D

In security operations, many security measures, such as monitoring, analysis, and response, are implemented manually, so the ability to carry them out depends heavily on human skills.

By implmenting a platform with our technologies, we will constantly monitor the status of devices and applications that make up infrastructure and services and automatically execute security measures on systems in advance as soon as a vulnerable situation is found. The platform provides an environment to conduct stable, effective, and efficient security measures (**Fig. 3**).

4. Challenges in implementing the platform

To automatically and proactively implement security measures, we will conduct R&D on the following three technologies (**Fig. 4**) and create intelligence, as shown in **Fig. 5**.

(1) Technologies for actively visualizing and minimizing vulnerabilities, and implementing automatic correction cycles

To provide robust security, we will conduct R&D on visualizing and minimizing vulnerabilities, and also on implementing automatic correction cycles to enable shift-left security measures that can nip vulnerabilities in the bud and drastically improve efficiency of security operations.

(2) Technologies for generating and using intelligence that follows environmental changes

Security measures are continuously and autonomously implemented in a wide variety of ICT environments through technologies for automatically generating intelligence unique to telecommunication carriers and automatically using intelligence that does not require awareness.

(3) Technologies for countering human-induced risks

We will conduct R&D on security technologies that can respond to risks arising from humans and drastically reduce risks related to human errors, fraudulent attacks targeting humans, internal fraud by employees, etc., which can lead to security damage.

In the following section, we introduce our major R&D efforts.

5. Current activities

(1) Configuration and status analysis technology (**Fig. 6**)

We are currently conducting R&D on software agents and communication-analysis engines that analyze the configuration and status of Internet of Things devices for people and things as a security technology to protect complex cyber-physical systems composed of various elements such as smart cities. We will conduct R&D on crossing-analysis technology for multiple domains to detect signs of security anomalies and estimate probable causes and measures, which have been difficult in the past, by analyzing the correlation between elements across systems and services in addition to configuration and status.

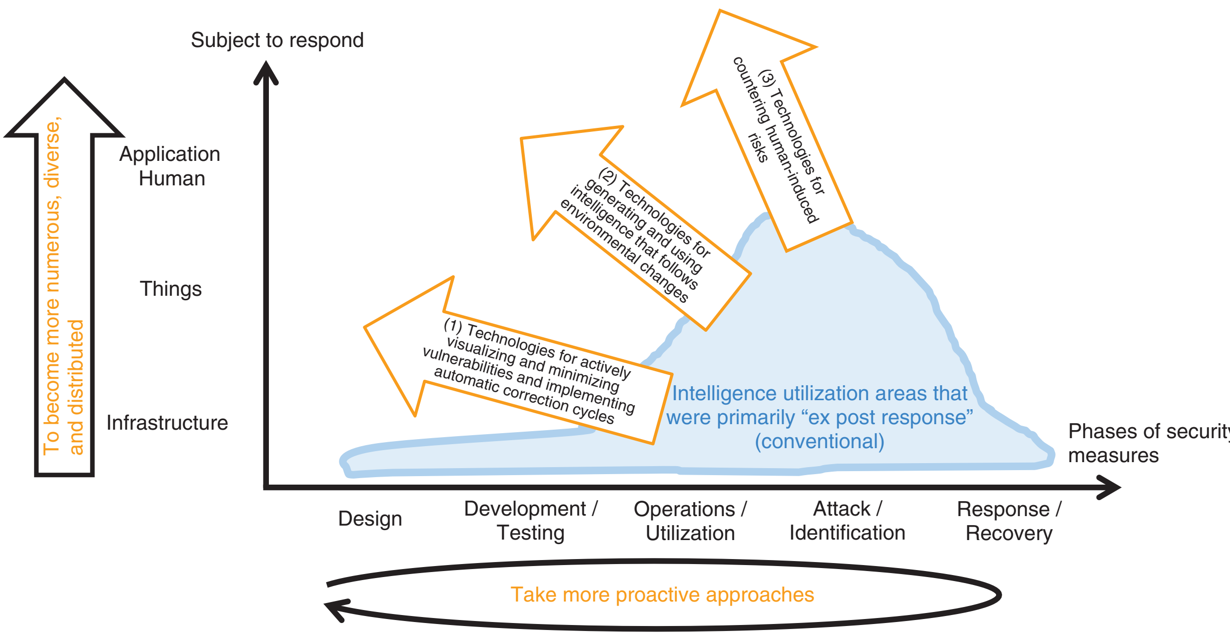


Fig. 4. Three technical issues.

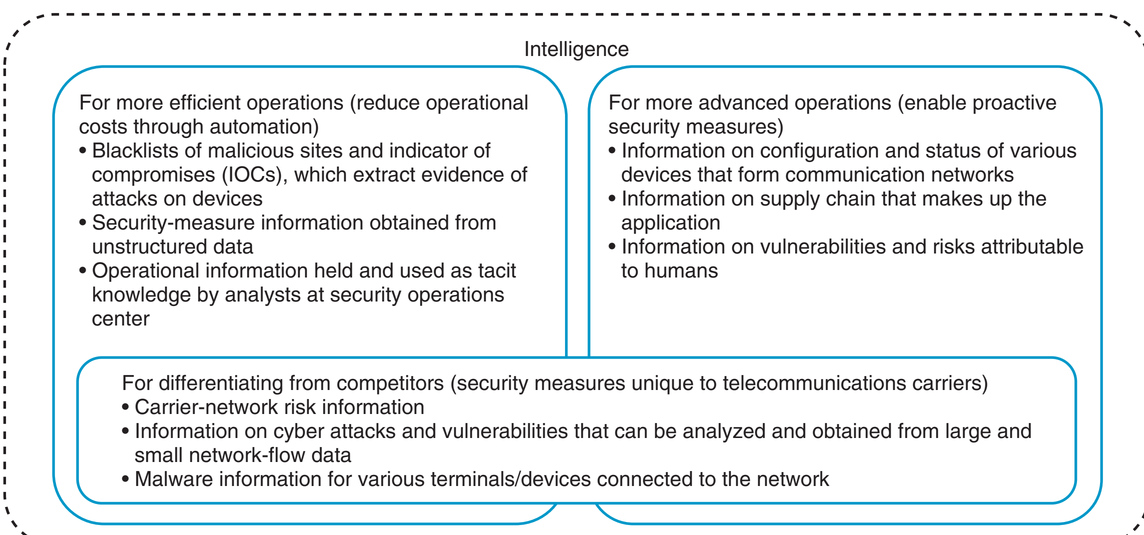


Fig. 5. Intelligence created from our R&D.

(2) Initial-forensic-investigation technology (**Fig. 7**)

In cyber forensic investigation, a terminal that is suspected of being attacked is preserved, and a security analyst extracts evidence of an attack. While detailed analysis is possible from investigation by humans, it depends on the analyst’s experience and can take several days. In the initial investigation phase, therefore, its accuracy and speed remain issues for early clarification of the entire damage. Therefore, we are developing a technology for preserving only important logs and automatically extracting traces of attacks. The goal with this technology is to create an intelligence database of attack procedures that are often used by attackers and processing them

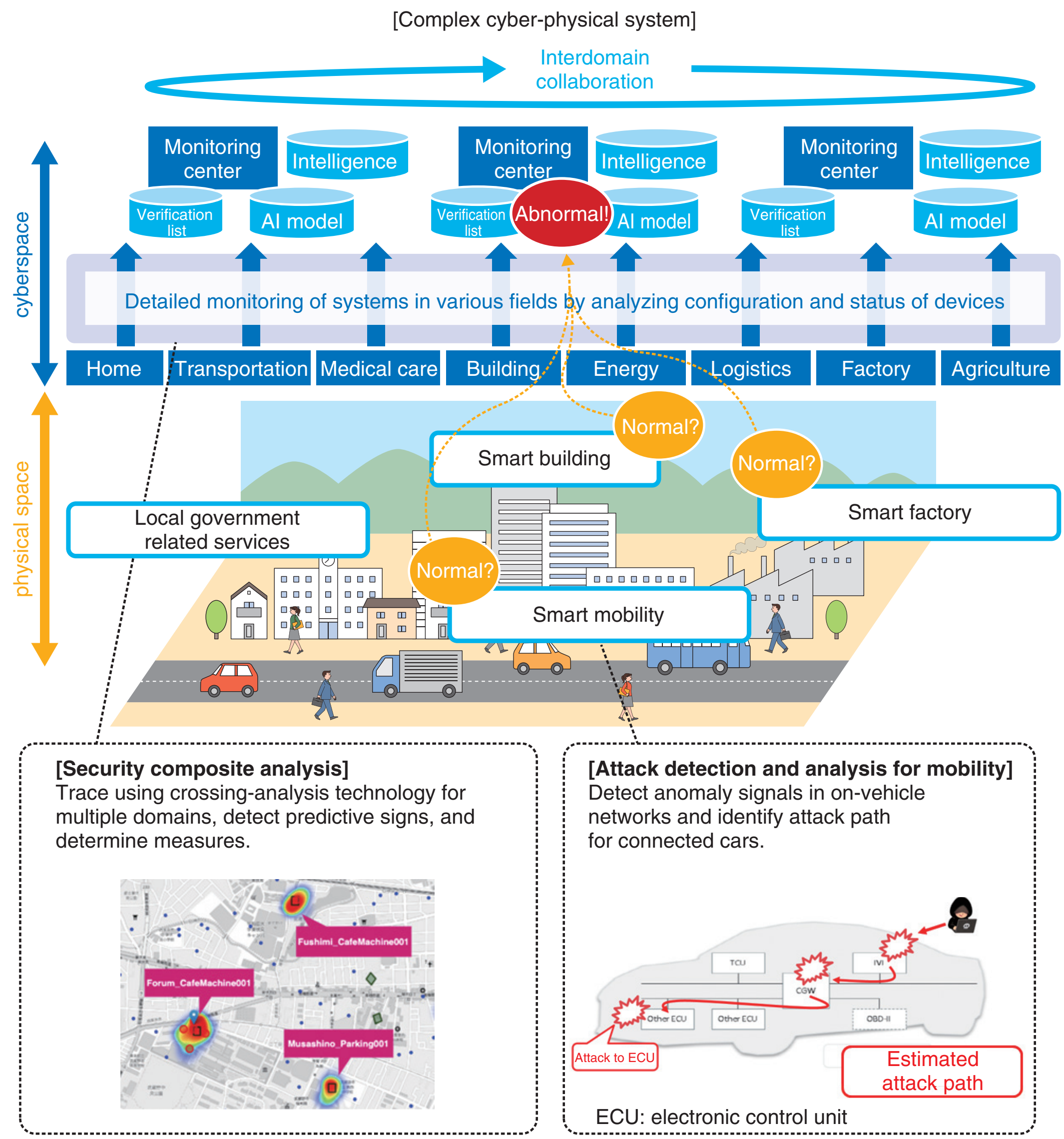


Fig. 6. Configuration and status analysis technology.

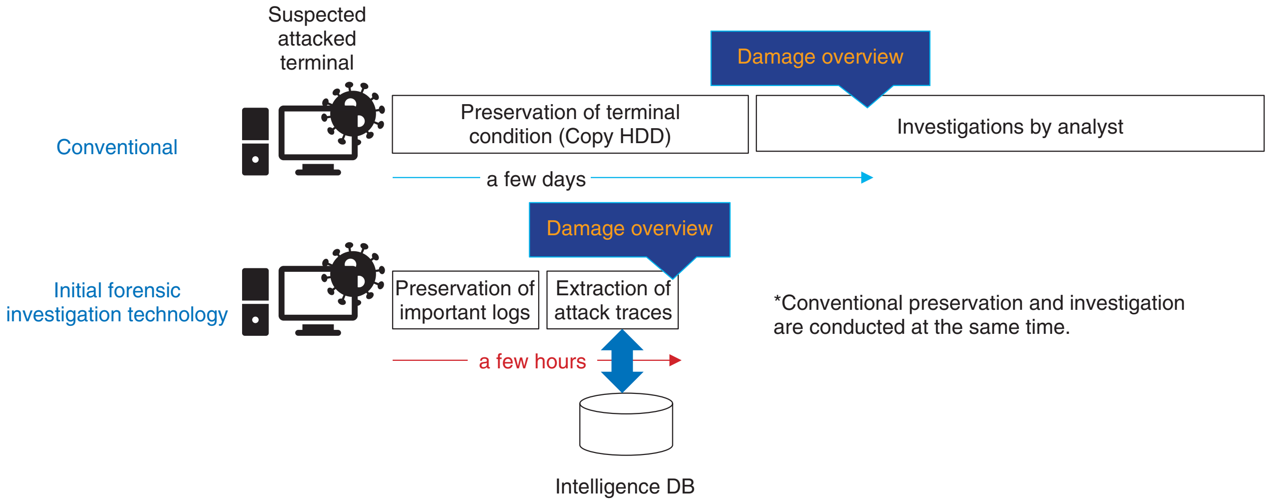
automatically. Initial investigations can be conducted in a few hours, regardless of the skill levels of analysts.

(3) Technology for detecting web-based social-engineering attacks that exploit human psychological vulnerabilities (**Fig. 8**)

Attackers use opportunities such as international sporting events and the spread of COVID-19 infection to attract people's interests and carry out cyber attacks that deceive users. Attackers can trick users into visiting a malicious site with interesting content or fake warning messages, causing malware infections and theft of money and personal information. We are conducting R&D on technology that can emulate the browser operations of deceived people, automatically crawl and collect webpages, and detect malicious sites with high accuracy and speed based on the image, language, and feature amount of the arrival path with the aim of reducing fraud damage targeting such people.

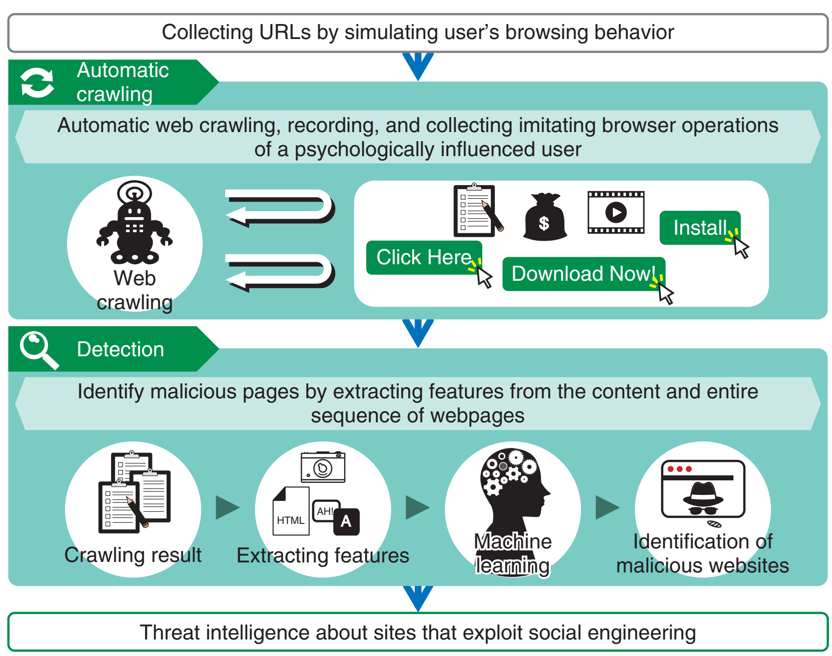
6. For the future

Cybersecurity risks can now threaten countries and are one of the most serious social problems. As the situation continues to be dominated by attackers, we



DB: database
HDD: hard disk drive

Fig. 7. Initial forensic investigation technology.



HTML: Hyper Text Markup Language
URL: uniform resource locator

Fig. 8. Technology for detecting web-based social-engineering attacks that exploit human psychological vulnerabilities.

will continue to contribute to the betterment of society by creating new security technologies that can overcome the current severe cybersecurity situation.

Yuzo Koga

Director, Head of Cyber Security Project, NTT Secure Platform Laboratories.

He received a B.E., M.E., and Ph.D. in instrumentation engineering from Keio University in 1996, 1998, and 2001. He joined NTT in 2001, and has had several years of experience in designing, building, and operating various communication services including identity management, cloud computing, the Internet exchange point, and the Internet access network. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE).

Takaaki Koyama

Director, Security Operation Project, NTT Secure Platform Laboratories.

He received an M.M.G. in media and governance from Keio University in 1996. He joined NTT in 1996 and has been studying several types of virtual private networks and software-defined networking as well as security operation systems for these network technologies. His research interests have recently extended to security analysis and operation technologies for smart cities. He is a member of IPSJ.

Yoshiaki Nakajima

Director, Head of Security Operation Project, NTT Secure Platform Laboratories.

He received a B.S. in information science and an M.S. in mathematical and computing science from Tokyo Institute of Technology in 1995 and 1997. He joined NTT Information and Communication Systems Laboratories in 1997, where he worked on R&D of information security. From 2009 to 2013, he was with the Security Strategy Section of the Technology Planning Department. He has been involved in R&D of information and communication platforms, security platforms, and other areas. He is a Certified Information Systems Security Professional (CISSP) and Registered Information Security Specialist (RISS).

Hidehiro Shito

Director, Security Operation Project, NTT Secure Platform Laboratories.

He received a B.E. and M.E. in mechanical and system engineering from Yamanashi University in 1994 and 1996. He joined NTT in 1997. After several years of experience in R&D, operation, and construction of communications infrastructure, he started his career as a member of computer security incident response teams (CSIRTs) of organizations such as NTT EAST and NTT DATA. He joined NTT R&D in 2018, and his current position is a director of NTT-CERT (Computer Security Incident Response and Readiness Coordination Team), the representative CSIRT of the NTT Group.

Naoko Chiba

Director, Cyber Security Project, NTT Secure Platform Laboratories.

She received a B.S. and M.S. from Tokyo Institute of Technology in 1998 and 2000. She joined NTT R&D in 2000 and has been working for more than 20 years in the information security field. Her research interest lies in high-quality and usable cybersecurity intelligence. She is a CISSP and a member of Information Processing Society of Japan (IPSJ).

Asami Miyajima

Director, Security Operation Project, NTT Secure Platform Laboratories.

She received a B.S. and M.S. in science and technology from Keio University in 1998 and 2000. She joined NTT R&D in 2000, and her research interests include cyber-physical systems security.

Jun Miyoshi

Director, Cyber Security Project, NTT Secure Platform Laboratories.

He received a B.E. and M.E. in system science from Kyoto University in 1993 and 1995. Since joining NTT in 1995, he has been researching and developing network security technologies. Prior to his current position, he was engaged in R&D strategy management of the Labs. from 2011 to 2015. He is a member of IEICE.

Security Based on Quantum Information Technology and Data Protection of Quantum Information

Yuuki Tokunaga, Yasunari Suzuki, Suguru Endo, Ryo Nishimaki, Fuyuki Kitagawa, and Sachi Tamechika

Abstract

Quantum information processing is expected to have unique security applications such as communication security and copy protection based on physical principles in addition to high-speed computation. For the practical use of quantum information processing, fault-tolerant processing is essential to protect quantum information from noise, and fault-tolerant processing for quantum communication based on quantum repeaters is the key for networking. We introduce our efforts in this area in this article.

Keywords: quantum information processing, security, fault-tolerant technology

1. Introduction

The possibility of new high-speed computation using quantum information processing has been attracting attention, and new security using such processing and data protection of quantum information are also important research topics. Quantum information is known to be very sensitive to noise, and to process information correctly, it is necessary to protect quantum information from noise and errors. Protecting the *availability* of such information processing is one of the three elements of security*, and is one of the important roles of security. Without this, no matter how fast the computation is or how many new security applications there are, the information cannot be processed correctly. The ability to protect quantum data from noise is the most important issue in quantum information processing, and the security of quantum information processing supports the backbone of such processing.

The possibility for new security using quantum information processing is, in a sense, to take advantage of this weakness against noise, but the nature of quantum states is such that if one touches a quantum state to eavesdrop or forge it, traces as noise will inevitably be left behind. Quantum cryptography takes advantage of this property to detect eavesdroppers and maintain security in principle. (Quantum cryptography is also called quantum key distribution because it is usually used to distribute secret keys.) The nature of quantum states can also be used to prevent counterfeiting and has potential applications in quantum money and quantum copyright protection, where counterfeiting by copying is impossible in principle. Such functions will become more valuable when quantum networks are enhanced; therefore, it is necessary to develop quantum repeaters and construct a large-scale quantum network. Since quantum communication is also vulnerable to loss and noise, the ability to protect data from noise in quantum communication can be regarded as the security of such communication.

In this article, we first introduce quantum error correction and quantum error mitigation, which are two important technologies for protecting quantum information data. We then discuss copy protection as a new application possibility and finally introduce

* The three elements of information security: confidentiality, integrity, and availability.

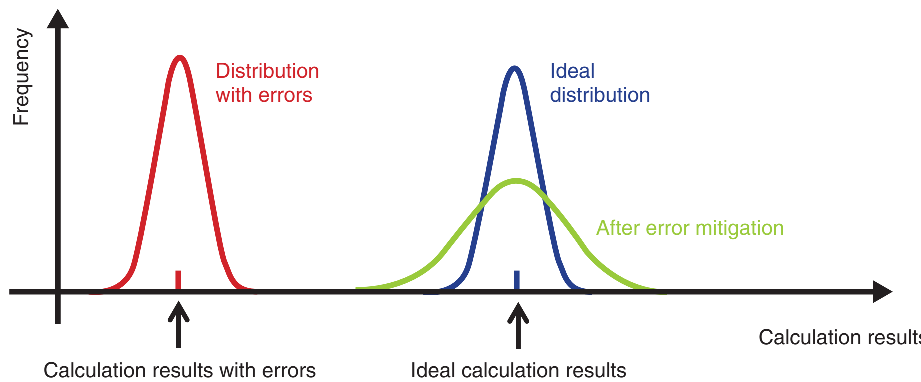


Fig. 1. A schematic of how quantum error mitigation works. The near-term quantum algorithm obtains the average measurement results as the calculation results. After quantum error mitigation, the probability distribution will be distributed around the correct mean value, but the variance will increase, so more measurements are needed.

research on quantum repeaters, which is a fundamental technology for quantum networks.

2. Fault-tolerant technology to protect quantum information data

In many applications of quantum information processing, error rates during computation must be sufficiently small. Quantum error correction is a technology that can significantly reduce effective error rates by encoding the information of qubits using multiple noisy qubits and by detecting and correcting errors sequentially. Building a fault-tolerant quantum computer (FTQC) [1], which enables fault-tolerant quantum information processing using quantum error correction, is one of the most promising ways to demonstrate practical applications in a scalable manner. However, it is not easy to build an FTQC with practical performance because quantum error correction requires many qubits, feedback, and other complicated processing [2]. Therefore, to build a useful FTQC, it is necessary to research and develop an efficient architecture from software to hardware by considering many trade-off relations and performance bottlenecks. We are working on the research and development of software infrastructure for building a practical FTQC. Specifically, we are developing a method of quantum error correction for distributed computing systems [3], method for optimizing decoding circuits for small codes by machine learning [4], circuit design of peripheral devices for low-latency decoding algorithms [5], calibration method for accurate control of integrated qubits [6], framework for high-speed measurements of qubits, and series of fundamental software to comprehensively evaluate and improve the accuracy of these methods.

Near-term quantum computation has attracted a great deal of attention. This is because in October 2019, Google announced that it was able to solve a very specific, impractical problem, which was said to take a very long time to solve with existing computers, by using a 53-qubit quantum computer. Researchers worldwide are studying how to make practical use of such quantum devices and applications such as machine learning and chemical calculations. However, to exploit the computational power of such small-scale quantum computers, it is necessary to suppress computational errors. Quantum error correction has been studied for many years for removing computational errors, but this method uses qubits as a resource for error suppression, which is incompatible with small-scale quantum devices that can be fabricated now or in the near future due to the limited number of qubits. Instead, quantum error mitigation (or quantum noise compensation) has been proposed as an alternative to suppressing errors without (significantly) increasing the number of qubits, and a number of papers have been published recently. Quantum error mitigation is a method for effectively suppressing computational errors by adding error-suppression operations to the quantum algorithm then executing existing classical information processing on the readout measurement results (**Fig. 1**). In this case, the resource required for quantum error mitigation is a larger number of measurements (number of calculations). For error mitigation, there is an overhead of larger number of samples, thus it is not scalable. Nevertheless, it has been shown that error

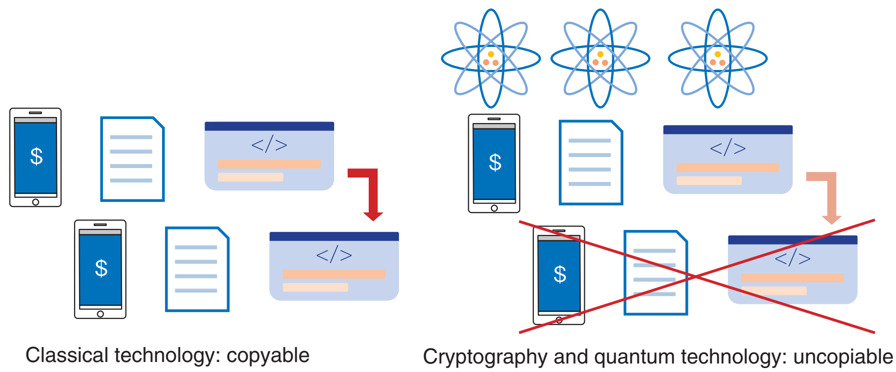


Fig. 2. Uncopiability with quantum technology.

mitigation can effectively suppress errors if the frequency of computational errors is small in the quantum algorithm [7]. Our group has also recently shown that the number of qubits required for FTQC can be reduced in a practical manner by incorporating quantum-error-mitigation methods into FTQC, indicating that quantum error mitigation is a method with a wide range of applications [8].

3. Secure copy protection from cryptography and quantum information technology

There are various topics at the intersection of cryptography and quantum information processing. Technology related to these two fields are roughly categorized into (1) cryptography secure against quantum computers (post-quantum cryptography) [9], (2) quantum cryptography, which uses quantum information processing to achieve secure communication [10], and (3) cryptography with new functionalities that can be achieved by using only quantum information processing. The main theme of this section is about (3), but we briefly explain (1) and (2). Post-quantum cryptography does not require the power of quantum information processing or quantum computers, but it is designed to guarantee its security even against quantum computers. Quantum cryptography requires the power of quantum information processing or quantum computers to achieve cryptographic functionalities, but its functionalities are the same as those of classical cryptography. For example, we can achieve secure encrypted communication without the power of quantum information theory, but we can enhance security by using this power. In contrast, (3) is cryptography with new functionalities that cannot be achieved without using the power of quantum information theory. A typical example is data copy protection or software copy protection (**Fig. 2**).

We can generate an unbounded number of copies of digital data. It is impossible to prevent the copying of digital data and software. However, this is the case in which we do not consider quantum information technology. In quantum information theory, there exists a no-cloning theorem that states that copying an unknown quantum state is impossible [11, 12]. By applying this theorem to cryptography, we might be able to achieve data copy protection or software copy protection. Currency is a type of data that we want to prevent from being copied. Quantum money was proposed as currency that can never be copied [13, 14].

Since current software is digital data, it is hard to prevent software piracy in principle and there is no copy-protection method that guarantees security. Provably secure software copy protection [14] makes it impossible to generate a copy of software by using cryptography and quantum technology. Achieving secure software copy protection is one of our goals. Copy-protection techniques have many applications other than quantum money and secure software copy protection. For example, it is possible to securely delete (encrypted) data that were stored in a cloud storage and prevent the cloud from reconstructing the data [15]. It might be possible to securely implement the right to be forgotten (General Data Protection Regulation [16] Article 17). It is possible to lease software in a limited time and make the functionality unavailable after the software was returned [17]. Our group is conducting research and development to achieve cryptography with new functionalities above what can be achieved by using only the power of quantum information [18].

4. Quantum repeater technologies for quantum networks

Current computation and communication technologies are all based on the rules of classical physics and can only execute computation and communication within the limits of classical physics. The same is true for security. We can currently provide only security within the limits of classical physics, but we can expand the possibilities of security by using quantum mechanics. For example, we enable eavesdropper detection in key distribution [19] and an information-theoretically secure and simple secure computing protocol that uses only one server [20].

It is known that the resource for such quantum mechanical effects as communication is a correlation unique to quantum mechanics called entanglement. To make security applications based on quantum mechanics available on a global scale, it is necessary to create entanglement and construct quantum networks in which entanglement can be shared over long distances and in multiple locations (**Fig. 3**).

If we want to share the entanglement over long distances, we cannot use conventional relaying methods because simple amplification is not possible due to the property of quantum states; quantum states cannot be copied. Since the probability of direct transmission becomes exponentially smaller due to losses, a method of relaying entanglement distribution is required. The following is a brief description of the main points of the method. First, the direct transmission distance can be shortened by placing repeaters at a distance that does not cause large loss, thereby reducing the loss. However, a certain amount of loss and error is unavoidable, so multiple communications are executed redundantly at each repeater point, and a process equivalent to quantum error correction is applied to them to enable transmission with reduced loss and error. This is a fault-tolerant processing of entanglement communication and is called entanglement distillation (purification) because it is the process of extracting near-perfect entanglement from multiple noisy entanglements.

Our group is working on constructing quantum repeaters using ultra-low loss nano-fiber cavities [21]. The ultra-low loss nano-fiber cavity consists of two elements: an ultra-low loss tapered fiber and ultra-low loss fiber Bragg grating. We are investigating methods of improving the performance of the quantum memory by using it as follows. By trapping atoms, which are used as quantum memory, in the vicinity of a tapered fiber, which is much thinner than an ordinary fiber, we can enable photons through the tapered fiber and atoms to interact. By placing the entire repeater system inside the fiber, it is possible to reduce optical loss by eliminating the lossy process of emitting photons out into free space to interact with atoms. By using a cavity structure with a fiber Bragg grating, it is also possible to increase the probability that photons emitted from the quantum memory will be coupled into the fiber. This will increase the success probability of write and read operations on the quantum memory, improving the overall performance of the repeater.

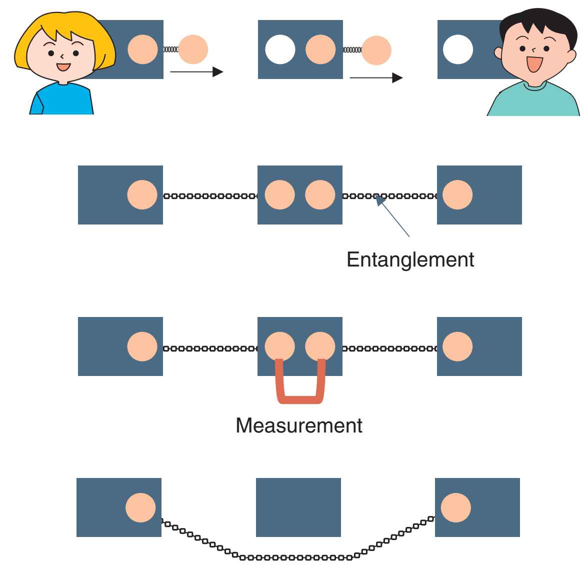


Fig. 3. Schematic of entanglement sharing using a quantum repeater.

The realization of quantum networks using high-performance quantum repeaters will provide various security applications, including those for diplomacy and defense, handling genetic information, and financial institutions.

5. Conclusion

It is important to emphasize once again that fault-tolerant and quantum repeater technologies, which protect the data of quantum information and quantum communication, are essential for the correct and safe execution of quantum information processing [22]. There are many unexplored areas of architectures for fault-tolerant processing in quantum information processing, and breakthroughs are expected through future research. For the security applications of quantum information processing, in addition to secure secret communication and copy protection, new applications such as quantum-secure computation and quantum-based reduction of communication complexity are expected. Near-term quantum security, which is not yet so large in scale, is also a promising research theme.

References

[1] A. G. Fowler and C. Gidney, "Low Overhead Quantum Computation Using Lattice Surgery," arXiv:1808.06709, 2018.

[2] P. Das, C. A. Pattison, S. Manne, D. Carmean, K. Svore, M. Qureshi, and N. Delfosse, "A Scalable Decoder Micro-architecture for Fault-tolerant Quantum Computing," arXiv:2001.06598, 2020.

[3] K. Fujii and Y. Tokunaga, "Fault-tolerant Topological One-way Quantum Computation with Probabilistic Two-qubit Gates," Phys. Rev. Lett., Vol. 105, No. 25, 250503, 2010.

[4] A. Davaasuren, Y. Suzuki, K. Fujii, and M. Koashi, "General Framework for Constructing Fast and Near-optimal Machine-learning-based Decoder of the Topological Stabilizer Codes," Phys. Rev. Research, Vol. 2, No. 3, 033399, 2020.

[5] Y. Ueno, M. Tanaka, Y. Suzuki, Y. Tabuchi, and M. Kondo, "Quantum Error Correction with a Superconducting Decoder," 2nd Workshop on Quantum and Classical Cryogenic Devices, Circuits, and Systems (QCCC 2020), Dec. 2020.

[6] K. Heya, Y. Suzuki, Y. Nakamura, and K. Fujii, "Variational Quantum Gate Optimization," arXiv:1810.12745, 2018.

[7] S. Endo, S. C. Benjamin, and Y. Li, "Practical Quantum Error Mitigation for Near-future Applications," Phys. Rev. X, Vol. 8, No. 3, 031027, 2018.

[8] Y. Suzuki, S. Endo, K. Fujii, and Y. Tokunaga, "Quantum Error Mitigation for Fault-tolerant Quantum Computing," arXiv:2010.03887, 2020.

[9] D. J. Bernstein, J. Buchmann, and E. Dahmen, "Post-quantum Cryptography," Springer, 2009.

[10] C. H. Bennet and G. Brassard, "Quantum Cryptography: Public Key Distribution and Coin Tossing," Proc. of IEEE International Conference on Computers, Systems and Signal Processing, Bangalore, India, Dec. 1984.

[11] W. K. Wootters and W. H. Zurek, "A Single Quantum Cannot Be Cloned," Nature, Vol. 299, pp. 802–803, 1982.

[12] D. Dieks, "Communication by EPR Devices," Phys. Lett. A, Vol. 92, No. 6, pp. 271–272, 1982.

[13] S. Wiesner, "Conjugate Coding," ACM SIGACT News, Vol. 15, No. 1, pp. 78–88, 1983.

[14] S. Aaronson, "Quantum Copy-protection and Quantum Money," Proc. of 24th IEEE Conference on Computational Complexity, pp. 229–242, Paris, France, July 2009.

[15] A. Broadbent and R. Islam, "Quantum Encryption with Certified Deletion," Proc. of 18th Theory of Cryptography Conference (TCC 2020), Nov. 2020.

[16] "Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing directive 95/46/EC (General Data Protection Regulation)," Official Journal of the European Union, Vol. 59, pp. 1–88, 294, 2016.

[17] P. Ananth and R. L. La Placa, "Secure Software Leasing," CoRR, abs/2005.05289, 2020.

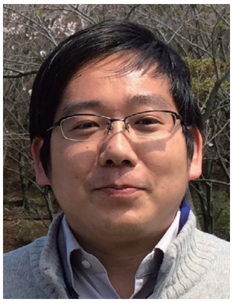
[18] F. Kitagawa, R. Nishimaki, and T. Yamakawa, "Secure Software Leasing from Standard Assumptions," CoRR, abs/2010.11186, 2020.

[19] C. H. Bennett and G. Brassard, "Quantum Cryptography: Public Key Distribution and Coin Tossing," Proc. of the International Conference on Computers, Systems and Signal Processing, pp. 175–179, Bangalore, India, Dec. 1984.

[20] T. Morimae, "Measurement-only Verifiable Blind Quantum Computing with Quantum Input Verification," Phys. Rev. A, Vol. 94, 042301, 2016.

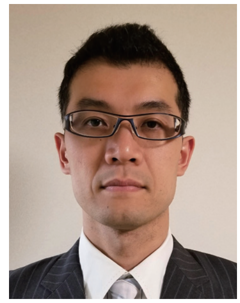
[21] S. Ruddell, K. E. Webb, M. Takahata, S. Kato, and T. Aoki, "Ultra-low-loss Nanofiber Fabry–Pérot Cavities Optimized for Cavity Quantum Electrodynamics," Opt. Lett., Vol. 45, No. 17, pp. 4875–4878, 2020.

[22] Y. Tokunaga, Y. Suzuki, S. Endo, and R. Asaoka, "Fault-tolerant Technology for Quantum Information Processing and Its Implementation Methods," NTT Technical Review, Vol. 19, No. 5, pp. 40–44, May 2021.
https://ntt-review.jp/archive/ntttechnical.php?contents=ntr202105fa6.html



Yuuki Tokunaga
Distinguished Researcher, NTT Secure Platform Laboratories.

He received a bachelor's degree from Kyoto University in 1999, master's degree from the University of Tokyo in 2001 and Ph.D. in science from Osaka University in 2007. He joined NTT in 2001, where he has been conducting research toward fault-tolerant universal quantum computing and long-distance secure quantum network.

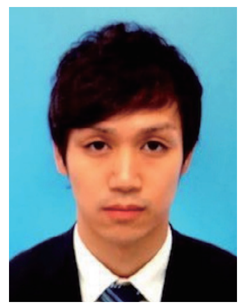


Ryo Nishimaki
Distinguished Researcher, Cryptography Research Laboratory, NTT Secure Platform Laboratories.

He received a B.E. and M.I. from Kyoto University and a D.S. from Tokyo Institute of Technology in 2005, 2007, and 2010. He joined NTT in 2007. His research work focuses on design and foundation of cryptography. He is currently researching cryptography and information security at NTT Secure Platform Laboratories.

Yasunari Suzuki
Researcher, NTT Secure Platform Laboratories.

He received a Ph.D. in science from the University of Tokyo in 2018 and joined NTT the same year. He has been focusing on practical quantum error correction and fault-tolerant quantum computing for achieving reliable quantum systems. He is currently working on the development of fault-tolerant quantum computing.

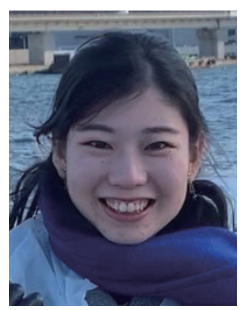


Fuyuki Kitagawa
Researcher, Cryptography Research Laboratory, NTT Secure Platform Laboratories.

He received bachelor's, master's, and Ph.D. degrees in science from Tokyo Institute of Technology in 2014, 2016, and 2019. From 2016 to 2019, he was a research fellow of Japan Society for the Promotion of Science. From 2019, he has been with NTT Secure Platform Laboratories. He is interested in the research of public key cryptography and provable security.

Suguru Endo
Researcher, NTT Secure Platform Laboratories.

He received bachelor's and master's degrees from Keio University, Kanagawa, in 2014 and 2016 and a Ph.D. from University of Oxford, UK, in 2019. He joined NTT Secure Platform Laboratories in 2020. His research interests focus on hybrid quantum-classical algorithms, quantum error mitigation, and circuit quantum electrodynamics.



Sachi Tamechika
NTT Secure Platform Laboratories.

She received a B.S. and M.S. from Tokyo Metropolitan University in 2017 and 2019. She joined NTT the same year, where she is working on an experiment using cavity quantum electrodynamics.

Neutron-energy-dependent Semiconductor Soft Errors Successfully Measured for the First Time

Hidenori Iwashita, Hirotaka Sato, and Yoshiaki Kiyanagi

Abstract

Problems caused by neutron-induced soft errors in electrical devices are becoming increasingly common in various applications. The neutron-energy-dependent soft-error rate is indispensable for evaluating the frequency of such errors in different neutron environments. We observed the energy-dependent neutron-induced soft-error rates continuously over the energy range of 1–800 MeV at the Los Alamos Neutron Science Center, USA. This measurement was made possible with a method we developed that uses extremely fast circuits built into field-programmable gate arrays coupled with a neutron time-of-flight technique.

Keywords: soft error, cosmic rays, field-programmable gate arrays (FPGAs)

1. Introduction

Modern society's infrastructures are becoming increasingly dependent on digital technologies and are undergoing a digital transformation. Although people enjoy greater convenience in their everyday lives, various issues such as software bugs in electrical device logic and security compromises have become major social problems. There are also random phenomena called bit errors in semiconductor devices such as in large-scale integrated circuits (LSIs) including memory chips. Soft errors caused by cosmic rays are a type of bit errors [1], but there are many cases in which the causes are unknown, making them very difficult problems to solve. Neutrons generated by cosmic rays are currently the main cause of soft errors in semiconductor devices of electrical equipment used on the ground [2, 3]. When cosmic rays arrive from outer space, they collide with oxygen or nitrogen nuclei in the atmosphere, generating various secondary particles by a spallation reaction (**Fig. 1**). Neutrons have particularly high penetrating power because they are uncharged and can pass through the concrete structures of buildings. When neutrons pass through a semiconductor device on an electrical circuit board, they can interact with a silicon nucleus and generate secondary ionizing particles, though this is very rare. The ionizing particles can reverse internal logic states in the chip, referred to as a single event upset (SEU). The rate of SEUs per device (unit area) becomes non-negligible as the degree of LSI integration becomes greater. This is because the design rule, which is related to the minimum processing line width, becomes narrower each year, and the critical charge to cause an SEU lessens along with the line width. Recent progress in larger integration and increasingly finer microfabrication technologies has resulted in a dramatic increase in the occurrence of soft errors in contrast to hard errors that permanently disable semiconductor devices [4]. **Figure 2** shows the relationship between the design rule and failure in time (FIT), which is the number of failures per billion hours per device, in static random access memory (SRAM)-based field programmable

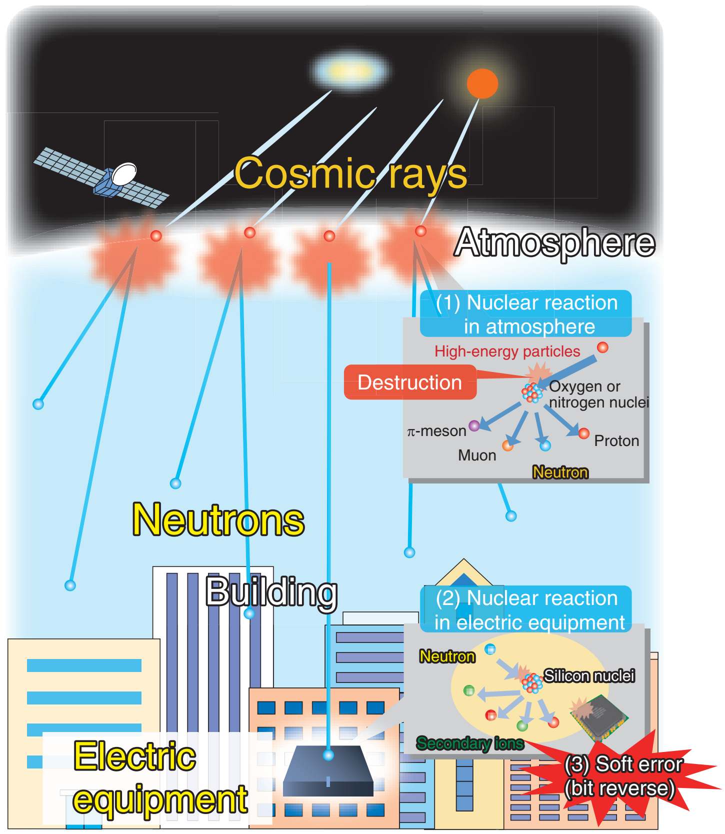


Fig. 1. Mechanism of soft error.

gate arrays (FPGAs). The rate of multiple bit upsets is increasing with narrowing design rules. For example, in a real-world information network consisting of 10,000 communication units, each with 5 of the 10,000 FIT LSIs in stacks, about 12 soft errors will occur on a daily basis. At this rate, network operators would not be able to handle all errors. Also, soft errors may cause network equipment to be hung up, leading to breakdown in some network services. In a worst case scenario, the breakdown can occasionally become widespread. Therefore, SEUs are not limited to occurring in information network devices but also in various other electrical devices. Consequently, SEUs may have a serious impact when such devices are incorporated into medical instruments, automobiles, airplanes, trains, and personal computers (PCs), to name but a few.

Therefore, it is crucial to design and fabricate semiconductor devices and systems to minimize the SEU error rate measured in FIT units to ensure the reliability and safety of these devices and systems. To calculate the expected number of failures due to soft

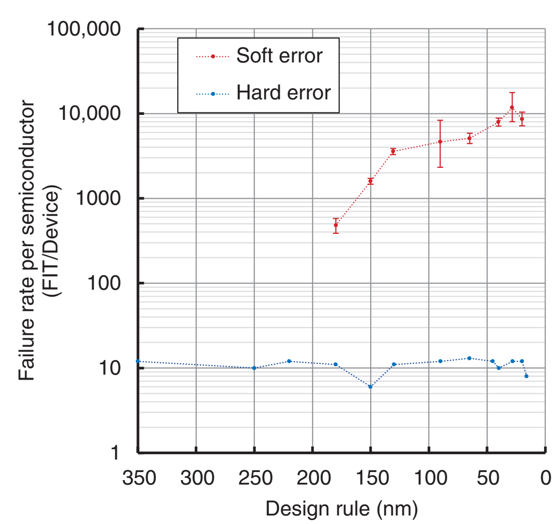


Fig. 2. Relationship between the design rule and failure rate.

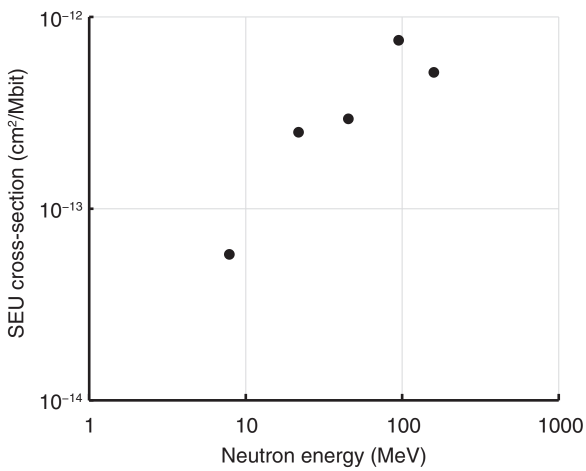


Fig. 3. Conventional technology (SEU cross-section measurement results).

errors in various neutron environments (natural, space, building, accelerator, nuclear plant, underground, etc.), the number of neutrons per unit time at each neutron energy, and the SEU cross-section at this energy are required for a wide energy range of impinging neutrons. The SEU cross-section depending on the neutron energy σ*SEU*(*En*) is defined as

$$\sigma_{SEU}\,(E_n) = \frac{N_{SEU}(E_n)}{\Phi(E_n)}\,, \qquad (1)$$

which identifies a neutron fluence $\Phi(E_n)$ as the total number of neutrons per unit area impinging on the semiconductor device and the total number of SEUs, $N_{SEU}(E_n)$, generated by these neutrons. Specifically, $\sigma_{SEU}(E_n)$ indicates the probability that one neutron per unit area causes a soft error. Note that the SEU cross-section for each neutron energy will differ for each semiconductor device. In addition, neutrons in the natural environment and those generated by accelerators have distinct energy distributions. Therefore, the soft error rate (SER) in a specific neutron-irradiation environment can be defined as

$$SER = \int_0^{\infty} \sigma_{SEU}(E_n)\phi(E_n)dE_n \qquad (2)$$

using the neutron flux $\phi(E_n)$ (number of neutrons with E_n crossing a unit area in a unit time) at each neutron energy and $\sigma_{SEU}(E_n)$. Thus, the SEU cross-section is the most important basic datum necessary for calculating the failure rate of semiconductor devices due to soft errors. However, the SEU cross-section has been measured at only a few points in the neutron energy range from 1 to 176 MeV [5, 6] (**Fig. 3**). As a consequence, there are no data on SEU cross-sections continuously covering a wide range of neutron energy using this method, so the whole picture of the cross-section is yet to be clarified.

Therefore, we attempted to measure energy-resolved SEU cross-sections by using the neutron time-of-flight (TOF) technique for a wide neutron energy range. Accordingly, we developed a method of detecting errors in the desired time resolution using FPGAs and measured SEU cross-sections using the TOF technique at the Los Alamos Neutron Science Center (LANSCE), USA.

2. Measurement methods

2.1 TOF technique

The TOF technique makes it possible to determine the neutron velocity v (i.e., E_n) by measuring the flight time of a neutron along a flight path with a known length. In the sub-GeV region, neutrons have velocities close to the speed of light; thus, we need to consider the relativistic effects. The E_n is determined as

$$E_n = \frac{m_0\,c^2}{\sqrt{1-\left(\frac{v}{c}\right)^2}} - m_0\,c^2 = \frac{m_0\,c^2}{\sqrt{1-\left(\frac{L}{ct}\right)^2}} - m_0\,c^2\,, \qquad (3)$$

where m_0 is the neutron rest mass, v is its velocity, c is the velocity of light, L is the flight path length, and t is the neutron flight time. Using the TOF technique, it is possible to determine the energy of the neutron that caused a soft error by measuring the time at which the soft error occurred. The TOF of the sub-GeV is very short, for example 1.4 µs at 1 MeV and 79.3 ns at 800 MeV with the LANSCE L = 20 m (**Fig. 4**). Therefore, we chose a duration of 8 ns for detecting SEUs to obtain a time resolution of $\Delta t/t$ = 10% at 800 MeV (**Fig. 5**). However, it is impossible to measure TOF in the desired time resolution using conventional SRAM. Furthermore, because an ordinary SRAM reads data sequentially, it takes several milliseconds to scan sufficient data for soft-error detection. This makes it impossible to conduct nanosecond-order TOF measurements by using SRAM. Even if many sets of SRAM and memory-readout circuits are fabricated using on-chip SRAM in an FPGA, it is impossible to scan several M bits in nanoseconds. Therefore, we designed circuits that can

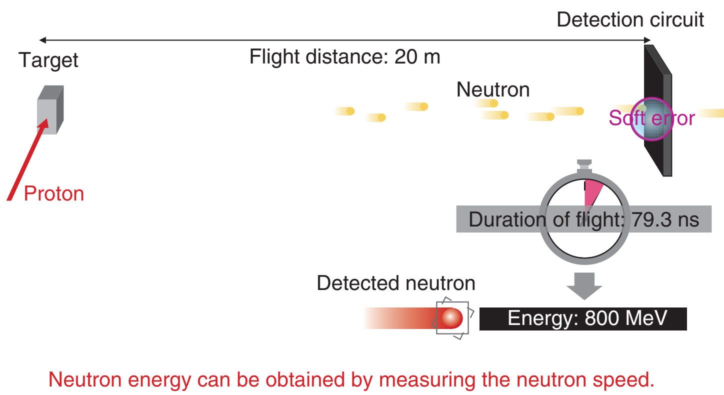


Fig. 4. Neutron TOF method.

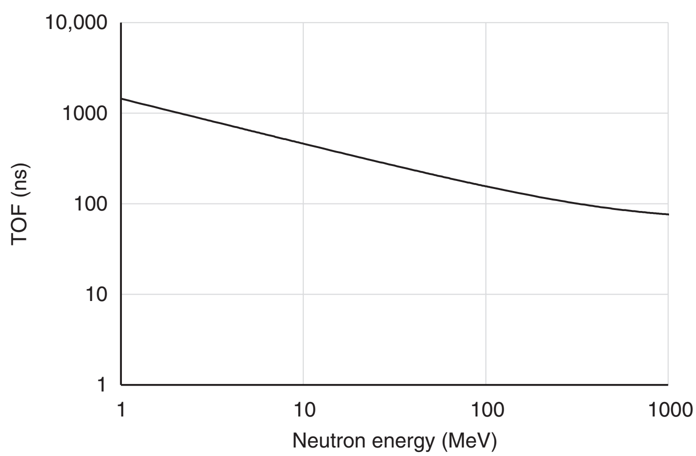


Fig. 5. TOF and neutron energy (flight over 20 m).

detect a soft error due to a malfunction in logic circuits composed of configuration random access memory (CRAM) that determines the logic of the FPGA. In this case, determination of a CRAM bit error is possible at the operating frequency of the FPGA. It is also possible to monitor a capacity equivalent to several 10-M-bit FPGAs. We devised a circuit that can detect an SEU in nanoseconds and conducted SEU cross-section measurements of FPGAs depending on the neutron energy using the TOF technique.

2.2 Soft-error detection in nanoseconds using FPGAs

We first considered using the cyclic redundancy check (CRC) circuit, which can detect the CRAM errors, built into modern FPGAs to obtain TOF information. An FPGA stores circuit design data in an SRAM-based CRAM and program logic circuits and wiring using bits of the CRAM. When a CRAM bit is inverted by an SEU, it is immediately transmitted to a logic circuit or a wiring, which is not the effect intended by the programmer of the FPGA. Recent FPGAs can detect bit errors by CRC to detect soft errors of the CRAM. However, the neutron energy cannot be specified with the TOF technique from the CRC of a CRAM because a detection time of several tens of milliseconds is required to check all the CRAM bits. Therefore, we focused on any logic malfunction in the circuit caused by CRAM errors. When a bit error occurs in a CRAM bit related to circuit operation, the circuit operation changes immediately, and a logic malfunction occurs. Since FPGA circuits can operate at several hundred megahertz, a logic malfunction can be detected in nanoseconds by

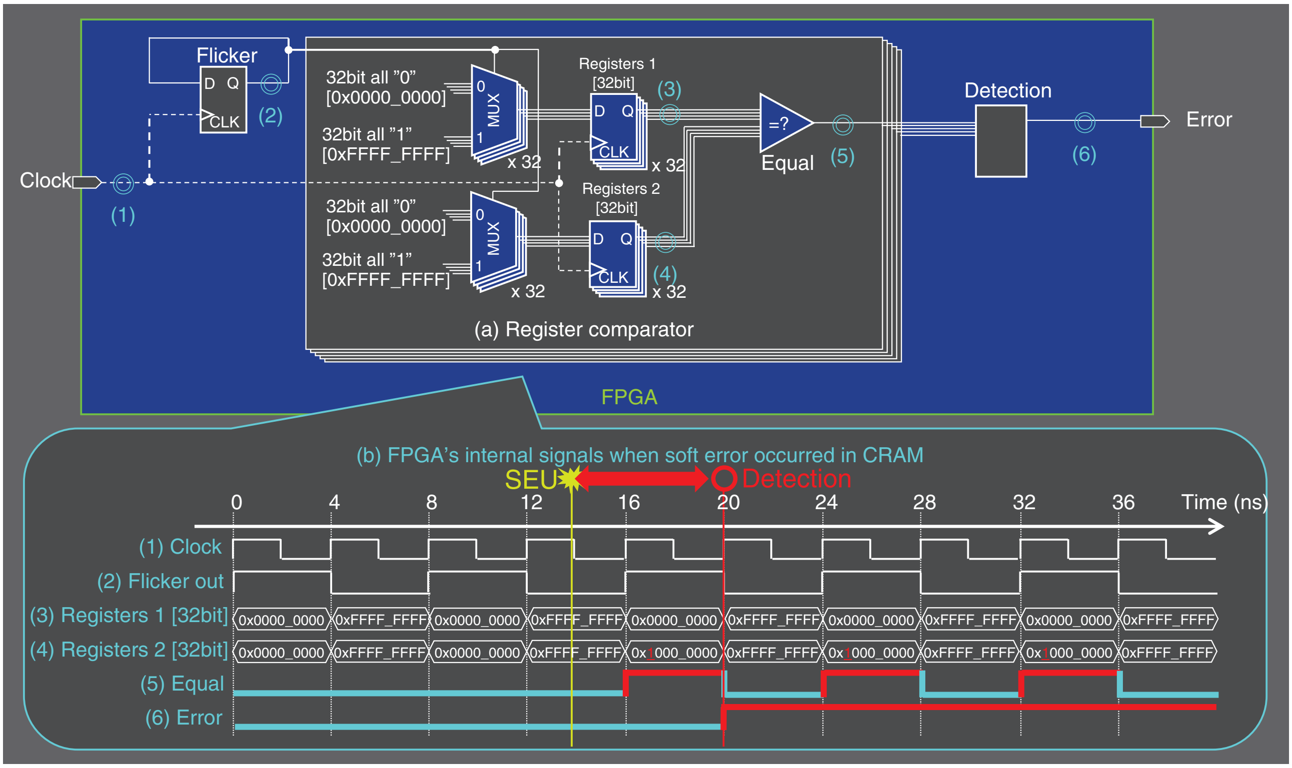


Fig. 6. High-speed error-detection circuit.

programming user circuits to detect the malfunction. For this purpose, we programmed a user circuit that has a large number of registers and monitors.

The basic principle of this measurement is shown in **Fig. 6**. This FPGA, which is also a device under test (DUT), operates at 250 MHz and outputs an error signal that triggers the TOF signal when a logic error occurs due to a soft error. As shown in Fig. 6, register comparator units (Fig. 6(a)) consist of two multiplexer units (MUXs), two 32-bit registers, and a comparator detecting a logic malfunction. Logic malfunction is detected by comparing the two output signals of the MUXs. Figure 6(b) shows a timing diagram of the FPGA's internal logic at signal monitoring points (1) to (6) when a soft error occurred in the CRAM. The output of the registers repeats all "0" (0x0000_0000) or all "1" (0xFFFF_FFFF) alternately in accordance with the flicker select signal. If none of the comparison results match, the detection module asserts an error and outputs it as a TOF trigger signal. The operation of each MUX is controlled by the look-up table (LUT) in the FPGA. The registers are all 32-bit ones, but we first focus on only one bit of them. The flicker signal is fed into one of the 4-bit input lines in the LUT, and all the other three lines are set to "0". As a result, one of the two SRAM bits is selected; one is initially set to 1 and the other 0, resulting in the time series of alternative "1" and "0". A corresponding bit pattern of the desired logic is stored in a 16-bit (= 24-bit) CRAM. When a condition is put into the 4-bit input lines, the result is output to the 1-bit line. The result is then held by a flip-flop circuit.

When a CRAM bit is inverted, therefore, an incorrect value is written to the register at the next clock timing. There are two identical 32-bit registers, but only one register output is affected by the soft error; therefore, by comparing the two registers, the error is detected with this circuit. When this circuit is operated with a 250-MHz clock, logic malfunction can be detected within 8 ns. The neutron energy can then be specified by obtaining the difference between the time at which neutrons were generated and the timing ((6) in Fig. 6) at which a logic malfunction was detected in a few-nanosecond resolution.

2.3 Facilities

There are four requirements for an accelerator facility

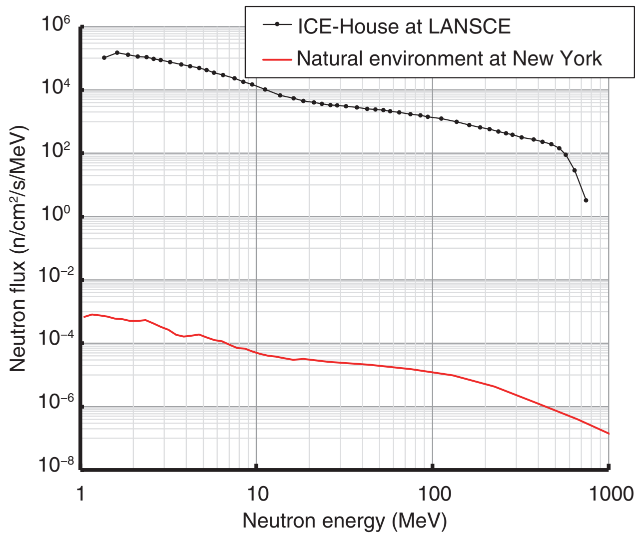


Fig. 7. Neutron energy spectrum obtained at LANSCE.

to execute this measurement. The first is a pulsed neutron source with a short pulse width. To measure high-energy neutrons using the TOF technique, the duration of the pulse of the accelerated particles entering the target is preferably 1 ns or less with a flight path of about 20 m. Note that this requires a beamline through which you can directly view the neutron production target without a neutron moderator from the position of DUTs. The second requirement is a high-energy white neutron source. To measure a wide E_n range up to hundreds of mega electron-volts, the neutron source driven by a high energy proton accelerator is indispensable. The third requirement is that the incident neutron energy spectrum should be available or measurable within a specified precision. It is crucial to calculate an SEU cross-section. The final requirement is that neutron intensity should be high enough. In this experiment, it took time to obtain data with satisfactory statistical accuracy because the logic malfunction rate with our method is lower than that of CRAM as a whole. In addition, to obtain a precise energy-dependent cross-section by using the TOF technique, a very high intensity neutron source is required to obtain high statistical accuracy in a short time bin for high energy resolution. The best accelerator facility that satisfies the above requirements is the ICE-House or ICE-II at LANSCE [7, 8]. LANSCE is based on an 800-MeV proton linac with relatively long pulse width but has a storage ring to compress the beam. It uses a short proton beam pulse of 125 ps. **Figure 7** shows the neutron energy spectrum measured in a fission chamber installed 19.7 m from the target at LANSCE, together with the neutron spectrum in a natural environment [9]. Thus, LANSCE has a neutron energy spectrum close to that in the natural environment, with about four orders of magnitude higher neutron flux.

3. Experiment

We conducted the experiment at the ICE-House in LANSCE involving irradiating DUTs, which were three types of commercially available FPGAs with design rules of 28, 40, and 55 nm. We measured logic malfunctions as a function of neutron energy. The experimental setup at the ICE-House is shown in **Fig. 8**. The experimental area is separated into two sections by thick concrete and polyethylene walls. One of the sections contains the neutron beam (beam area), in which the DUTs are placed. The yellow line shows the neutron beam entering from the right and exiting to the left. The other section is equipped with all the monitoring equipment (controller board and PC). The fission chamber was installed at a distance of 19.70 m from a tungsten neutron production target. The FPGAs were installed at distances of 20.05, 20.10, 20.15 m.

The controller board calculates the time difference between the proton pulse and error signal and executes recovery control of the FPGAs. The controller board outputs the time difference to the PC.

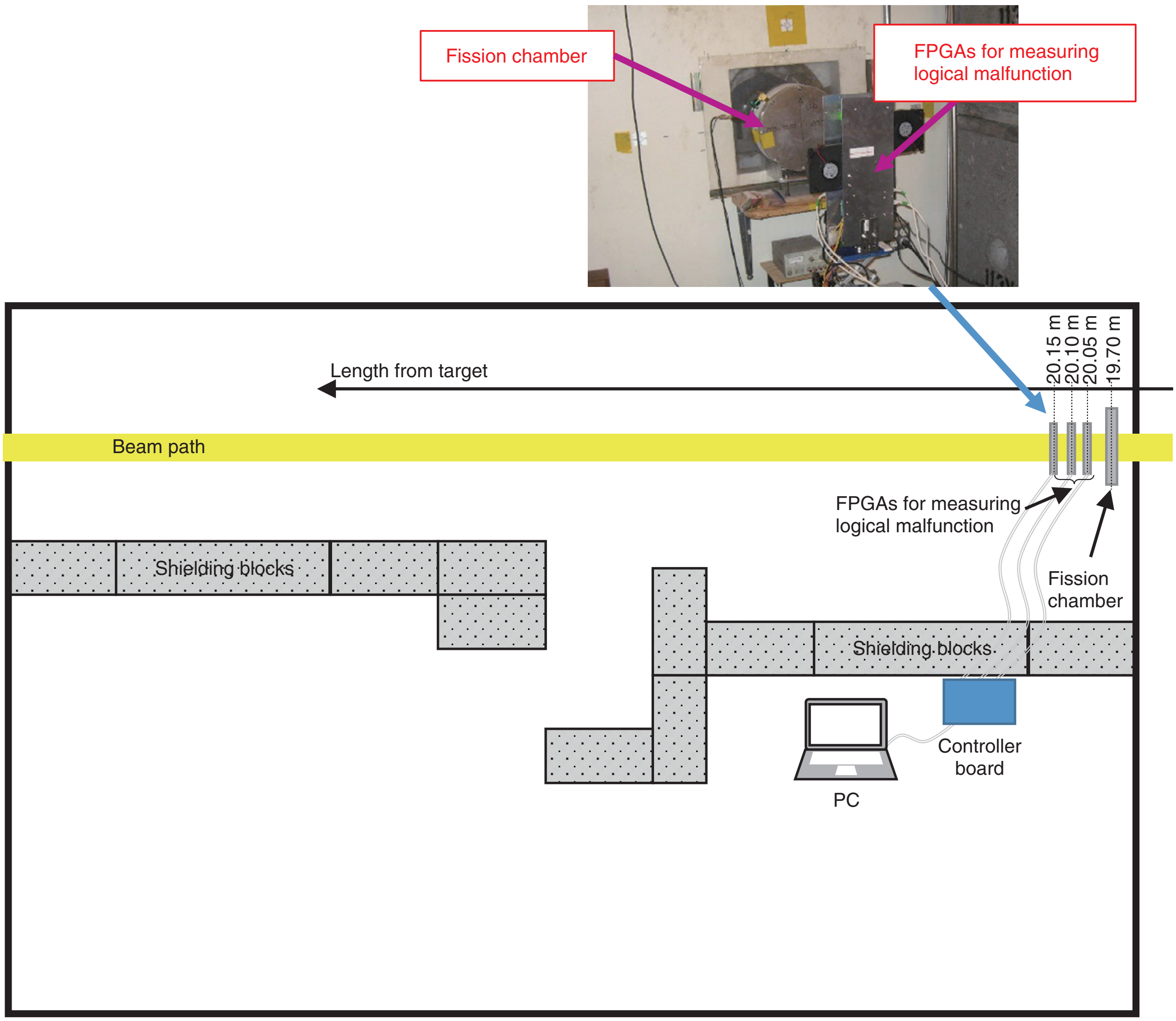


Fig. 8. Experimental setup at ICE-House.

4. Results and discussion

The TOF spectra of the number of logical malfunctions of the three FPGAs are shown in **Fig. 9**. The total number of logical malfunctions in each FPGA was as follows: 28-mm FPGA, 12,713; 40-mm FPGA, 2894; and 55-mm FPGA, 3719.

Figure 10 shows the CRAM SEU cross-sections calculated from the measured logical malfunction time distribution, number of CRAM errors, and neutron fluence [10, 11, 12]. The SEU cross-sections tended to increase rapidly from 3 to 20 MeV and remain almost constant thereafter. There was a difference in the absolute value of the cross-sections among the three FPGAs, although they were similar. In the energy range from 1 to 3 MeV, the difference in the cross-sections was significant. The device type for the simulation conducted by Abe and Watanabe [13] was not the same as the devices used in this experiment, but the trend of the measured SEU cross-sections was similar to that in their simulation. From their simulation, they found that SEUs below 5 MeV are attributed to elastic recoils of oxygen and silicon ions. They also found that the sharp increase in an SEU cross-section appears near the threshold energies of the (n, p) and (n, α) reactions caused by secondary helium and hydrogen ions. Their simulation showed that the sharp increase in gradient is enhanced

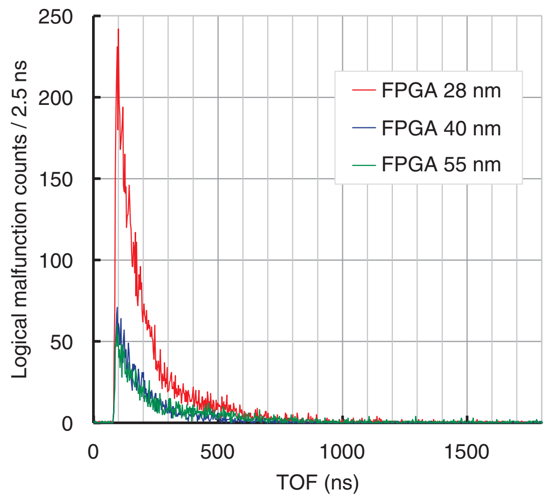


Fig. 9. TOF spectra of logical malfunction counts.

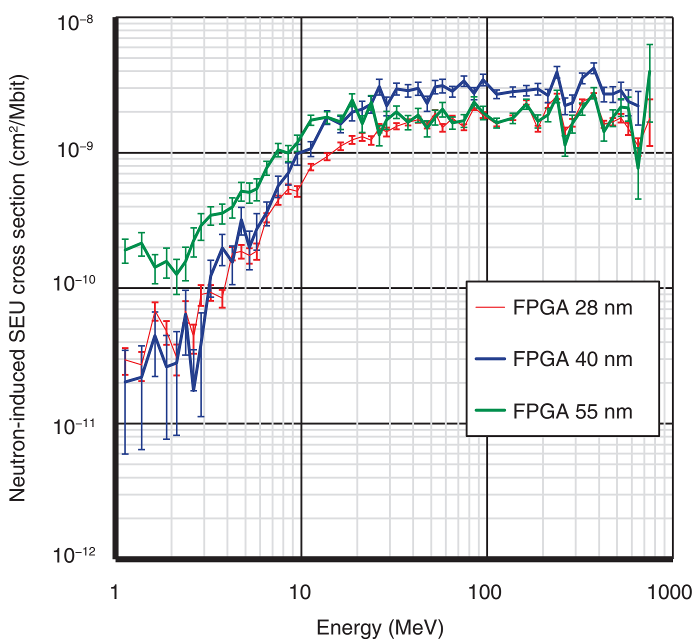


Fig. 10. SEU cross section of CRAM.

by making the critical charge smaller. Generally, the smaller the design rule, the smaller the critical charge tends to be, but the 40-nm FPGA showed the largest sharp increase. We infer the reason for this is that the 28-nm FPGA uses high-k metal gate (HKMG) technology. An HKMG achieves a high dielectric constant by having metal for the gate. As a result, both the gate capacitance and critical charge increases, so it is speculated that the 28-nm FPGA had a milder increase than the 40-nm one. To confirm this, it is necessary to conduct measurements with an HKMG and silicon dioxide gate devices under the same design rules.

5. Conclusion

We measured the SEU cross-sections with high energy resolution from 1 to 800 MeV at the ICE-House of LANSCE with our method of measuring the neutron-induced SEU cross-sections for FPGAs using the TOF technique. The results clarified the complete picture of the SEU cross-sections. The most important contribution of these cross-sections is that they enable us to calculate the SERs in any type of neutron environment.

References

[1] E. Ibe, "Introduction," in Terrestrial Radiation Effects in ULSI Devices and Electronic Systems, 1st ed., pp. 1–12, Wiley, Hoboken, NJ, USA, 2015.

[2] J. F. Ziegler, "Terrestrial Cosmic Rays," IBM J. Res. Dev., Vol. 40, No. 1, pp. 19–39, 1996.

[3] E. Normand, "Single Event Upset at Ground Level," IEEE Trans. Nucl. Sci., Vol. 43, No. 6, pp. 2742–2750, 1996.

[4] P. Hazucha and C. Svensson, "Impact of CMOS Technology Scaling on the Atmospheric Neutron Soft Error Rate," IEEE Trans. Nucl. Sci., Vol. 47, No. 6, pp. 2586–2594, 2000.

[5] K. Johansson, P. Dyreklev, B. Granbom, N. Olsson, J. Blomgren, and P. U. Renberg, "Energy-resolved Neutron SEU Measurements from 22 to 160 MeV," IEEE Trans. Nucl. Sci., Vol. 45, No. 6, pp. 2519–2526, 1998.

[6] C. S. Dyer, S. N. Clucas, C. Sanderson, A. D. Frydland, and R. T. Green, "An Experimental Study of Single-event Effects Induced in Commercial SRAMs by Neutrons and Protons from Thermal Energies to 500 MeV," IEEE Trans. Nucl. Sci., Vol. 51, No. 5, pp. 2817–2824, 2004.

[7] B. E. Takala, "THE ICE HOUSE: Neutron Testing Leads to More-reliable Electronics," Los Alamos Science, pp. 96–103, 2006.
https://permalink.lanl.gov/object/tr?what=info:lanl-repo/lareport/LA-UR-05-8767

[8] P. E. Dodd, M. R. Shaneyfelt, J. R. Schwank, and G. L. Hash, "Neutron-induced Soft Errors, Latchup, and Comparison of SER Test Methods for SRAM Technologies," Technical Digest - International Electron Devices Meeting, pp. 333–336, San Francisco, CA, USA, 2002.

[9] JEDEC Standard, "Measurement and Reporting of Alpha Particle and Terrestrial Cosmic Ray Induced Soft Error in Semiconductor Devices," JESD89A, 2006.

[10] H. Iwashita, G. Funatsu, H. Sato, T. Kamiyama, M. Furusaka, S. A. Wender, E. Pitcher, and Y. Kiyanagi, "Energy-resolved Soft-error Rate Measurements for 1–800 MeV Neutrons by the Time-of-flight Technique at LANSCE," IEEE Trans. Nucl. Sci., Vol. 67, No. 11, pp. 2363–2369, 2020, doi: 10.1109/TNS.2020.3025727.

[11] NTT press release, "Neutron Energy Dependence of Semiconductor Soft Errors Was Successfully Measured for the First Time," Nov. 25, 2020.
https://group.ntt/en/newsrelease/2020/11/25/201125a.html

[12] NTT video, "Neutron Energy Dependence of Semiconductor Soft Errors Was Successfully Measured" (long version), https://www.youtube.com/watch?v=mhQmhzj6Zcg

[13] S. Abe and Y. Watanabe, "Analysis of Charge Deposition and Collection Caused by Low Energy Neutrons in a 25-nm bulk CMOS Technology," IEEE Trans. Nucl. Sci., Vol. 61, No. 6, pp. 3519–3526, 2014.

Hidenori Iwashita

Senior Research Engineer, NTT Space Environment and Energy Laboratories.

He received a B.S. and M.S. in nuclear engineering from Hokkaido University in 2006 and 2008. He has been researching soft errors since 2012 at NTT Network Service Systems Laboratories and has been engaged in research on a mitigation technique of soft errors in space at NTT Space Environment and Energy Laboratories since 2020.

Hirotaka Sato

Associate Professor, Laboratory of Applied Neutron Beam Science and Engineering, Division of Applied Quantum Science and Engineering, Faculty of Engineering, Hokkaido University.

He received a B.E., M.E., and Ph.D. in quantum science and engineering from Hokkaido University in 2006, 2008, and 2011. He was a research fellow of Japan Society for the Promotion of Science from 2008 to 2011, postdoctoral fellow in Japan Proton Accelerator Research Complex (J-PARC), Japan Atomic Energy Agency from 2011 to 2012, assistant professor in Hokkaido University from 2012 to 2020, and has been an associate professor at Hokkaido University since 2020. He studied particle accelerator-driven neutron sources, neutron optical devices, neutron detectors, and neutron imaging techniques. He applied neutron imaging techniques he developed to materials science. He has been a member of several research collaborations for neutron-induced soft errors since 2012. He received internal prizes for best student and best young professor from Faculty of Engineering, Hokkaido University, four best presentation awards from the Atomic Energy Society of Japan, young scientist award and best paper award from the Japanese Society for Neutron Science, best presentation award from the Society of Materials Science, Japan, and two best paper awards from Japan Institute of Metals and Materials.

Yoshiaki Kiyanagi

Honorable Professor at Hokkaido University and Honorable Professor at Xi'an Jiaotong University, China.

He received a B.E., M.E., and Ph.D. from Hokkaido University in 1971, 1973, and 1993. He was a professor at Hokkaido University from 1995 to 2012. After retiring, he moved to Nagoya University as a designated professor from 2013 and retired from that position in 2021. He has been working on accelerator-based neutron sources and developed the world's most efficient cold neutron source to use at Japan Particle Accelerator Research Complex (J-PARC). He constructed two neutron instruments for nuclear data measurement and neutron imaging at J-PARC. The imaging instrument is the world's first to use the pulsed nature of the neutron source, which he proposed to J-PARC on the basis of his pioneer work. He applied this method to analyze the crystallographic characteristic of Japanese swords. He engaged in the design of neutron sources for boron neutron capture therapy and contributed to related activities at International Atomic Energy Agency. He joined a research program at NTT to measure neutron-induced soft errors by using compact accelerator-driven neutron sources and supported measurements domestically and abroad. He twice received the Best Paper Award from the Japan Institute of Metals and Materials and the Science Award from Japanese Society for Neutron Science. He is an honorary member of the International Society for Neutron Radiography from 2018.

Recent Standardization Activities of Optical Connectors in IEC

Ryo Koyama and Yoshiteru Abe

Abstract

Optical communication networks and datacenters worldwide use a huge number of optical connectors made in many countries. Optical connectors are products that require precise components because a dimensional error of only 1 µm can affect the optical signal quality. To ensure the compatibility of connectors, it is essential to internationally standardize the component shapes, connector performance, and the measurement methods for testing them. This article introduces the standardization activities and recent trends in optical connectors.

Keywords: optical connector, international standard, optical communication

1. Introduction

International standards for optical connectors are developed by the International Electrotechnical Commission (IEC). The IEC was established in 1906 to promote international cooperation and communication on standardization and related matters in the field of electrical and electronic technology. The work related to the development of the standard is carried out by the technical committee (TC) and subcommittee (SC) established under it, and the standardization for optical connectors is discussed in TC 86 (Fibre optics)/SC 86B (Fibre optic interconnecting devices and passive components). As of February 2021, SC 86B published the second largest number of documents in IEC after TC 61 (Household appliance safety), and the second largest number of documents in work after TC 82 (Photovoltaic power generation). Optical connector standardization activities are one of the most active in IEC.

In the field of optical connectors, the single-fiber coupling (SC) connector and multi-fiber push-on (MPO) connector developed by NTT have held the top share of the market for more than 30 years. In March 2021, both connectors received IEEE Milestone*1 certification [1]. Japan has also made a significant contribution to the standardization of optical connectors and has served as the secretariat of SC 86B since 2003.

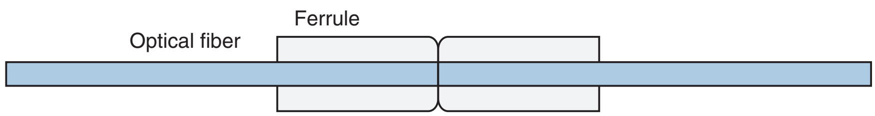
IEC TC 86/SC 86B consists of three working groups (WGs), and standardization documents related to optical connectors are deliberated by WG 4 (Standard tests and measurement methods for fibre optic interconnecting devices and passive components) and WG 6 (Standards and specifications for fibre optic interconnecting devices and related components). Although the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) specifies the performance of optical connectors from the viewpoint of system requirements for communication networks, IEC documents and ITU-T documents are standardized in cooperation to prevent them from becoming double standards.

The IEC standards for optical connectors are divided into four document series, as shown in **Table 1**: basic test and measurement procedures, performance standard, fiber optic connector interfaces, and connector optical interfaces. **Figure 1** shows the specification scopes of the connector optical interfaces and fiber optic connector interfaces standards. Optical

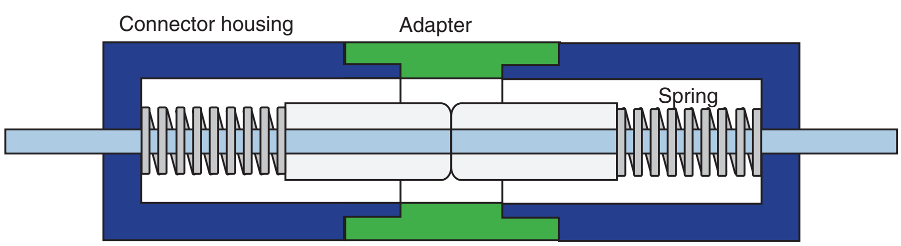
*1 IEEE Milestone: An award certified by the Institute of Electrical and Electronics Engineers (IEEE) to honor the historical achievements of technological innovation and has been internationally acclaimed since its inception more than 25 years ago in the fields of electricity, electronics, information, and communications.

Table 1. Standard document series of optical connectors in IEC.

Document series number	Number of documents	Description
IEC 61300 Series	84	Basic test and measurement procedures
IEC 61753 Series	8	Performance standard
IEC 61754 Series	37	Fiber optic connector interfaces
IEC 61755 Series	15	Connector optical interfaces



(a) Scope of connector optical interfaces



(b) Scope of fiber optic connector interfaces

Fig. 1. Difference between connector optical interfaces and fiber optic connector interfaces.

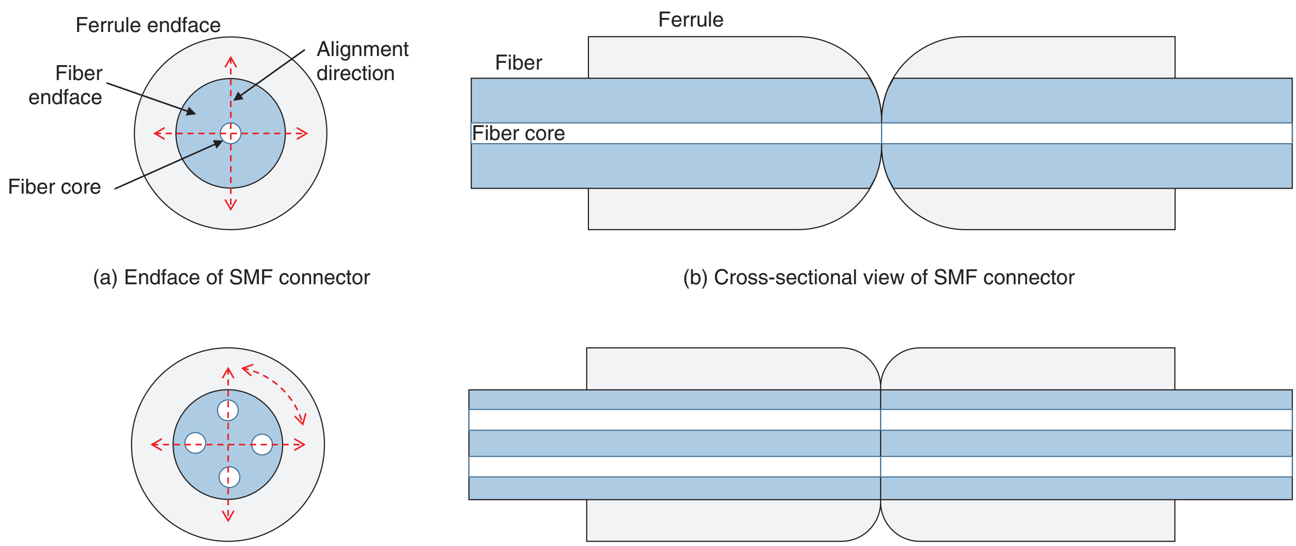
connectors connect optical fibers by aligning and adhering the fiber cores. This connection method is called physical contact (PC) connection. An alignment part called a ferrule*2 is used to align the fiber cores, and the connector optical interfaces standard specifies the dimensions of the ferrule necessary for the fiber cores to adhere to each other. The connector housings and an adapter are rigidly coupled when the connectors are connected, and the ferrules are pressed against each other using a spring built into the housing. The fiber optic connector interfaces standard defines the dimensions and spring force of the housing required for this coupling of connector housings and an adapter. Though PC connection and this coupling structure are adopted in almost all optical connectors, they are independent technologies. For example, the same SC connector requires different ferrules for single-mode optical fiber (SMF) and multimode optical fiber (MMF). The same ferrule is used for different optical connectors such as SC and FC*3 connectors. Considering the actual products, IEC standardized the PC connection and coupling structure separately as the connector optical interfaces and fiber optic connector interfaces standards, respectively.

2. Trends in standardization of optical connectors

SC and Lucent (LC) connectors, which are used for connecting single-core fibers in buildings, have been widely used for connecting long-distance transmission optical fiber cables and transmission equipment. MPO connectors, which are multi-core connectors, have been extensively used for high-speed communication wiring connecting information-processing equipment in datacenters. Outdoor use of optical connectors is also becoming widespread for connecting wireless antennas to fiber optic cables. The communication capacity of SMF, which has supported

*2 Ferrule: A connector component to align optical fibers. It has holes of approximately the same size as the outer diameter of the fiber, and the optical fiber is inserted into the hole and bonded.

*3 FC stands for fiber connector.



(a) Endface of SMF connector

(b) Cross-sectional view of SMF connector

(c) Endface of MCF (4-core) connector

(d) Cross-sectional view of MCF connector

Fig. 2. Endfaces and cross-sectional views of optical connectors.

high-speed and large-capacity communication for a long time, will reach its limit in the 2020s. The research and development of optical fiber for space division multiplexing (SDM), which is expected to enable large-capacity transmission over SMF, has recently been conducted. In the standardization of optical connectors, a new standardization was proposed for use in datacenters and outdoors, and activities related to the standardization of optical fibers for SDM are ongoing.

2.1 Trends in standardization of test and measurement procedures

The standardization of measuring methods of connection loss and return loss has been promoted since 2020 for optical connectors of multi-core optical fiber (MCF), which is one of optical fibers for SDM. **Figure 2** shows the SMF and MCF connector endfaces and their cross sectional views when connected. Since the optical connector for SMF has a fiber core at the center of the connector endface, the center axis of the connector is aligned only horizontally and vertically to reduce connection loss. On the other hand, MCF has a fiber core at the periphery, so the rotational direction must be adjusted. In optical connectors, the endfaces of the connectors are pressed against each other using a spring, and the fiber core adheres to ensure a sufficient amount of return loss. Connection loss and return loss are important optical characteristics that affect optical signal quality, but the farther the fiber core is from the center, the more precise rotational alignment and larger spring force are required to ensure sufficient signal quality. For this reason, it is important to evaluate the connection loss and return loss of optical connectors for MCF when deciding the core configuration of MCF. NTT aims to standardize optical fibers, optical cables, and optical connectors for SDM, but is promoting the standardization of these two measuring methods first.

2.2 Trends in standardization of performance standards

The performance standard for optical connectors specifies optical characteristics, such as connection loss and wavelength characteristics, mechanical characteristics, such as tensile resistance and impact resistance, and environmental resistance to temperature and humidity in the installation environment. High-speed wireless devices, such as mobile antennas and wireless local area networks, have recently been installed outdoors, and demand for optical connectors with environmental resistance for outdoor use is increasing. **Table 2** lists the environmental categories in the IEC optical connector standardization revised in 2018. Before the revision, there were four categories, but the category OP+, which assumes outdoor installation in a more severe climate environment, and C^{HD}, OP^{HD}, $OP+^{HD}$, and I^{HD}, which assume electric

Table 2. Environmental categories for optical connectors in IEC.

Environmental category	Circumstance	Temperature and humidity condition
Category C	Indoor controlled condition	Temperature –10°C to 60°C Humidity 5% to 93%
Category OP	Outdoor protected by a sealed closure	Temperature –25°C to 70°C Humidity 0% to 95%
Category OP+	Outdoor protected by a sealed closure in extreme climate	Temperature –40°C to 75°C Humidity 0% to 95%
Category I	Industrial condition	Temperature –40°C to 70°C Humidity 0% to 95%
Category E	Extreme condition	Temperature –40°C to 85°C Humidity 0% to 100%
Category C^{HD}	Indoor controlled condition settled with electric devices	Temperature –10°C to 70°C Humidity 5% to 93%
Category OP^{HD}	Outdoor protected by a sealed closure settled with electric devices	Temperature –25°C to 85°C Humidity 0% to 95%
Category OP+^{HD}	Outdoor protected by a sealed closure in extreme climate settled with electric devices	Temperature –40°C to 85°C Humidity 0% to 95%
Category I^{HD}	Industrial condition settled with electric devices	Temperature –40°C to 85°C Humidity 0% to 95%

☐ Added in 2018

parts as heat sources in each environment have been added, now totalling nine categories. Optical connectors had generally been used indoors, so most of the performance standard adopted the environmental conditions of category C. However, from 2020, the new standardization work of connector performance with the environmental conditions of category OP+^{HD}, which is the highest temperature, started.

2.3 Trends in standardization of fiber optic connector interfaces

The fiber optic connector interfaces standard mainly specifies the coupling structure of the connector plug and connector adapter and the spring force that presses the ferrule endfaces against each other. **Figure 3** shows the coupling mechanisms of an SC and MPO connectors. With the recent increase in speed of communication wiring in datacenters, the standards with more fiber cores than the conventional 12 cores have been actively standardized for MPO connectors. As mentioned above, optical connectors require physical contact between fiber cores to ensure a sufficient amount of return loss, and a larger spring force is required as the number of fiber cores in the MPO connector increases. Since the MPO connector has an angled endface, if the spring force is increased, a shear force is generated, the alignment of the fiber core deviates, and connection loss deteriorates. Therefore, the number of cores required for each application and the optical characteristics that can be achieved are taken into consideration, and the standardization is carried out by dividing documents into 16 cores, 24 cores, and 32 cores. Twenty-four cores and 32 cores were enacted in 2017 and 2019, and 16 cores are expected to be enacted in 2022. In addition, standardization work for 36 cores is scheduled to begin in 2021.

2.4 Trends in standardization of connector optical interfaces

The connector optical interfaces standard mainly specifies the position of the fiber core relative to the alignment datum of the ferrule. **Figure 4** shows the endface of the zirconia ferrule used in an endface SC connector and mechanical transferable (MT) ferrule used in the MPO connector. Zirconia ferrules use a component called a split sleeve to align the outer diameter of the ferrule to the same position, thus defining the range of the fiber core relative to the ferrule center. Since the MT ferrule is aligned by inserting a guide pin into two guide holes, the fiber core position is defined by the midpoint of the line connecting the two guide hole centers. The connector optical interfaces standard defines those for standard connectors used in ordinary optical communications and those for reference connectors used for high-precision connection measurement of optical connectors. As the use of MPO connectors in datacenters has

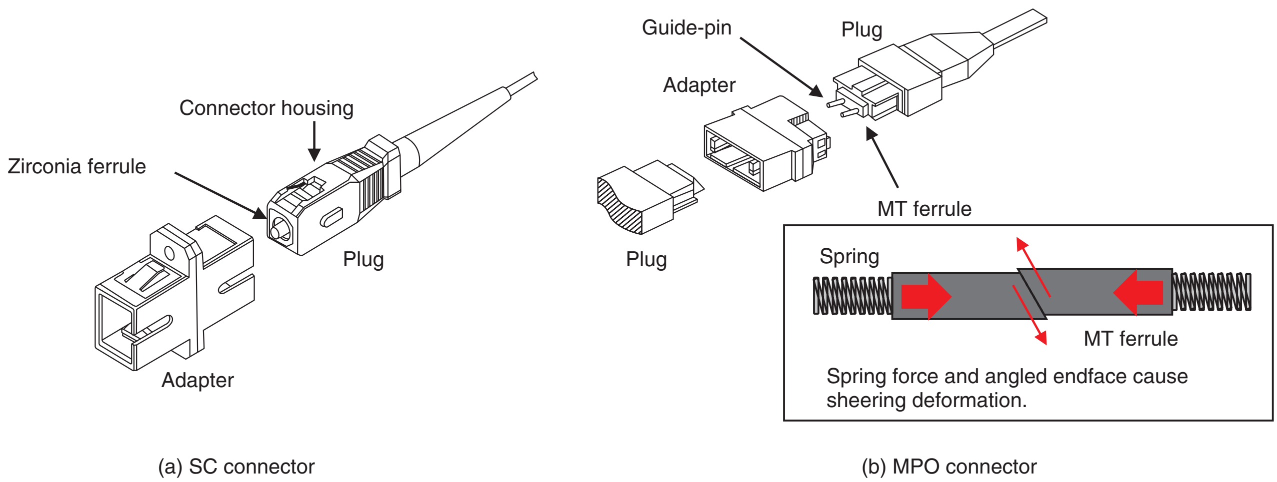


Fig. 3. Coupling mechanism of SC and MPO connectors.

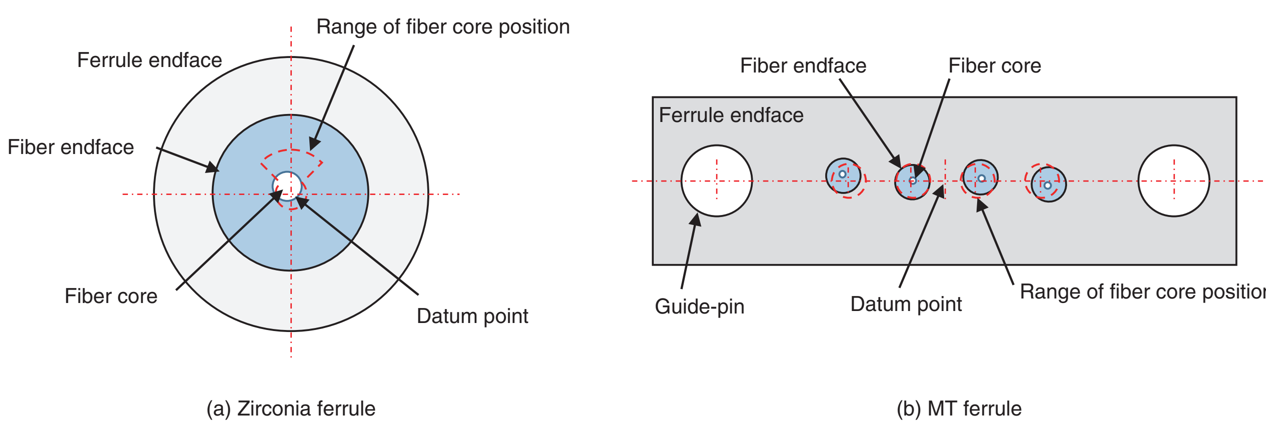


Fig. 4. Fiber core positions of zirconia and MT ferrules.

recently expanded, the number of connector suppliers has increased, and it has become necessary to accurately measure the loss of MPO connectors. MPO reference connectors are not currently standardized, so IEC started to establish new optical compatibility standards for MPO reference connectors in 2019. In theory, the maximum error in the fiber core position for the MT ferrule for the reference connector should be less than 1 µm, but since this error exceeds the measurement accuracy of the current fiber core position, there is no measurement method to confirm this even if it is specified. Therefore, NTT proposed a method for ferrule specification using fiber hole position with higher measurement accuracy and connector selection through a connection loss test.

3. Future outlook

The increasing use of optical wiring in datacenters and high-speed wireless devices and efforts to standardize optical connectors for multi-fiber and outdoor use are expected to continue. In the future, optical wiring is expected to be used on substrates in information equipment and inside automobiles in place of the conventional metal wiring to further speed up information processing, so the standardization of a higher density optical connector and improved environmental resistance optical connector will become important. In optical communications applications, the standardization of optical connectors for connecting SDM transmission fibers is expected to advance due to the development of SDM transmission technology and the progress of its standardization at ITU-T.

Reference

[1] IEEE Milestones: "Physical Contact Push-Pull Technology for Fiber Optic Connectors, 1986," http://ieeemilestones.ethw.org/Milestones:Fiber_optic_connectors

Ryo Koyama

Senior Research Engineer, NTT Access Network Service Systems Laboratories.

He received a B.S. and M.S. in precision engineering from the University of Tokyo in 2001 and 2003. In 2003, he joined NTT Access Network Service Systems Laboratories, where he has been engaged in research on optical fiber wiring and splicing techniques for optical access networks. He is an assistant secretary of the IEC SC 86B and member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.

Yoshiteru Abe

Senior Research Engineer, NTT Access Network Service Systems Laboratories.

He received a B.E., M.E., and D.E. in information science and electrical engineering from Kyushu University, Fukuoka, in 1996, 1998, and 2005. In 1998, he joined NTT Photonics Laboratories and has been engaged in the research of optical connectors. He is a member of the IEC SC 86B and IEICE.

Sulfur Damage and Its Countermeasures in Telecommunication Equipment and Facilities

Technical Assistance and Support Center, NTT EAST

Abstract

This article introduces cases of corrosion caused by hydrogen sulfide in telecommunication equipment and facilities and countermeasures against it. This is the sixty-fourth article in a series on telecommunication technologies.

Keywords: hydrogen sulfide, sulfur damage, corrosion

1. Introduction

Telecommunication facilities, such as utility poles (**Fig. 1**), are installed throughout Japan and exposed to various natural phenomena. These facilities are composed of various materials, such as metals, plastic, and concrete, and gradually deteriorate due to corrosion and abrasion caused by the surrounding environment. In coastal areas, for example, salt damage—which is corrosion caused by particles of sea salt being blown by strong winds and landing onto telecommunication facilities containing metal—is a well-known phenomenon. In Japan, salt damage is unavoidable because of the long coastline. Japan is also a volcanic country, having numerous hot springs. In many of these areas, hydrogen sulfide (H_2S), which is a gas containing sulfur, is emitted from these hot springs. Since H_2S is highly corrosive, it can deteriorate not only outdoor telecommunication facilities but also indoor ones. This type of corrosion is called sulfur damage. Where sulfur damage is severe, terminal equipment fails every few months, so maintenance operations to fix such failures are burdensome. In response to on-site requests, the Technical Assistance and Support Center (TASC), NTT EAST, has investigated instances of sulfur damage on outdoor and indoor equipment and facilities. This article introduces the mechanism of sulfur damage, actual cases of sulfur damage to telecommunication equipment and facilities, and countermeasures against it.

2. Mechanism and actual cases of sulfur damage in telecommunication equipment and facilities

2.1 Mechanism of sulfur damage

The corrosion reaction that causes sulfur damage occurs when a water film is formed on the surface of a material by condensation or moisture adsorption. As shown in **Fig. 2(a)**, when H_2S is absent, the corrosion of iron is caused by oxygen in the atmosphere dissolving in the water film, followed by reduction of the dissolved oxygen on the surface of the iron and simultaneous dissolution of the iron. When sea salt is also dissolved in the water film, the corrosion rate of iron will increase due to the increased electrical conductivity of the water film. When there is H_2S present

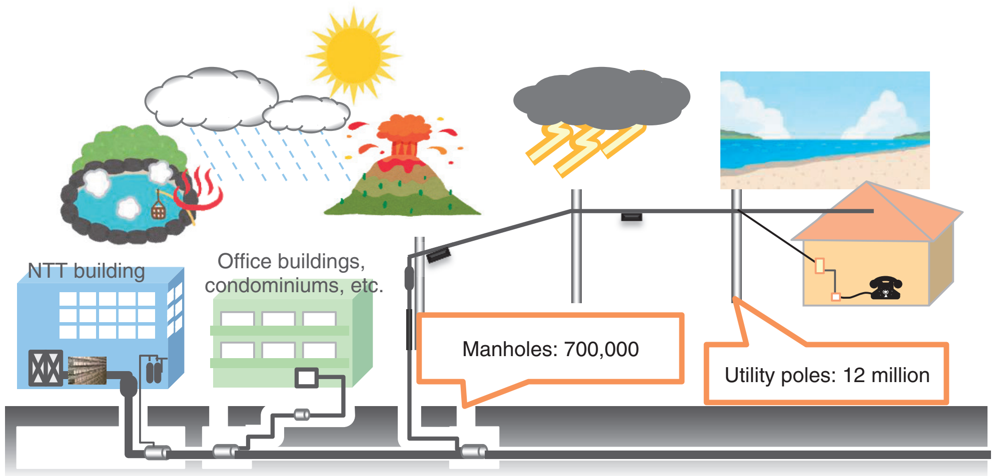


Fig. 1. Telecommunication equipment and facilities exposed to natural phenomena.

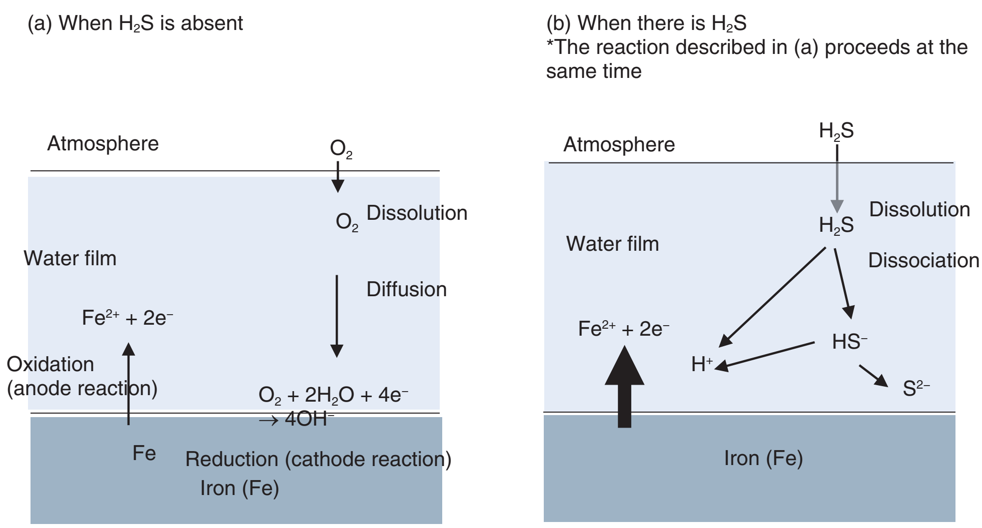


Fig. 2. Corrosion mechanism.

(**Fig. 2(b)**) in addition to the reactions illustrated in Fig. 2(a), the H_2S dissolves and dissociates in the water film to produce H^+ ions, which results in an acidic environment in the water film. This acidity accelerates the dissolution of iron and results in a high corrosion rate.

2.2 Actual cases of sulfur damage

2.2.1 Sulfur damage to outdoor facilities

Examples of sulfur damage to outdoor facilities at a hot-spring area are shown in **Fig. 3**. Significant rusting (reddish brown) was found on the metal bands at the lower part of the guy-line rod and scaffolding bolts on the utility pole. Thinning can be seen in the central part of the guy-line rod, so the rod may break when corrosion progresses. Although this type of corrosion can be caused by either salt or sulfur damage, since this hot-spring area is located in a mountainous area far from the coast, the effect of salt damage is considered small. Moreover, measurements of gas concentration at the locations shown in Figs. 3(a) and (b) detected H_2S at 1.5 ppm (parts per million) and 0.9 ppm, respectively. The above corrosion phenomena are thus considered to be sulfur damage, the main

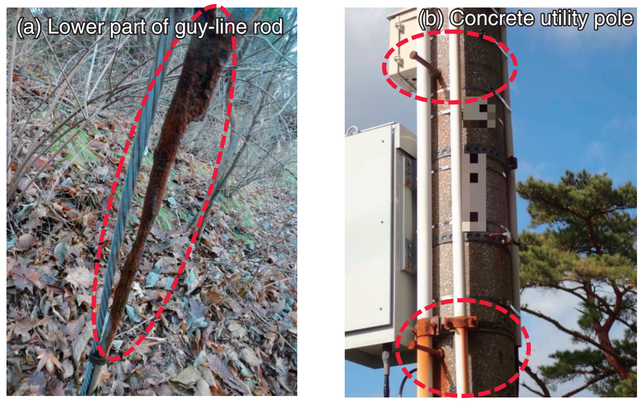


Fig. 3. Examples of sulfur damage to outdoor facilities.

factor of which is H_2S. The regulation value for atmospheric concentration of H_2S stipulated by the Offensive Odor Control Law is 0.06 to 0.2 ppm [1], and the Industrial Safety and Health Act stipulates that the concentration of H_2S should be less than 1 ppm to ensure a safe working environment [2]. Accordingly, the measured H_2S concentrations (1.5 and 0.9 ppm) at these facilities indicate that H_2S exists at high concentrations at those locations.

2.2.2 Sulfur damage to indoor equipment

The corrosion rate of metals in an indoor environment is generally lower than that in an outdoor environment because the intrusion of sea-salt particles and H_2S is hindered. However, if indoor spaces (rooms, etc.) are not sufficiently sealed, corrosion may occur due to the intrusion of sea-salt particles or H_2S. Since H_2S is a gas, it is difficult to completely prevent it from entering indoor spaces.

TASC has conducted a number of field investigations of indoor equipment after receiving requests for technical consultations from service personnel. An example of sulfur damage to indoor equipment is shown in **Fig. 4**, which illustrates sources of H_2S (Fig. 4(a)), examples of metal corrosion in indoor equipment (Fig. 4(b)), and micrographs of a circuit board inside a piece of terminal equipment (Fig. 4(c)). In this example, the concentrations of H_2S near the hot-spring-water vat and fumaroles, which are thought to be the sources of H_2S, were 0.1 and 0.9 ppm, respectively. It was also confirmed that metal fixtures, such as windows and faucets, were significantly corroded in the indoor environment, and it is considered that the corrosion is caused by the intrusion of H_2S from outdoors.

In the other case investigated by TASC, a ppb (parts per billion, where 1 ppb = 1/1000 ppm) level of H_2S concentration was detected in indoor environments. From the results of scanning electron microscopy - energy dispersive X-ray spectrometry (SEM-EDS) analysis, the main component of the corrosion depicted in the figure was sulfide, which indicates that a reaction between the metal and H_2S had occurred. Black corrosion was found on copper wiring and around through holes by microscopic observation of a circuit board collected from a faulty piece of terminal equipment installed in the same indoor space. SEM-EDS analysis of this black corrosion revealed that it contained sulfur in a similar manner to the indoor metal fixtures described above, and X-ray-diffraction analysis of the corrosion identified the main component as copper sulfide. When the copper wiring pattern on a circuit board is corroded by H_2S and becomes copper sulfide, it grows on the circuit board and connects to adjacent wiring, through holes, etc. It is thought that since the copper sulfide is conductive, a short circuit occurred between the wiring and through holes, which should not be connected, causing the equipment failure.

3. Countermeasures against sulfur damage

3.1 Basic requirements for countermeasures against sulfur damage

As the installation standard for terminal equipment, JEITA IT-1004 (Standard for Operating Conditions of Industrial Computer/Control System) of the Japan Electronics and Information Technology Industries Association [3] recommends controlling H_2S concentration to 3 ppb or less. There are several methods of suppressing corrosion caused by H_2S, as listed in

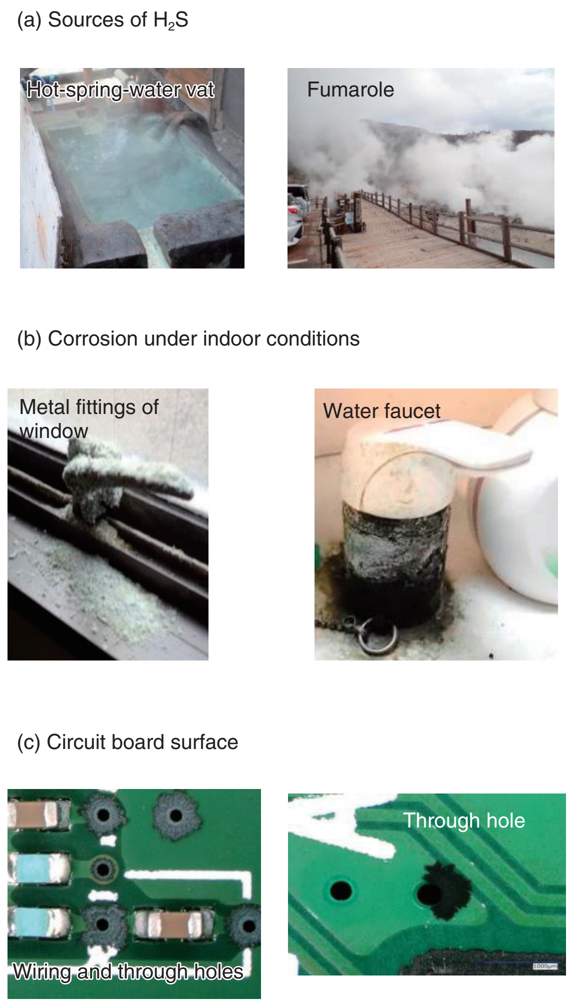


Fig. 4. Examples of sulfur damage to indoor equipment.

Table 1. Methods of suppressing corrosion caused by sulfur and their application to telecommunication equipment and facilities.

Methods of suppressing corrosion	Application to telecommunication equipment and facilities	Application status and reasons for judgment
Selection of appropriate materials (use materials with low reactivity with H_2S)	Difficult	Steel and copper currently in use are very versatile, and it is difficult to select alternative materials.
Isolation from the environment (suppresses contact with H_2S)	Applicable	Outdoor facilities: Painting and plating Indoor equipment: Coating surface of circuit board
Control environmental conditions (reduce H_2S concentration)	Applicable	Install equipment in an enclosed space Use gas adsorbent
Electrochemical control such as using sacrificial electrodes	Difficult	Difficult to implement for a large number of facilities

Table 1. Taking costs and other factors into consideration, the basic requirements of countermeasures against sulfur damage to telecommunication equipment and facilities were determined as suppressing contact with H_2S and reducing H_2S concentration.

Fig. 5. Example countermeasure against sulfur damage to outdoor telecommunication facilities (metal bands with powder coating).

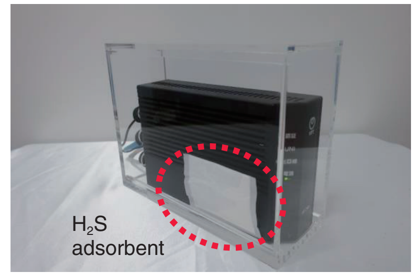


Fig. 6. Countermeasure against sulfur damage to indoor telecommunication equipment.

3.2 Countermeasures to suppress corrosion due to sulfur outdoors

Since concentration of H_2S is higher outdoors than indoors, namely, at the ppm level, countermeasures are required to provide higher corrosion protection performance. To meet this requirement, it is necessary to ensure that outdoor facilities and equipment are prevented from coming into contact with H_2S. One way to prevent contact is to coat the surface of the base metal with a paint that has stronger adhesion. By increasing the adhesion between the paint coating and base metal, it is possible to suppress (i) direct contact between H_2S and the metal and (ii) the adhesion of moisture (water film) containing H_2S to the metal. Therefore, it is possible to reduce the occurrence of sulfur damage. An example of metal bands coated with a powder coating, which has stronger adhesion and higher corrosion resistance than conventional coatings, attached to a concrete utility pole is shown in **Fig. 5**.

3.3 Countermeasures to suppress corrosion due to sulfur indoors

An example of a countermeasure against sulfur damage to indoor telecommunication equipment is shown in **Fig. 6**. The concentration of H_2S can be reduced by installing the terminal equipment inside a sealable acrylic box and placing H_2S adsorbent inside. In fact, a customer who had been experiencing failures of terminal equipment every two months or so has been free of failures for more than 10 months after starting to use an acrylic box.

4. Conclusion

Effective countermeasures to protect telecommunication equipment from sulfur damage is to (i) prevent the equipment from coming into contact with H_2S and (ii) reduce the concentration of H_2S in the vicinity of the equipment. Housing indoor equipment in acrylic boxes containing H_2S adsorbent has been implemented. For outdoor facilities, a powder coating, which provides better corrosion protection than conventional zinc plating, can be used. Applying these countermeasures will extend the life of telecommunication equipment and facilities.

TASC will continue to promote technical-cooperation activities to solve problems in the field, such as those related to degradation of equipment and facilities due to sulfur and salt damage. Through these activities, we will contribute to improving the quality and reliability of telecommunication services.

References

[1] Website of the Ministry of the Environment, Offensive odor control law (in Japanese), https://www.env.go.jp/hourei/10/000013.html

[2] Website of the Ministry of Health, Labor and Welfare, Laws and regulations concerning chemical substances (in Japanese), https://www.mhlw.go.jp/content/11303000/000541391.pdf

[3] JEITA IT-1004: Standard for Operating Conditions of Industrial Computer/Control System (in Japanese), https://home.jeita.or.jp/is/publica/standard/IT-1004.pdf

External Awards

Activity Contribution Award

Winner: Jun Terada, NTT Device Technology Laboratories and NTT Device Innovation Center
Date: March 11, 2021
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE) Electronics Society

For his contribution as a director of general affairs in Electronics Society.

IPSJ Journal Specially Selected Paper

Winners: Masamichi Hosoda, NTT Smart Data Science Center/NTT Service Evolution Laboratories; Hiroshi Sakamoto and Tomoki Murakami, NTT Access Network Service Systems Laboratories; Tadashi Mouri, NTT Service Evolution Laboratories; Akira Nakayama, NTT Research and Development Planning Department; Tomoaki Ogawa, NTT Access Network Service Systems Laboratories; Masaru Miyamoto, NTT Smart Data Science Center/NTT Service Evolution Laboratories
Date: March 15, 2021
Organization: Information Processing Society of Japan (IPSJ)

For "2D Position Estimation for Wireless LAN Terminals by the Access Point Using Distributed Antenna System."
Published as: M. Hosoda, H. Sakamoto, T. Murakami, T. Mouri, A. Nakayama, T. Ogawa, and M. Miyamoto, "2D Position Estimation for Wireless LAN Terminals by the Access Point Using Distributed Antenna System," IPSJ Journal, Vol. 62, No. 3, pp. 946–958, Mar. 2021.

Research Encouragement Award

Winner: Hiraku Toida, NTT Basic Research Laboratories
Date: March 16, 2021
Organization: Superconductivity Division of the Japan Society of Applied Physics

For "Electron Paramagnetic Resonance Spectroscopy Using a Single Artificial Atom."
Published as: H. Toida, Y. Matsuzaki, K. Kakuyanagi, X. Zhu, W. J. Munro, H. Yamaguchi, and S. Saito, "Electron Paramagnetic Resonance Spectroscopy Using a Single Artificial Atom," Commun. Phys., Vol. 2, 33, Mar. 2019.

Young Researcher Best Presentation Award

Winner: Kosuke Takiguchi, NTT Basic Research Laboratories
Date: March 16, 2021
Organization: The 49th Autumn Meeting of the Japan Society of Applied Physics

For "Quantum Transport Evidence of Weyl Fermions in an Epitaxial Ferromagnetic Oxide."
Published as: K. Takiguchi, Y. K. Wakabayashi, H. Irie, Y. Krockenberger, T. Otsuka, H. Sawada, S. A. Nikolaev, H. Das, M. Tanaka, Y. Taniyasu, and H. Yamamoto, "Quantum Transport Evidence of Weyl Fermions in an Epitaxial Ferromagnetic Oxide," Nat. Commun., Vol. 11, 4969, Oct. 2020.

IEEE SSCS Japan Industry Contribution Award

Winner: Jun Terada, NTT Device Technology Laboratories and NTT Device Innovation Center
Date: March 17, 2021
Organization: IEEE Solid-State Circuits Society Japan/Kansai Chapter

For his contribution to activities of the Solid-State Circuits Society Japan in promoting outstanding papers written by researchers in the corporate sector in the International Solid-State Circuits Conference.

The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, Prize for Science and Technology (Development Category)

Winners: Hiroyuki Oto and Shinya Hasegawa, NTT DOCOMO; Yasuyuki Uchiyama, DOCOMO Technology; Kazuaki Obana, NTT Smart Data Science Center; Yoshihiro Nakajima, NTT DOCOMO
Date: April 14, 2021
Organization: Ministry of Education, Culture, Sports, Science and Technology

For the commercial deployment of network functions virtualization technology enabling inter-operability with multi-vendor solutions.

ITU-AJ Encouragement Award

Winner: Taiji Sakamoto, NTT Access Network Service Systems Laboratories
Date: May 17, 2021
Organization: The ITU Association of Japan

Dr. Sakamoto promoted the development of high-speed optical fiber and submarine optical communication systems under Questions 5 and 8 in ITU-T Study Group 15. He has submitted more than 30 contributions to enable Japanese technologies to be reflected in international standards and led the drafting of three ITU-T Recommendations as the editor. His contributions are especially noteworthy in recommending G.654.E (High Speed Long-Haul Optical Fiber) and incorporating Japan's technology into the recommendation. He is expected to continue to play an important role in international standardization activities in the future.