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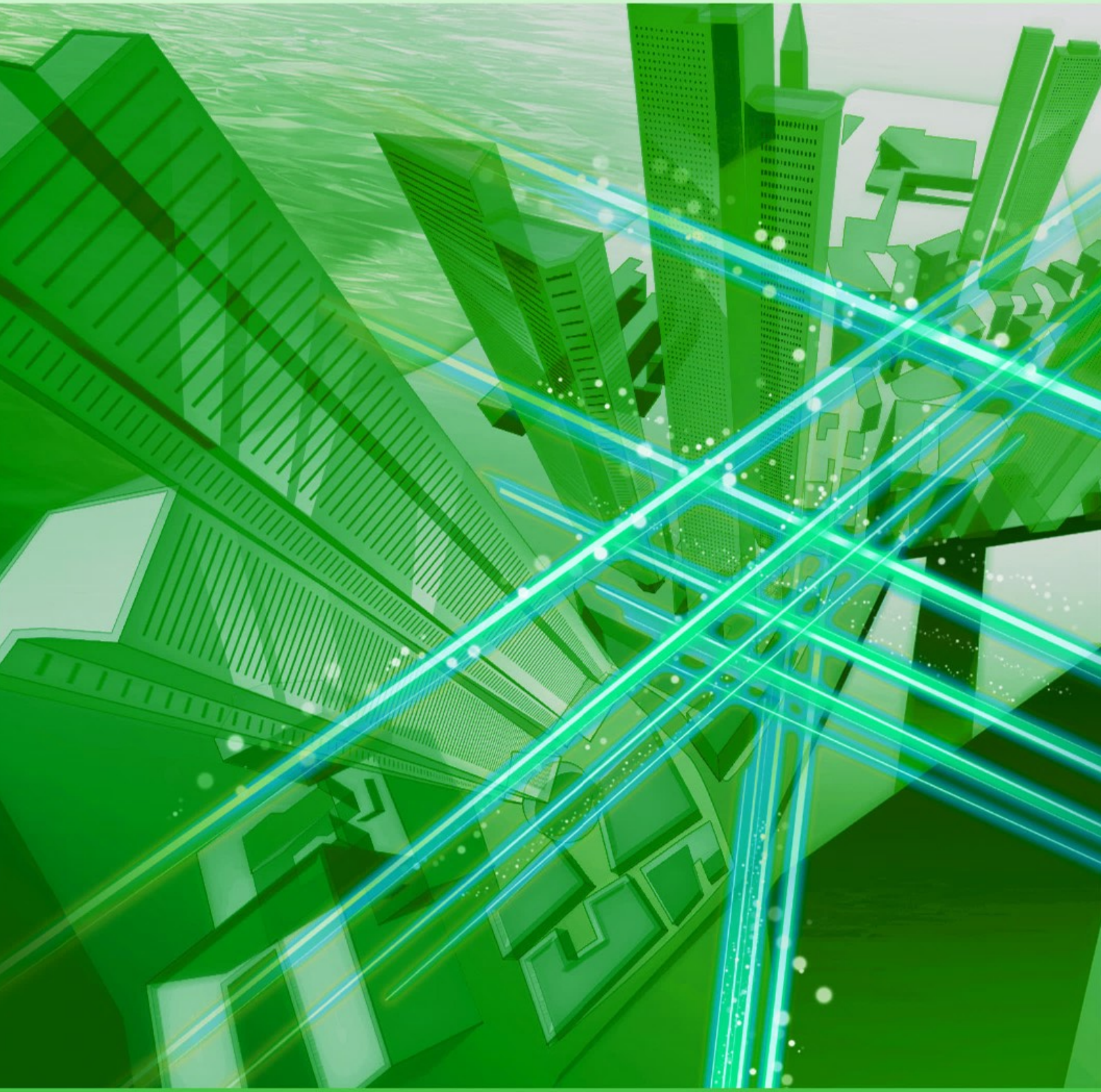

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Taking on Challenges with Three Strategies: Expansion, Evolution, and Maximization for the Global Top 5

Tsuyoshi Kitani
Executive Vice President and Director, Head of Technology and Innovation General Headquarters, NTT DATA

Overview

NTT DATA ranked ninth in "Brand Finance IT Services 15 2019" published by Brand Finance in 2019, showing its brand value to the world [1]. The company is striving to expand its business globally across 53 countries. We asked Tsuyoshi Kitani, NTT DATA executive vice president and director, about the medium-term management plan announced in May 2019 and his attitude toward work.

Keywords: strategy, global, center of excellence

Understanding people and cultures and foresight into social needs are key

—Can you tell us about NTT DATA's medium-term management plan?

Regarding our medium-term management plan announced in May 2019, in addition to further accelerating digital transformation to maximize value provided to our clients, we want to increase global synergy within the NTT Group based on the following three strategies: (i) expanding global digital offerings, (ii) delivering greater value to clients based on regional needs, and (iii) unleashing our employee's potential that maximizes organizational strengths. Through these strategies, we aim to achieve net sales of 2.5 trillion yen and an operating income margin of 8% in fiscal year 2021, ending March 31, 2022.

This is a pretty challenging goal. At the same time, we are aiming to break into the global top 5 in terms of sales in the information technology (IT)-service industry. Although we are currently in eighth place and our competitors are quite strong, we want to expand our business in North America and Europe to further increase our overseas sales ratio to reach the top 5. This target is also a challenge; even so, we want to spread our brand as an innovative company trusted by clients worldwide.

Regarding the first strategy, expanding global digital offerings, I think it would be easier to understand if you consider our offerings as *solutions*. These solutions can be used both in Japan and globally. Focusing on finance, insurance, cars, distribution, healthcare, and life science industries, we intend to create these solutions in collaboration with domestic and international team members and provide them to clients.

For the second strategy, delivering greater value to clients based on regional needs, companies we acquired have been providing IT services in each region, and even from a global perspective, there is no such thing as a *uniform business*. Our clients' businesses also vary, so it is necessary to adapt to the

characteristics of each region. For example, the current scale of business in the US—which focuses on outsourcing—is about 400 billion yen. Outsourcing in this case refers to *IT outsourcing*, namely, provision of total services from the development of business applications and maintenance and management of software to take charge of infrastructure-related operations such as server computers and networks, and *business-process outsourcing*. To achieve further growth, we have begun to develop automation tools and organize processes and will continue to develop and execute business strategies according to regional characteristics.

Finally, the third strategy, unleashing our employee's potential that maximizes organizational strengths, means maximizing organizational strengths by enhancing the capability of employees globally according to our common values—namely, *clients first*, *foresight*, and *teamwork*. We are currently training employees to improve their digital and technical skills. By fully taking advantage of these skills, we can not only propose new services to clients but also improve our productivity. I believe these benefits will lead to the reforming of work styles. We will also establish an appropriate governance system to prevent unprofitable projects from continuing and strengthen information security governance. Regarding information security, we and our clients may be subject to various attacks; accordingly, we have launched a project called "ZEN" to protect corporate organizations and data and are promoting it globally by skillfully applying new security measures and IT mechanisms.

—What is the key behind these strategies?

I think it is understanding people and cultures and having the foresight into the needs of society.

The NTT DATA Group currently has about 130,000 employees, and those overseas account for about 90,000 of this total. The number of employees outside Japan is the largest, and sales outside Japan account for about 41% of totals sales, so this naturally infers that clients outside Japan are increasing in number. Under these circumstances, we must consider strategies not only from the Japanese perspective but also from those of other countries. Each region and country has a different cultural background, and businesses are established on the basis of such background. A strategy can only become global through understanding each other's cultural backgrounds, and the NTT DATA Group can work together as a united global company to grow our business.

I believe that by promoting cutting-edge technologies and innovations and using them effectively, we will be able to meet the expectations of society and reach the targets in our management plan. This is the foresight I mentioned previously. Being in charge of technologies, I'm in a position to plan and execute technology and innovation strategies for the entire group while promoting technologies—and their applications and development—that should draw the attention of the group. It is necessary to introduce new technologies to clients in a way that is easy to understand and clearly explain how they can be useful; to that end, it is important to understand client needs, create the technologies required to meet those needs, and provide them to clients in a stable manner. To promote this strategy globally, appropriate technical skills are required. In particular, I make sure new employees thoroughly study technologies then gain experience through on-the-job training.

The artificial intelligence (AI)-related business is growing rapidly; thus, we are focusing on it. Among the fields in which AI is used, healthcare is a particular focus of ours. An easy-to-understand use case is AI analysis of medical images. For example, X-ray, magnetic resonance imaging, and computed-tomography-scanned images are analyzed by specialists such as radiologists to diagnose diseases, and AI is used to assist such analysis. Since the accuracy of AI is quite high, it is also useful for addressing the shortage of doctors as well as reducing the rates of misdiagnosis. We have increased our efforts concerning deep learning and are collaborating with partners abroad. To that end, we have launched a center of excellence (CoE) that is tasked with nurturing technical skills and spreading the associated knowledge through leadership positions. As an organization for

consolidating technical knowledge for NTT DATA as a whole, the CoE is collecting good practices and methods, supporting client projects, and providing training for employees. The CoE represents a pretty significant move for us.

We also are developing software at home and abroad, and it is very important to improve the productivity of that development. With that importance in mind, we are currently working on automating software development. Major initiatives are automatically generating and running source code of programs from design information and providing a development environment containing a wealth of development tools on the cloud.

Spare time for communication

—What do you value when carrying out these tasks?

I value communicating, which is the key behind our strategies as I mentioned earlier. Ways of thinking and cultures worldwide and even within Japan naturally differ; thus, it is very important to understand those differences. To attain such understanding, it is best to meet in person and speak as much as possible. However, such meetings are often difficult, so I frequently exchange emails and make phone calls in an effort to understand others. My schedule is usually full from morning until night, and even if I can talk to people during meetings, I cannot travel to far-away places. Therefore, I have to rely on emails and phone calls, and such communication may not be timely. As a result, I try to make as much time as possible and communicate in various ways. Through these actions, I feel that I have gained people's trust when they come to me in regard to various consultations and proposals. I think that's because I gradually built relationships through daily communications.

I myself have been blessed with supportive superiors who have often listened to me. I started my career at the NTT Group as a researcher. When I transferred to NTT DATA, there were times when my research activities were not going as well as before. I was worried and finally told my boss, "Let me leave the company and go to graduate school." In fact, I was already preparing to leave the company and go to a university in the United States. My boss, however, said, "If you want to go on to graduate school, why not let the company send you there?" So, I ended up going to a university in the US for two years without having to leave the company. I'm convinced that being allowed to go to a US university at that time has helped me in my current position.

My work during those valuable two years was on natural-language processing based on text analysis, which is an area that is currently regaining attention. In addition to that research, I communicated with many people in the US and was exposed to US culture, and such research and experience are very useful for my current work. The importance of communication is definitely embodied in that experience.

My study abroad was triggered by a deadlock in research activities at the company, which can be called a setback. There are always small setbacks, disappointments, and regrets. However, I think that although such feelings can be forgotten over time, it is important to remember the events that occurred as facts. Failure to do so will result in repeated failures and setbacks. Therefore, I think we should convey the facts that should be told to those around us, and forget the rest. If your emotions have a lasting effect, that condition will affect other business.

Check the facts and forget the rest

—How have you accumulated facts so far?

I've been writing and storing notes, including memos for meetings, in notebooks for more than ten years, but I have stopped writing them on paper. The reason is that they cannot be taken outside the company.

These important memos contain client information and confidential company information, so it would be a serious problem if I dropped them in a public place such as on a train. Therefore, instead of using paper memos, I have switched to electronic memos, which are encrypted and stored safely. Even if a memo is lost, it is in a state in which it cannot be easily read. Also, by keeping records on the computer, I can perform searches that were difficult on paper. I have about ten notebooks that I used in the past, which are stored in a safe place.

Looking back on my past memos, I see that I was working on various initiatives. Since I am in the position of overseeing and supporting technical development, I don't work directly with clients on large projects. Even so, I noted that over the past two years, young members of my team started various types of businesses in Japan and overseas. I am happy that they have taken that path.

—What does work mean to you? And do you have a message for our engineers?

I enjoy my work. I enjoy experiencing new things. One of the most enjoyable endeavors recently is our CoE. It is a lot of fun because it gathers a variety of information from around the world and uses it to support many people and things. Since we belong to a company, performance and figures are indispensable, and we need to increase sales and profits. That is also one of the joys. The sense of achievement regarding performance and figures not only applies to me but also pleases my team members. However, contributing to society is also important. Contributing to the company will also contribute to society. In addition to doing business, we are actively engaged in corporate social responsibility activities such as picking up litter at Tokyo's Toyosu Station and nearby areas. These activities are fun because they lead to the realization that we are contributing to society.

I tell our engineers that they should aspire to be experts. We are in a competitive market, so I want them to increase their expertise and aim to become top in their respective fields. Achieving the top level means producing results through daily studies and projects. Society is full of varied information, so it is important to carefully scrutinize it as well as gather and examine new information.

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Interviewee profile

■ Career highlights

Tsuyoshi Kitani joined Nippon Telegraph and Telephone Public Corporation (now NTT) in 1983. In 2012, he became vice president and head of Research and Development Headquarters of NTT DATA. In 2016, he became executive vice president, concurrently serving as the head of Technology and Innovation General Headquarters, System Engineering Headquarters in Technology, and Innovation General Headquarters. He has held his current post since June 2017.

Imagination of Collectiveness Improves Our Well-being

Junji Watanabe
Senior Distinguished Researcher, NTT Communication Science Laboratories; NTT Service Evolution Laboratories (Concurrent)

Overview

The rapid advancement in digital technology, such as artificial intelligence and virtual reality, is changing the way society works, including the way we work. In Japan, a "super-aging" society, it is said that the population will decline to about 110 million in 2040, and the population over the age of 65 will reach about 30% of the total; in other words, an unprecedented population structure is expected. In such a situation, how will technology affect our lives? We asked Junji Watanabe, a senior distinguished researcher at NTT Communication Science Laboratories, who conducts research on tactile information technology and nonverbal communication, about our well-being and his initiatives to improve it.

Keywords: well-being, sports social view, workshop

Seeking "something" created by collectiveness goes beyond information transmission

—Could you tell us about your current research?

I'm mainly engaged in research and development on tactile sensation and communication, but I'm also involved in workshop-based initiatives on human well-being. Recently, I've become interested in how embodied communication works to improve people's well-being. Much research on sensation is centered on sensory communication, namely, transmitting information from A to B. However, I'm interested in *collective physicality*, which infers that *something* is created between the physical interaction of people and goes beyond information transmission.

Regarding sports broadcasts, for example, the place where spectators gather to watch an event, such as a stadium or public-viewing venue, interests me. Research on "*Ba*" (places where people gather) is extensive; however, I wanted to take another look at it in the context of watching sports. In other words, I wanted to learn what we can do when we think of sports as a way of connecting people. I wanted to reconsider "being with others" from emotional experiences such as the uplifting feeling we get when we witness a great performance together, a sense of unity when people's excitement coincide, and the feeling that it was nice to watch sports with someone.

One example of my research on watching sports is the project called *Sports Social View*, jointly conducted by Akiko Hayashi, a senior researcher at NTT

Service Evolution Laboratories, and Asa Ito, an associate professor from the Tokyo Institute of Technology [1]. This project aims to extract the essence of a sports event, transform it into a different physical experience, and share it with the visually impaired. In judo for example, two normally sighted people, acting as judo players, pull against each other while holding both ends of a piece of cloth mimicking the pulling on each player's judo uniforms, while the visually impaired person grasps the center of the cloth. By doing so, the visually impaired person can sense the strategy of how judo players use their strength during a Judo bout. The interesting aspect of this project is that spectators (two sighted people and visually impaired) do not need to be completely passive; they can play an active part as well. That is, each sighted person has to move along with the movement of the judo players, while the visually impaired person follows the pulling action with his/her hands so as not to let go of the cloth. It might be more apt to say that the sighted and visually impaired individuals are either recreating the judo bout or creating a new bout. In this project, this experience is called *generative viewing*.

For my current research, I began to think about collectiveness in a place to eat. Eating meals with someone is a collaborative physical activity we experience every day. For example, if you go out to eat the Japanese dish *sukiyaki*, you'll see not only the people who eat the food on one side but also see, on the other side, the *griller* grilling the meat with the skill of a craftsperson and serving it with perfect timing. The griller not only provides meals but also interacts with customers to create a pleasant dining experience. The general flow of a sporting event and the contents of a meal are fixed. Even so, we should not watch such an event by just passively listening to audio or eat by just waiting for the meal to be served; instead, I believe it is important for us to proactively engage in these activities and create a place that leads to autonomous satisfaction in the company of others.

It is possible to expand this concept to research in information and communication technology (ICT). By connecting people in distant locations via telecommunications, watching sports together remotely, and creating a system that allows us to recognize that someone is eating a meal or even to feel the sensation what another person feels when eating a meal, we can create a new form of "Ba." Naturally, this form will also include being with someone in cyberspace in which people, things, and events are digitized.

Fig. 1. Book cover of "Information Umwelt" [2].

—What is the meaning of working with people in research?

In April 2019, we published a book titled "Information Umwelt" (**Fig. 1**), which summarizes the results of earnest discussions on the theme *information umwelt* [2] among 17 experts from various fields, including researchers, artists, and designers, and the related workshops held over five months. Five people who attended a public talk at NTT Intercommunication Center (ICC) [3] in Shinjuku, Tokyo, became core members, and each member invited others with whom they thought would be interesting to carry out the research together. These core members participated in a total of ten meetings held over five months.

Various workshops were held over that period. In these workshops, participants recognized the differences in each other. The flow of a workshop is as follows. Each participant puts a piece of paper that describes three factors that constitute their well-being into a box. Each participant comes on stage, draws a piece of paper from the box, and talks about the three factors according to what is written on that paper as if he or she were the person who wrote it. In this way, the speakers verbally express unexpected sense of values, and those who heard their factors spoken about by others will have a different interpretation. The above-mentioned discussions, including these

workshops, were compiled as a single book. The term *Umwelt* is a German term that refers to the unique world of perception and movement experienced by a living organism. Taking ticks as an example, we know that they have little visual or auditory sense and live by choosing what is important to them using their sense of smell and temperature. That which can be created by the link between perception and movement is the tick's *Umwelt*. People too live in their own different worlds, but because those worlds are different, I think we can create something new between them.

Sense of balance between being subjective and objective

—You seem to be researching with a focus on the human mind and the individual.

In research on science and technology, experiments are conducted, papers presenting the results of those experiments are written, and the applications of the results are easy to understand. On the contrary, many of my current activities may be difficult to understand from the outside. Therefore, in addition to making sense of the results from social standards and external norms, it is necessary to express them from a perspective of internal norms while maintaining as much objectivity as possible; convincing people of research value while becoming a research communicator. I think it is important to incorporate these internal and external norms in a balanced manner.

A similar balance exists regarding research on well-being. It is important to balance subjective satisfaction (internal) with data or rating (external). We must first consider what well-being is. It may be easy to understand if you look at the "Workshop Manual for a Life of Well-being" [4], which was compiled as part of a project that I am involved in called "Development and Dissemination of Information Technology Guidelines for Promoting Japanese-style Well-being" in the research area called Human-Information Technology Ecosystem (HITE) initiated by the Research Institute of Science and Technology for Society (RISTEX) of the Japan Science and Technology Agency (JST). The aim of this project is designing well-being by focusing on not only subjective well-being—in an individualistic Western manner—but also the value system unique to Japan and how to incorporate ICT in this design. We have also been exploring how ICT can be used in addressing well-being issues unique to Japan.

The manual contains the results of a question asked to 1300 college students, "What are the three main factors that determine your well-being?" The factors that contribute to our sense of well-being can be divided into three main categories, *I* for individuals, *we/society* for relationships with others, and *universe* that goes beyond the other two types of factors. *I* factors include, for example, the autonomy that makes us feel able to make decisions and act and the sense of competence related to our ability. *We/society* factors include consideration and appreciation as well as good relationships within organizations and companies. *Universe* factors include the way the world looks from an overall perspective beyond our specific relationships, sense of peace and meaning of life, and social responsibility. I divided the factors given by the 1300 students into these three categories. While the students who gave all three factors as *I*, accounted for 37% of the respondents, most of the rest gave more than one factor as *we/society*. These results indicate that relationships with other people is important in the well-being of Japanese students.

—If your relationships with others lead to well-being, how you interact with people seems to be important.

The workshop manual also describes a workshop that considers well-being in our daily lives and aims to solve problems based on a sense of well-being (**Fig. 2**). It contains various scenarios from friction at home to product development. In this workshop, participants first try to loosen tensions between people in places and, as an icebreaker, take part in a task called "heartbeat picnic"—in which a device vibrates in sync with the heartbeat, and participants feel their own and other's heartbeats through their hands. This task is aimed at stopping the making of "good" or "bad" judgments and to focus on what is happening on the spot through physical sensations. After that, the participants work on a *partiality map/pain map* to verbalize one's likes and dislikes. At the same time, the participants listen to others speaking of their likes and dislikes and immediately recognize the diversity among them. What the participants are feeling is then abstracted as the three above-mentioned categories.

Then, problems dealt with in the workshop will be tackled in accordance with the factors that have been conceptualized. During the "vision boot camp" task, feedback is repeatedly received and given many times in a short time to determine the direction of an idea to solve problems in terms of well-being. Then in a four-frame storyboard, participants witness the creation of

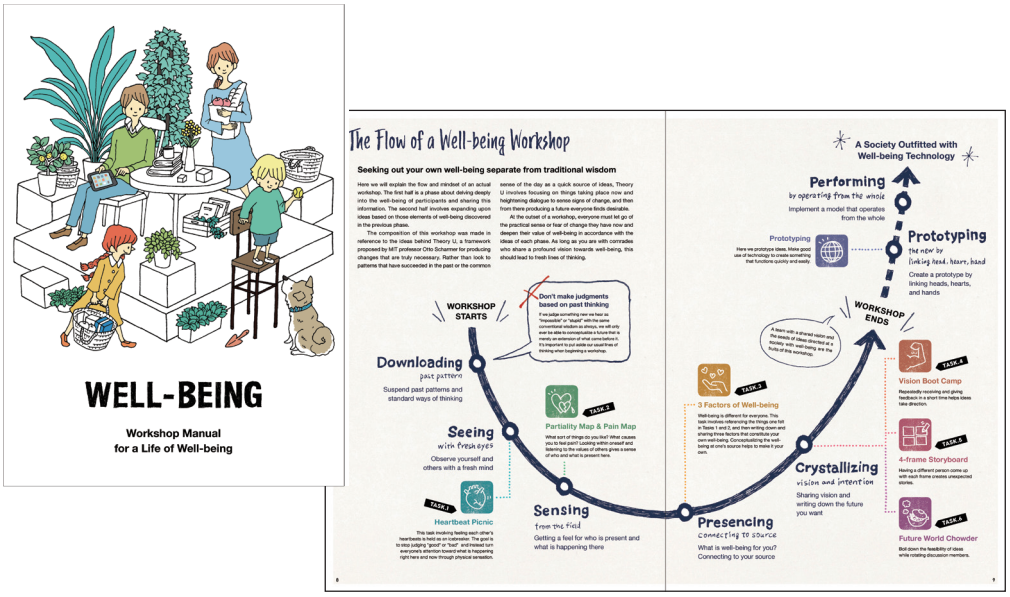

Fig. 2. Flow of well-being workshop [4].

an unexpected story by four people drawing each panel. In "future world chowder," participants discuss the feasibility of ideas from various perspectives through discussions in which members are changing.

The steps in this series of workshops aim at focusing on well-being, sharing the story of each participant's well-being as discussion materials on the spot, and solving problems. This is very different from an approach that focuses on a problem and trying to solve it efficiently. We are planning to experimentally implement such well-being workshops not only in Japan but also in countries with different cultures and values and develop a community base (living lab) for social design centered on well-being.

How to be collective and generative in research activity?

—Where did these ideas come from?

Rather than having a strong and clear will, an inner voice may say, I feel as if "You *might* want to do this." Even if you didn't intend to do it at first, you may notice that it matters to you as you continue your work. For example, I did not intend to be involved in research on eating, but the opportunity arose in which I had no choice. When I started getting involved in such research, I came to realize that it was deeply related to tactile sensation and well-being. In my case, I don't start research with an explicit goal; instead, if I feel *something* about a particular research topic, I will start it. Then, I think back about what was the *something* I had felt.

—Please give a few words to younger researchers.

Above all, make sure you have good peers. I can say that the book "Information Umwelt" was published because I could worked with the four co-authors and enjoyed it. You need to find peers with whom you can tackle large challenges. In addition, your research field doesn't need to be close to your peers' research fields. I also think it is necessary for your peers to be able to explain your work. It takes time to properly convey research to outsiders. Even if you can't explain well what you do, letting people know that what you do is significant will open up other possibilities. If you have difficulty speaking, it's a good idea to create printed material.

Lastly, I think it is important to conduct research and work without being passive and feeling you are forced to do something. If you look at yourself and others from the perspective of controlling someone versus being controlled by someone (like being made to do something) or investing in someone versus getting a return from someone (like doing something but getting no reward), that *something* (new value created by collectiveness) will not be born between you and

others. Although research is based on the abilities of individuals, *something* new is created in collaboration with other researchers, peers from different fields, and society. This mindset is necessary for pursuing your research.

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■ **Interviewee profile**

Junji Watanabe

Senior Distinguished Researcher, Human Information Science Laboratory, NTT Communication Science Laboratories; NTT Service Evolution Laboratories.

He received a Ph.D. in information science and technology from the University of Tokyo in 2005. His academic work has been published in scientific journals in the field of neuroscience and interface technologies. He has also presented his work at technology showcases, science museums, and art festivals such as at SIGGRAPH (2006–2009, 2014) and Ars Electronica (2002, 2004, 2007–2017, 2019). His research is focused on cognitive science and communication devices with applied perception.

Towards the Era of IOWN

Jun Sawada
President and Chief Executive Officer, NTT

Overview

This article presents a lecture given by Jun Sawada, NTT President and Chief Executive Officer, at NTT R&D Forum 2019 held on November 14th and 15th, 2019. The lecture introduced the concept of the Innovative Optical and Wireless Network (IOWN), which was announced by the NTT Group in 2019.

Keywords: IOWN, All-Photonics Network, Digital Twin Computing, Cognitive Foundation

1. Characteristics of Japan through history

In this lecture, I'll talk about a new information and communication infrastructure called the Innovative Optical and Wireless Network, or IOWN. Before introducing this new concept, I'd like to look back on the history of Japan. Since many international visitors are here today, I'll explain to you what kind of country Japan is.

1.1 Japan in ancient times (around third century)

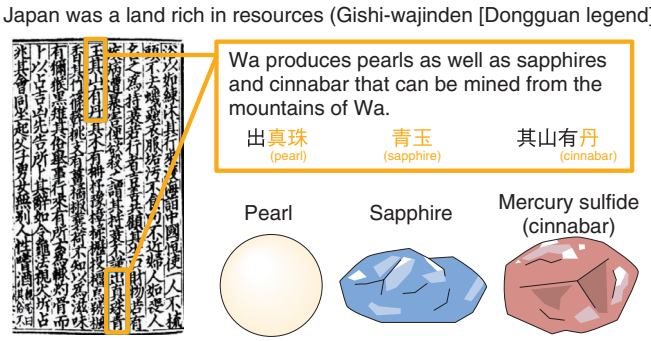
Japan was introduced in the "*Gishi-wajinden*"—a first history of Japan, which was written in China during the Three Kingdoms Period (220–280 CE) (**Fig. 1**). At that time, Japan was called "Wa," and it was written that "Wa produces pearls as well as sapphires and cinnabar that can be mined from the mountains of Wa." Sapphire is said to have been abundantly harvested in present-day Toyama and Nara. Cinnabar, also called vermilion, is a compound called mercury sulfide. Although it is very poisonous, it was used as a preservative and in various medicines and paints at the time. Mercury sulfide was mined in Nara in large quantities and Oita and Tokushima. Therefore, we can see from the China's history book that Japan was a rich resource-producing country.

1.2 Japan during the Edo period (17–19th centuries)

In the 17th century, although Japan was mostly a closed society, it actually traded extensively with the Netherlands. For example, in a picture painted by the Dutch painter Vermeer, geographers and astronomers are wearing Japanese-style kimonos, which are said to have been very prized in Europe [1].

Research has shown that 30% of the silver in the world during that time was produced in Japan. The Netherlands imported a considerable amount of silver from Japan through Dejima in Nagasaki. According to Yoshihiko Amino's book "A History of Japan 00: What is 'Japan'?" [2], 40% of peasants were engaged in various businesses, such as crafts, as opposed to farming. It seems that crafts produced by these skilled individuals were exported to Europe.

Let's compare Japan with Europe during the Industrial Revolution. The Industrial Revolution was a revolution in energy. For example, in London, labor was being saved, and while capital was being consolidated, energy was being invested in with the aim of spurring economic growth. In contrast, by concentrating labor and saving capital, Edo (present day Tokyo) had become a city with a population of one million with recycling-oriented eco-infrastructures such as a sewerage system. If we compare the two, we



Source: Gishi-wajinden and colorants (in Japanese), https://www.jstage.jst.go.jp/article/shikizai1937/75/7/75_330/_pdf

Fig. 1. Japan in ancient times (around the 3rd century).

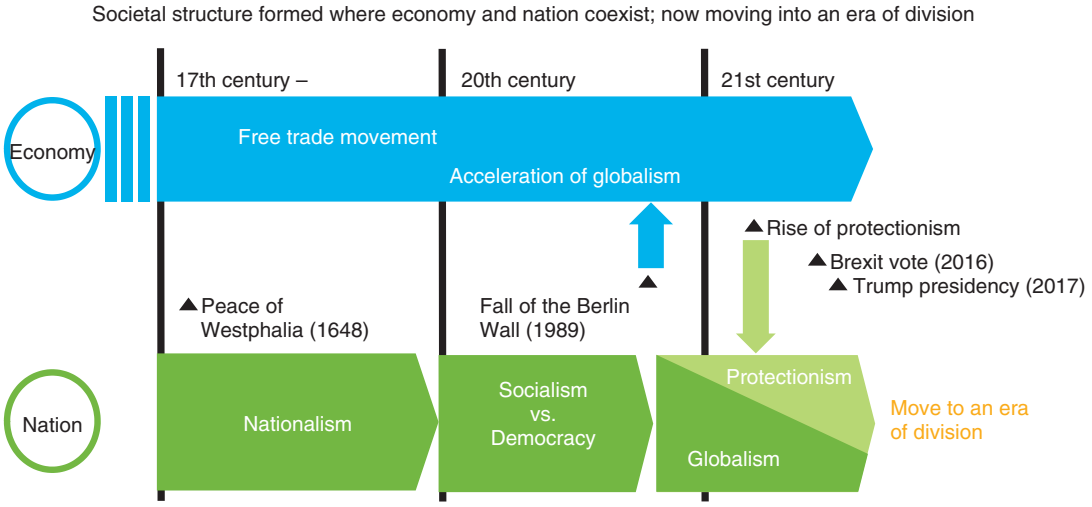


Fig. 2. Structure of modern society (division on national level).

can clearly see that the two cities had opposite outlooks.

By looking back on history in this way, we can say that Japan was a rich resource-producing country and influenced the world through exports, and Edo was one of the world's largest eco-metropolises (with a population of one million).

1.3 Structure of modern society

Let's look at the structure of modern society in terms of economy and the nation (**Fig. 2**). From an economic point of view, as we have seen in the examples concerning silver and kimonos I mentioned before that free trade existed much earlier than we previously thought. At the national level, the concept of the nation was born after the Peace of Westphalia Treaty in 1648, and after the conflict between socialism and capitalism during the 20th century, divisions between countries due to the rise of protectionism, such as the current US-China trade war, are now expanding. In addition, the flood of information due to big data and information filtering using artificial intelligence (AI) will provide only information that is biased to individual preferences, and this division between individuals will become more apparent.

Next, looking at modern society dualistically, we see contrasting concepts such as "global versus local" and "centralized versus decentralized" (**Fig. 3**). Telecommunications has transformed from an analog world to a digitized one, which has greatly changed

Fig. 3. Structure of modern society (dualism).

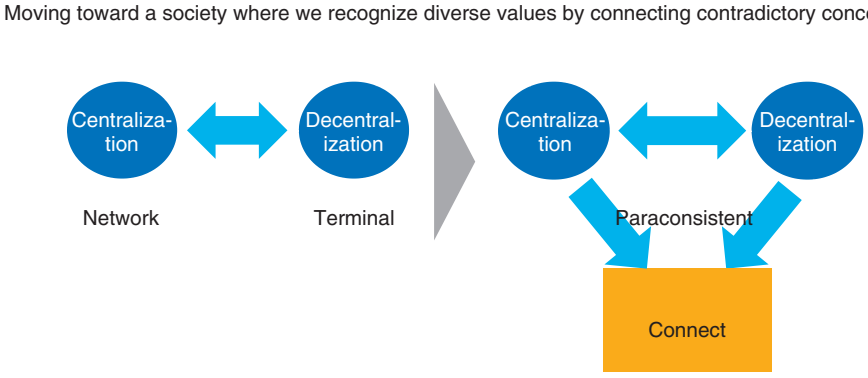


Fig. 4. Societal aspirations (paraconsistent management).

society. It was a process of integrating services and various types of information. However, the recent emergence of edge computing has created a situation in which services and information are integrated and distributed. Although computers have been downsized from mainframes and become widespread, they are also becoming re-centralized through the cloud and decentralized again through edge computing. In other words, we can consider a situation in which centralization and decentralization currently co-exist.

In the past, there were many issues involved in choosing between centralization and decentralization. Today, however, to handle such conflicting concepts, it is necessary to develop a *paraconsistent* world by connecting both concepts while allowing for such contradictions and to build a society that recognizes diverse values (**Fig. 4**). Specifically, I believe that sustainable growth can be achieved by reconciling the characteristics of the economic expansion of modern European societies with the recycling society of Edo (**Fig. 5**).

1.4 From electronics to photonics

Extreme global weather events, such as intense heatwaves in Europe and strong typhoons in Japan, have been occurring more frequently. Experts say that these events are due to global warming. To achieve sustainable growth, I believe that certain technical issues must be overcome. First, the use of the Internet of Things, big data, AI, etc. is progressing rapidly, and power consumption tends to increase with the processing of large amounts of data. What's more, issues regarding the end of the semiconductor evolution are also being raised. To address these issues, NTT has been researching signal processing using photonics-electronics convergence technologies, which introduces photonics technology into chips, instead of using conventional electronic technology. In April 2019, we announced the development of an optical transistor that operates with the lowest energy consumption in the world [3]. In addition, Intel, Sony, and NTT have announced the establishment of the IOWN Global Forum in the United States as an international initiative to promote photonics-related

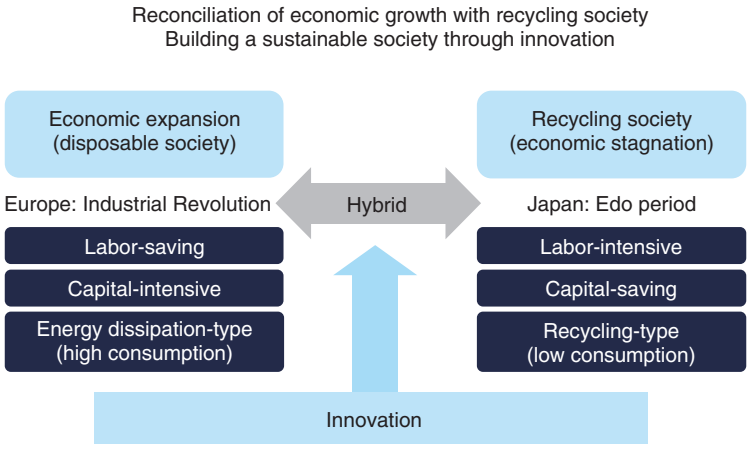


Fig. 5. Innovation.

research and development using photonics-electronics convergence technologies [4]. Photonic devices using photonics-electronics convergence technologies are the basis of IOWN, and we want to use such devices to expand the capabilities of terminals, devices, and applications supported by networks.

2. What is IOWN?

IOWN consists of three elements: (i) the All-Photonics Network, which introduces photonics technology from the network to terminals; (ii) Digital Twin Computing, which enables future predictions by integrating the real world with the digital world; and (iii) Cognitive Foundation®, which controls information and communication technology (ICT) resources by connecting everything.

2.1 All-Photonics Network

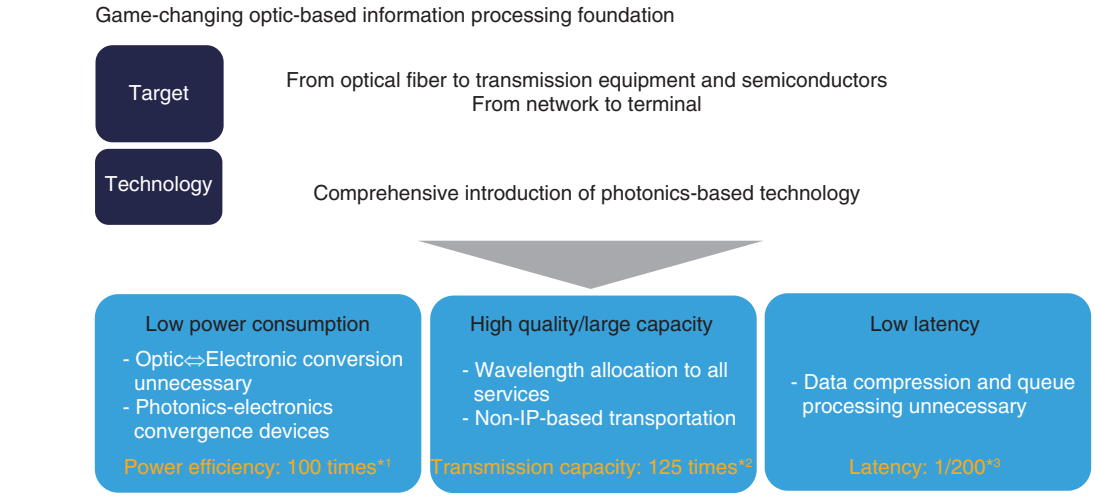
In current networks, it is necessary to convert optical signals into electrical signals at routers for switching paths, etc. In contrast, the All-Photonics Network achieves low power consumption, high quality, large capacity, and low latency by introducing photonics-based technologies for everything from optical fibers to transmission equipment and semiconductors as well as from networks to terminals (**Fig. 6**). We have begun discussions on wireless technologies for IOWN to increase transmission capacity. We have also announced the beginning of joint research with Japan Aerospace Exploration Agency (JAXA) to expand the use of outer space through, for example, application of satellite MIMO (multiple-input and multiple-output) technology to increase the capacity of communications between low-earth orbit satellites and ground stations. Moreover, we want to develop wireless connection technology for dynamically allocating optimal radio frequencies to users. The creation of the All-Photonics Network will expand the range of optical transmission from end to end, enabling quantum communication by transmitting quantum-entangled states. We want to build a quantum-communication-based platform that will enable quantum cryptography on which eavesdropping cannot occur.

2.2 Digital Twin Computing

Digital twin is a concept that accurately represents real-world objects and people in cyberspace so that predictions and optimal proposals can be made (**Fig. 7**).

The second element of IOWN, Digital Twin Computing, is an extension of the conventional concept of digital twin. We believe that a new world beyond the real world can be created by multiplying various digital twins. By duplicating, fusing, and exchanging digital twins that even digitize people's minds such as emotions and values, it will be possible to build a new world in cyberspace and feed back simulation results from that world to the real world.

In the meantime, concrete problems concerning what to do to achieve Digital Twin Computing will become apparent. Such problems include configuration and expression of digital twins, interaction with



*1 Target value for power efficiency of photonics technology portions. *2 Target value for transmission capacity per optical fiber.
*3 Target value for end-to-end delay in image traffic no longer requiring compression processing within same prefecture.

Fig. 6. All-Photonics Network.

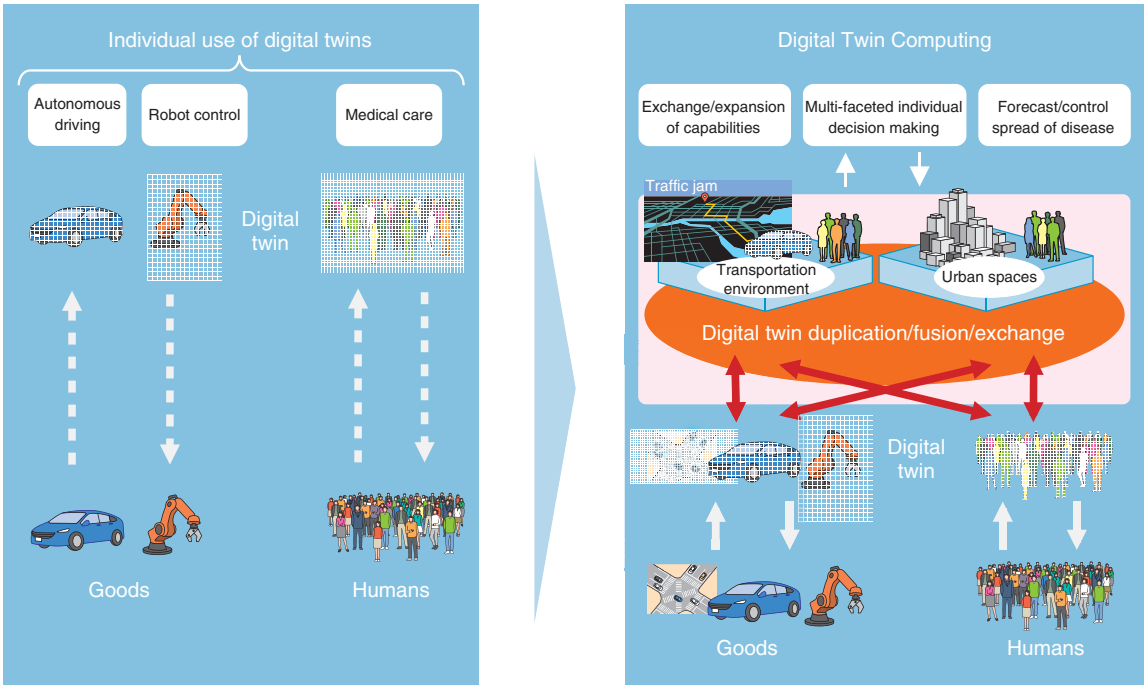


Fig. 7. Digital Twin Computing.

the real world, precise future prediction via digital twins, and construction of a new world view (social-science considerations). I believe that some of these problems will include social-science issues that cannot be dealt with using technological theory alone. Accordingly, we started a collaborative project with a group led by Professor Yasuo Deguchi of Kyoto University. In this project, we will investigate an *inclusive parallel world view* as a new viewpoint of the real and digital realms based on the philosophy of an

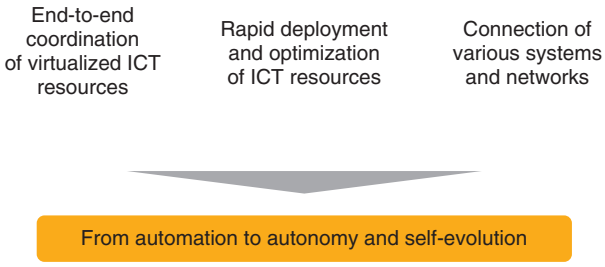


Fig. 8. Cognitive Foundation®.

Eastern self-view. To put that more concretely, we will consider the world created by digital technology in parallel and inclusively with the real world and study the purpose of life, ethics, and social systems in that digital world.

2.3 Cognitive Foundation®

Cognitive Foundation can centrally execute construction, configuration, management, and operation of, for example, the ICT resources of users (**Fig. 8**). It enables rapid deployment of ICT resources and optimization of configurations of such resources in multi-domain, multi-layer, and multi-service/multi-vendor environments. In the future, it will evolve into fully automated, autonomous, and self-evolving operations.

The current version of Cognitive Foundation has been commercially deployed in Las Vegas, USA. Co-developed with Dell Technologies, it uses the orchestration function from NTT Comware, which implements software by UBiqube (based on the virtualization software of VMware). It allows data to be collected from various systems without being bound by format, and the city can be provided with solutions based on those data to enable reactive responses and proactive predictions. We are planning to expand Cognitive Foundation to other cities.

2.4 A roadmap for IOWN

I'll first describe the roadmaps for each of the three components of IOWN. Regarding the All-Photonics Network, starting with miniaturizing optical transceivers in a few years as devices incorporating photonics-electronics convergence technology, we aim to enable inter-chip optical transmission in the medium term, and in the long term, enable on-chip optical transmission. Also in the medium term, we plan to establish technologies to allocate wavelengths to each service and speed up satellite communications.

Regarding Digital Twin Computing, we plan to establish zero-latency media technology for enabling immediate interaction in the short term then build a new world view based on social-science considerations and create digital twins of people (i.e., modeling people's minds). Finally, from the results of these plans, we aim to develop ultra-high-speed future-prediction technology for driving a virtual society.

Regarding Cognitive Foundation, from the level of predictive maintenance in a single system (such as anomaly detection based on deep learning), we are aiming to advance into optimal wireless connection through multi-wireless control technology, autonomous operation of multiple systems, and finally autonomy that uses cooperative autonomous control technology. As 5G (fifth-generation mobile communications) becomes more advanced in parallel with these technological developments, base stations will become software based by working with the Open Radio Access Network (ORAN) in the wireless-access section. In core networks, we believe that white-boxing of hardware will be promoted by the Telecom Infra Project (TIP) and other organizations.

The founding members of the IOWN Global Forum, which I mentioned earlier, are Intel, Sony, and NTT, and 65 other companies are currently considering to participate in it, including Orange, Verizon, Microsoft, and Chunghwa Telecom. This forum is expected to receive applications from many organizations in the future, and we want people with knowledge of the humanities and social sciences to join us and study the new world together.

3. Concluding remarks

Although the NTT R&D Forum introduced exhibitions focused on the keyword IOWN, IOWN is currently evolving and may change periodically into the future. NTT is currently promoting the business

model *B2B2X* (business-to-business-to-X) to create a *smart world*. The main players are the second "B" in this model (service providers), and NTT's role is to assist customer transformation as an enabler (namely, a catalyst and supporter). While strengthening our efforts toward a smart world, we hope to simultaneously develop new infrastructure.

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What's IOWN? - Change the World

Katsuhiko Kawazoe
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Overview

This article presents a lecture presented by Katsuhiko Kawazoe, NTT Senior Vice President, Head of Research and Development Planning Department, at NTT R&D Forum 2019 held on November 14th and 15th, 2019. The lecture introduced NTT's latest research and development activities, focusing on Innovative Optical and Wireless Network (IOWN).

Keywords: IOWN, All-Photonics Network, Digital Twin Computing, Cognitive Foundation, smart agriculture

1. Diverse value judgments and umwelts

The title of my presentation today is "What's IOWN? - Change the World." Last year, I spoke here on the subject: "Making the World Smart and Technology Natural." This year, I'll be introducing specific implementations of that theme; namely, Innovative Optical and Wireless Network, or IOWN. I'll explain the significance of IOWN from a slightly different perspective from that of the previous presentation.

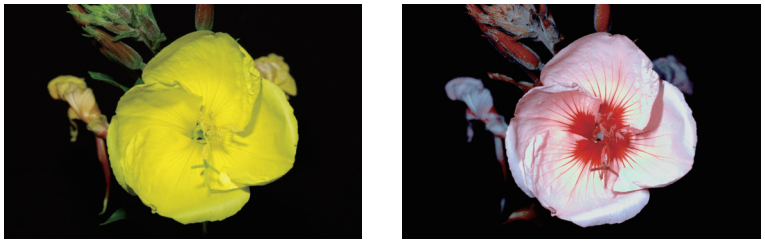
1.1 Creating innovation through learning from living things

Imagine we are suddenly away from the city. We are in the middle of a pleasant green meadow. Beautiful wildflowers are blooming all over the meadow. If I close my eyes, I can sense the fragrance of various flowers. Let's get closer. This yellow flower is an evening primrose. It's beautiful (**Fig. 1(a)**). Now, look at this image (**Fig. 1(b)**). This is the same primrose flower captured by Bjorn Roslett, a Norwegian scientist, from the perspective of living things that are not human beings. The yellow primrose that we humans see looks like this to those organisms.

They are honeybees. Honeybees can see ultraviolet rays, which humans cannot. The flower looks yellow to human eyes. But, if you could see ultraviolet rays, you could detect that there is pollen and nectar in the central part of the flower. For honeybees, a flower looking beautiful is of no value. However, information about where they can collect nectar and pollen is very valuable to them.

Let's go under the sea. There's something in the gloom. It's a squilla. It is said that squillae have the best visual system of any animal. They have receptors that can discriminate as many as 12 different colors. Humans discriminate intermediate colors based on three primary color (red, blue, and green) receptors and information processing in the brain. In contrast, squillae sense things extremely rapidly with their 12-color receptors and minimal information-processing (**Fig. 2**). What's of value to them is a high-speed response to capture animals moving in the water. In the case of honeybees, what's remarkable is that they can see what humans cannot. What is notable about squillae is that they have a mechanism for directly processing information.

For a long time, humans have created innovation through learning from other living things, especially by mimicking them. The designs of jet planes and trains are examples of using such a mimicry approach. We want to take it a step further. Every animal species has its unique sensory world in which it lives. Jakob



(a) (b)

Photo by Bjorn Roslett/Science Photo Library (Aflo)

Fig. 1. Flower as viewed by humans (a) and honeybees (b).

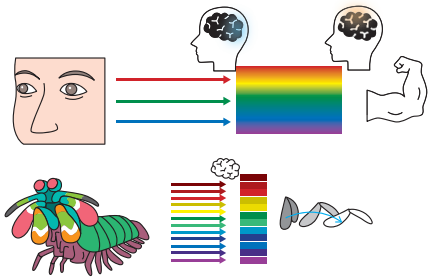


Fig. 2. Comparison between the ways in which humans and squillae see something.

von Uexküll, a German biologist, called this interpretation "umwelt" to signify a self-centered world, using the German term for "environment." It means that how things look varies depending on the viewer. Accordingly, the type of information a species transmits and the way it processes information vary depending on the value judgment of that species.

1.2 Technology to capture diverse value judgments

An example of diversity in value judgment can be seen in the recent developments in smartphones. For example, the latest models have multiple camera sensors with different focal lengths and exposures and incorporate technology for taking photos that best suit the needs of the user.

One of the basic research projects exhibited in this R&D Forum is the optical meta-surface. Its minute, nano-sized structure makes it possible to manipulate wavelength, polarization, and phase of light at will. We are hoping that this technology will enable us to produce sensors comparable to the eyes of honeybees.

We believe that if we regard the world as a field that holds diverse values, and if we can use information hitherto unused due to the apparent absence of any value in it, we will be able to create new values that we could have never previously imagined. A connected car is an obvious example. What is vital for drivers is the ability to confirm, instantaneously and accurately, that the road ahead is safe. Getting a clear image of the road using 4K or 8K is less important than exhaustively capturing information that can be used to determine if the road surface is icy or if there are any dangerous objects on the road.

2. IOWN

2.1 Aims of IOWN

The conventional motivations for developments in information and communication processing have been to increase speed, capacity, and efficiency using digital signal processing. For example, the Internet has proven useful for many services and business activities through adoption of common protocols to provide an inexpensive network based on the "best-effort" principle. However, if we are to evolve technology to simultaneously capture the diverse values that exist in the world, we need to penetrate new technical domains. Both the umwelt of honeybees and that of squillae actually exist in this world. However, these types of worlds are missing from the current world of the Internet protocol (IP) or the digital world. We want to convey sufficient information, process it appropriately based on diverse values, and provide benefits naturally. This is innovation that can be achieved through IOWN (**Fig. 3**).

With IOWN, we aim to create an innovative information processing base that will process a greatly expanded volume of information than is currently

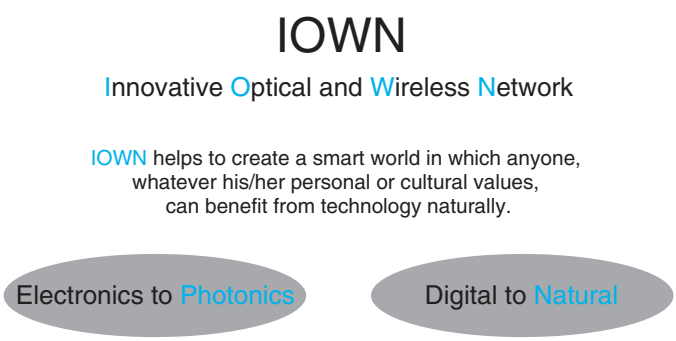


Fig. 3. IOWN.

possible, thereby bring about an innovative means to break out of conventional technical constraints, such as power consumption limitations. Wouldn't you agree that, these days, the Internet is used for almost everything? For example, there is no need for everything to be connected to the Internet, but Internet of Things (IoT) is taken for granted. IOWN is our initiative for mustering the courage to shift from the logic of sheer numbers, the logic that supports our attachment to the Internet, to the logic of values. For this purpose, we are pursuing a transition from digital to natural and, equally important, from electronics to photonics, which is necessary for overcoming technical limitations. Through these two transitions, we aim to provide ultimate safety, security, and reliability, enable sustainable economic growth in an environmentally friendly manner, and achieve local and global optimization that is tolerant of diversity.

2.2 IOWN Global Forum

On October 31, NTT, Intel Corporation (Intel), and Sony Corporation (Sony) announced the establishment of a new industrial forum called IOWN Global Forum for the purpose of cooperating with global partners in driving research and development (R&D) for IOWN. During my presentation, Ms. Asha Keddy from Intel and Mr. Masayuki Hattori from Sony, both heading up IOWN projects in their respective companies, were invited to come to the podium to speak about their expectations for IOWN.

2.3 Elements of IOWN

IOWN consists of three elements.

- All-Photonics Network, which is aimed at dramatically enhancing the potential of the information processing base.
- Digital Twin Computing, which is aimed at creating a new environment for services and applications.
- Cognitive Foundation®, which is aimed at optimally harmonizing all information and communication technology (ICT) resources.

I will explain these elements in more detail and conclude by focusing on the "W" (wireless technology) in IOWN.

3. All-Photonics Network

The first element is the All-Photonics Network. The intent of all-photonics is not necessarily to replace all electrical components with optical parts but, rather, to use optical technology everywhere.

3.1 Photonics-electronics convergence technology

Optical technology was first applied to long-distance transmission. The fact that Japan is a leading country in the penetration of FTTH (fiber-to-the-home) owes much to NTT's optical technology. However, information processing components, such as CPUs (central processing units), are fabricated using electronic technology called complementary metal oxide semiconductor (CMOS).

IOWN applies optical technology not only to networks but also inside semiconductors in terminals and servers. The intent is to expand the use of photonics technology. The basis for achieving all-photonics technology is photonics-electronics convergence, which makes it possible to process light and electricity on a single chip. This technology is already beginning to be used in network interfaces called coherent optical subassembly (COSA). Silicon photonics technology is used to fabricate tiny optical transceivers and an optoelectronic converter on silicon chips. The left photo in **Fig. 4** shows an initial 40-Gbit/s optical

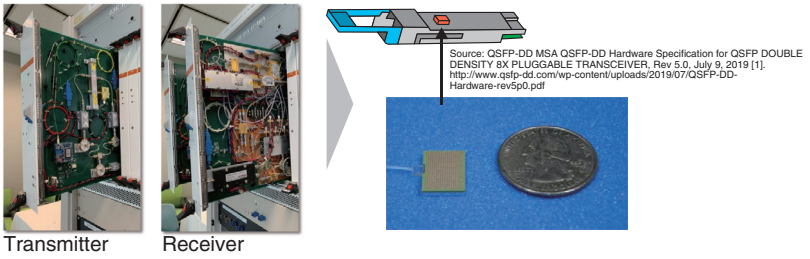


Fig. 4. COSA.

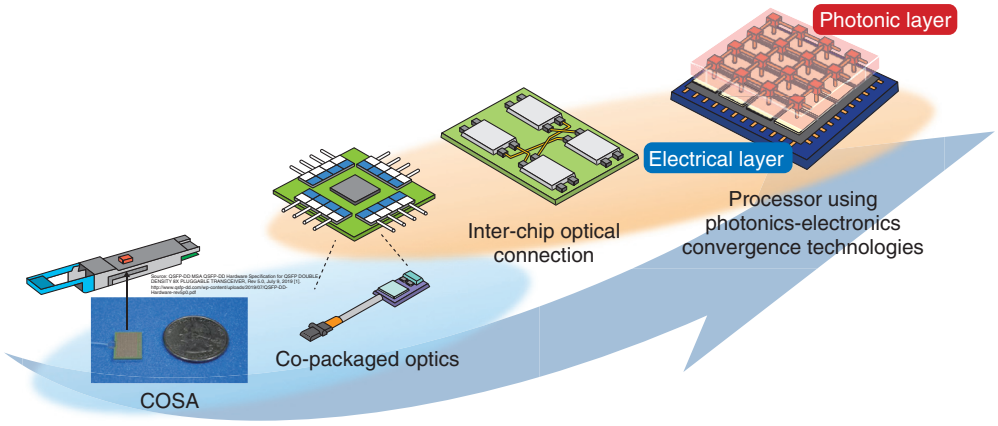


Fig. 5. Photonics-electronics convergence technologies.

transmission device that did not use photonics-electronics convergence. The device in the right photo uses COSA. The respective sizes of the two devices are dramatically different [1].

This photonics-electronics convergence technology will be applied even to information processing parts (**Fig. 5**). Initially, optics will be brought close to chips. This stage may be called "co-packaged optics." Then, optics will be applied to communication between chips. IOWN aims at achieving the fabrication depicted in the right figure to dramatically reduce power consumption. Optical input/output functions are directly fabricated on CMOS chips to produce a photonics-electronics convergence processor in which optical processing and electrical processing converge.

NTT was the first to develop an optical transistor based on photonics-electronics convergence that can operate at high speed with extremely low power consumption [2] (**Fig. 6**). In April 2019, a paper on this transistor was published in *Nature Photonics* in the UK [3]. This invention reduces power consumption by about two orders of magnitude in comparison to that of a transistor based on conventional photonics-electronics convergence. The invention of this optical transistor capable of operating with the world's smallest energy consumption was, in fact, the seed for the birth of the IOWN concept.

3.2 Values of the All-Photonics Network

In the All-Photonics Network, it is conceivable that a function or service can be assigned to each wavelength. For example, let us consider critical services, such as automated driving and remote medical operations. It is difficult to eliminate misgivings about the safety of medical operations conducted via the Internet because the latter operates on the "best-effort" principle. However, with IOWN, it is possible, depending on the service used, that, instead of converting data into IP packets, we could provide a

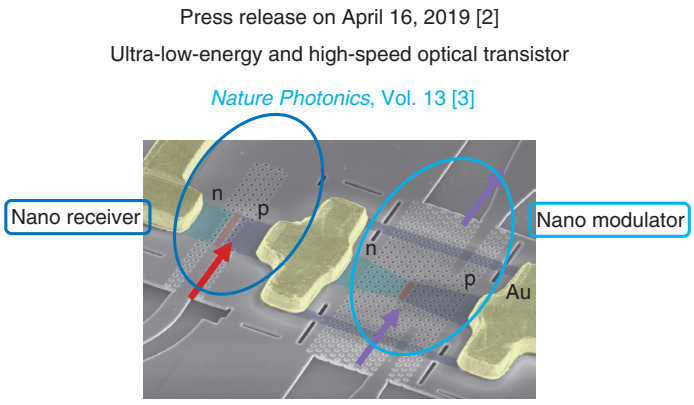


Fig. 6. Ultra-low-energy and high-speed optical transistor.

dedicated ultra-low-latency circuit with its bandwidth guaranteed by its large-capacity wavelength, a circuit that is dedicated to each individual function. This is similar to the mechanism whereby squillae use 12 types of receptors to achieve a rapid response with minimal information processing.

What other things will a photonics network enable us to do? Currently, NTT is collaborating with Professor Katori of the University of Tokyo to connect optical lattice clocks, which he invented, through NTT's photonics network. An optical lattice clock has achieved 10^{-18} level of total uncertainties of clock frequency. This is about 1000 times more precise than can be obtained with a conventional cesium-based atomic clock. It is so accurate that its degree of error will be less than a single second, even 30 billion years from now. What could we do with such a clock? For example, do you think time at the summit of Mt. Fuji advances at exactly the same rate as time down on Tokyo Bay? According to Albert Einstein's general theory of relativity, the higher a place is, the faster time elapses. By connecting optical lattice clocks at these two locations via a photonics network, you could measure the difference in altitude between the two places in real time, even if the difference is as small as a centimeter. If this can be done, you could measure volcanic activity and crustal movements and use the measurements to provide safety information or manage infrastructures.

4. Digital Twin Computing

Next, I want to talk about Digital Twin Computing. There are two major points. The first is creation of large-scale and diverse cyber worlds that perceive the entire world based on the umwelts that I mentioned earlier and on various value judgements. The other is self-awareness for leading a contented life.

4.1 Cyber worlds that perceive the entire world

Today, digital twin technology is attracting attention across a wide range of industrial fields. However, most current approaches are focused on creating a single umwelt in cyberspace, which is simply a copy of the real world. However, as can be seen in the examples of the umwelts of bees and squillae, our world is full of various types of information that humans cannot perceive. Thanks to technical innovation, humankind will be able to go beyond its own umwelt and access all types of available information. We are aiming to capture everything in the real world and re-present it in cyberspace so that we can create types of values previously inconceivable to humans (**Fig. 7**).

4.2 Self-awareness for leading a contented life

However, we believe that there are issues that cannot be resolved through technology alone. They have to do with ethics. When our lives expand beyond the real world to embrace cyberspace, issues will arise that cannot be measured based on conventional value judgements, issues that relate to new value judgments, ethics, and morals. Even today, unethical statements are posted on Internet message boards, and the posters are protected by anonymity. In the world of computer games, you can easily take the life of an opponent's character. At a time when our lives are extending into cyberspace, and what happens there becomes a part of everyday life, can we remain complacent about the current state of ethics in

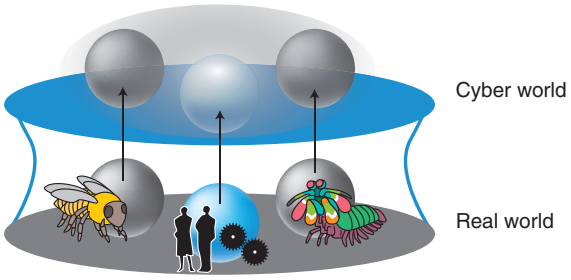


Fig. 7. Digital Twin Computing that captures the entire world.

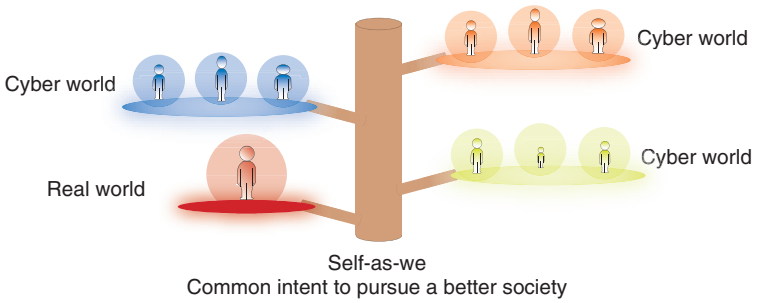


Fig. 8. Parallel universes in which the real and cyber worlds embrace each other.

cyberspace?

Let me explain a little about the joint research with Professor Deguchi of Kyoto University, which President Sawada referred to. Being a philosopher, Professor Deguchi propounds a philosophical concept that he calls "self-as-we." His idea is that an individual does not exist in isolation but, rather, exists in conformity with the objective or intent of the world related to him or her. For example, the mindset to pursue a better society. If this mindset could be shared as a common intent and used to link the real world with cyberspace, we would be able to realize a more contented society. In other words, in a world made possible by IOWN, the real world and cyberspace are independent but share the same intent. We define this intent as "self." This is our concept of a parallel world in which the real and cyber worlds embrace each other (**Fig. 8**).

4.3 Avatar and digital twin

Since my talk has become somewhat abstract, let me give you a specific example of a simulation of myself. This is a very simple example. The camera there is filming me. An image of myself is extracted from the captured image to create my avatar. However, what you see is but a copy of me. In the future, once IOWN has been implemented, it will be possible to create an avatar that shares my sense of values. Both his image and his voice can be synthesized to appear and sound almost exactly as I look and speak. However, this is not simply a copy of me. He can think and speak on his own.

My avatar-cum-digital twin will do a lot of things on my behalf. For example, suppose there's a phone call for me while I'm making a presentation. He can recognize my whisper and answer the call for me. He can provide additional information. For example, he estimates the time remaining in my presentation and tells the caller when I can call back.

Furthermore, since my twin is closely linked to society via cyberspace, he can obtain information that I cannot perceive. For example, he can measure the degree of excitement of the audience and give me advice about improving my presentation style or information that broadens my perspective. He can also predict my future state of health based on the medical data of many people and the trends of various technologies and industries that are not necessarily

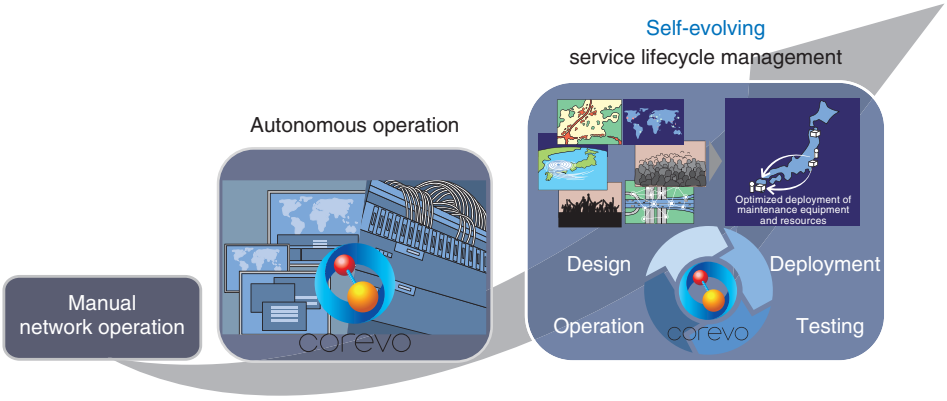


Fig. 9. Self-evolving service lifecycle management.

confined to the healthcare field. He may give me a sense of enjoyment by virtually experiencing an adventure that I would not dare to undertake in the real world and conveying his excitement to me.

Several necessary basic technologies are already being developed. The technologies for recognizing whispers and synthesizing a person's voice have already reached a practical level. As part of its health databank service, NTT DATA provides a service that predicts the user's likely rate of incidence of lifestyle-related diseases a few years from now based on past health examination data of NTT Group employees. We are also collaborating with a life insurance company toward developing this type of business.

If the real world and cyber world can have a good relationship, a better future will come about. When it does, people's lives may change as follows [4]. For example, while you take a day off, your twin in the cyber world can hold a discussion with the twin of another person and work according to your thinking and knowledge; you only get involved in the discussion or work when it is necessary to make a critical decision. What is important is that the real you and your twin share thoughts that each other most cares about.

5. Cognitive Foundation®

Next, I'll explain the Cognitive Foundation. The Cognitive Foundation flexibly controls and harmonizes all ICT resources. Its key points are self-evolution and optimization.

5.1 Self-evolving service lifecycle management

Some months ago, Japan was hit by two powerful typhoons: Typhoons 15 (Faxai) and 19 (Hagibis). They had a tremendous impact on telecommunications services as well. I sincerely extend my sympathy to all those affected. NTT has been developing technology for using AI (artificial intelligence) to detect failures based on logs issued by telecommunications infrastructure devices and to deal with them autonomously. We'll move one step ahead of that. We'll enter into the Cognitive Foundation a wide variety of information that cannot be monitored by the network, such as weather prediction information about the strength and path of an approaching typhoon and information about planned events. We'll also enter information about various umwelts, which I described earlier. Based on the collected information, the system will optimize the network autonomously. It will plan and execute measures against a disaster before it occurs. It will make predictions and evolve itself accordingly. We are aiming at such self-evolving service lifecycle management (**Fig. 9**).

5.2 Cradio

We will also work on the development of the "W" in IOWN; namely, wireless technology. Today, there are various wireless systems. In addition to conventional 4G/LTE (fourth-generation mobile communications/Long-Term Evolution), there is satellite communication, Wi-Fi, WiMAX, LPWA (low power wide area) for IoT, fifth-generation mobile communications (5G), Local 5G, and so on. The world of wireless technology has become very complex. NTT is studying technology for optimizing wireless access so that the user can enjoy access best suited to his or her situation without any need to be conscious of what wireless system is used, how it is to be used, or

what network service is used. This is "Cradio." Cradio proactively optimizes wireless connections based on the location and predicted traffic congestion and quality.

For example, a person urgently wishes to send a message to me at Tokyo Station, where Wi-Fi throughput is low. It will become possible for the sender's side to control the network to select a wireless access system that is optimal for reaching me. The Cognitive Foundation will incorporate wireless control technology that enables the user to make wireless access optimal for his or her particular location, application, and situation, without needing to know what wireless technology will be used or which company will provide the service.

5.3 Future development of wireless networks

When combined with the All-Photonics Network, wireless access technology in IOWN will be able to penetrate new areas. A world is waiting in which things can be connected, quite literally, everywhere through IOWN, whether they are under the sea, in the air, or in outer space.

We are undertaking R&D for this purpose. For example, we are combining a physical quantity in quantum mechanics called orbital angular momentum with NTT's space-division multiplexing technology that uses multiple antennas and a technology called multiple-input and multiple-output (MIMO). Combining these, we are working on developing world-leading large-capacity wireless transmission. To date, we have achieved a wireless transmission rate of 200-Gbit/s. We are seeking to achieve a wireless transmission rate on the order of terabits per second, which is 100 times faster than that of 5G.

We are also studying undersea wireless communication that can be used by heavy machines and drones in underwater situations. A drawback of conventional visible light communication is that transmission distance is significantly reduced when water becomes muddy. Instead, we have applied MIMO technology to acoustic communication that uses ultrasonic waves. We have achieved a transmission rate that is as much as two orders of magnitude higher than that of conventional acoustic communication. This communication system will make it possible to transmit high-definition video.

We are also developing wireless transmission in outer space. NTT has concluded an agreement with Japan Aerospace Exploration Agency (JAXA) on a vision-sharing-type joint research project with the aim of developing an ultra-high-capacity and secure optical and wireless communication infrastructure that can seamlessly connect outer space and ground stations. It will combine JAXA's space-quality system configuration technology with NTT's optical and wireless network technology and the IOWN concept to establish a new social infrastructure in space. We will start with joint research on developing unprecedented satellite MIMO communication between a low-orbit satellite and an earth station. Once this has been implemented, we can contribute to the establishment of a space communication infrastructure that enables ultra-high-speed and high-capacity communication in outer space.

6. World made possible by IOWN

Thus far, I have explained the three elements of IOWN. Now, I want to introduce some examples of how IOWN can be useful for industries.

6.1 Smart agriculture

The NTT Group has signed an agreement involving a corporation, academic institution, and a city government; NTT, Hokkaido University, and Iwamizawa City in Hokkaido. The aim of this project is to develop world-leading smart agriculture using cutting-edge agricultural robot technology and ICT. We have here with us Professor Noguchi of Hokkaido University, who will work with the NTT Group on this project.

Kawazoe: Professor Noguchi, what is the biggest problem confronting Japanese agriculture today?

Professor Noguchi: A big problem with Japanese agriculture is the labor shortage. The number of farmers has decreased by 15% over the last five years. The average age among farmers is 67. More than 65% of all farmers are 65 or older. Aging of farmers is a serious problem.

Kawazoe: Are you finding NTT's technology and IOWN useful for your smart agriculture project, which was initiated in June of this year (2019)?

Professor Noguchi: Since the agreement was concluded, we are already commanding great attention. We have been visited by the Cabinet Office, relevant ministries, and delegates from the German Bundestag and have been interviewed by overseas media. It is a great honor to work with the NTT Group on developing world-leading smart agriculture. Through this collaboration, we are conducting a test of remote monitoring using an extremely precise positioning service provided by NTT DOCOMO based on its base stations and 5G (**Fig. 10**). The Japanese

Fig. 10. Feasibility test of smart agriculture in collaboration with Hokkaido University and Iwamizawa City.

government is aiming at implementing robot farming that will be made possible by remote monitoring and automated driving by 2020. I believe that our team is the most advanced in pursuing these capabilities. The ground resolution of monitored video is 2 mm when full high definition is used, and 1 mm when 4K is used. When such high-definition video becomes available, it can be used not only for simple monitoring but also for surveying the growth rates of farm products and identifying incidences of diseases. This is a very promising technology.

Kawazoe: One last question. Earlier I talked about technology for achieving sensing capabilities like those of bees and squillae. I think that this technology would be particularly useful in the field of agriculture. What do you think?

Professor Noguchi: Yes, I totally agree with you. Today, it has become important to reduce the use of pesticides to maintain biodiversity. For this purpose, biological prevention, that is, robot insects that have a mechanism whereby natural predators eat pest insects, holds great potential.

Kawazoe: Thank you. Let's work together to achieve smart agriculture. Thank you for making the time to join us, here.

6.2 Heart-warming elderly care

Finally, I'd like to introduce to you our activities for supporting dementia sufferers. Today, there are numerous research projects looking into ways to prevent the development of dementia. However, there is a paucity of research on ways to support people who have already developed dementia. We are studying technology for enabling people with dementia to lead rewarding lives. Please watch this concept video [5] (**Fig. 11**).

This person suffers from dementia and she seems to have forgotten the name of her son. The son brings her a cube-shaped device. To help her recall her memories, her digital twin displays videos of his childhood. Watching the videos, she tries her best to recall something. A pendant-like device that she is wearing senses her emotions and thoughts and finds a piece of music that can awaken her memory. She seems to have recaptured something.

Her grandson comes in. This seems to be his birthday. Her digital twin records information about her grandson as a new memory. We intend to pursue R&D with the aim of bringing about a future in which everyone can be connected to his or her memories, be connected to other people, and enjoy a contented life supported by mental and physical health.

7. IOWN for the future

IOWN is aimed at 2030 and beyond. Abnormal climatic conditions, rising medical costs, the aging of populations, and a greater demand for ensuring food safety—besides these known social issues that currently concern us, we will certainly be confronted with risks that we have never previously experienced. To meet these challenges, humankind will continue to pursue technical innovation. It will be necessary to surmount a high wall, unconstrained by stereotypes or fear of taking risks.

To protect the global environment and ensure sustainable development, we should think outside the box and pursue the welfare and prosperity of humankind with an enhanced zeal for technical innovation. The IOWN concept represents our commitment to

Fig. 11. Heart-warming elderly care [5].

thinking deeply about and creating the future of humankind in cooperation with many other people and organizations.

IOWN for the future: What I have introduced to you today is but a tiny, tiny start that NTT has formulated. We will expand this concept by working in collaboration with many people and organizations.

Thank you.

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Initiatives to Achieve the IOWN (Innovative Optical and Wireless Network) Concept

Shigeru Iwashina, Yosuke Aragane, Kunihiko Minamihata, Katsushi Shindo, and Masakatsu Fujiwara

Abstract

NTT proposed the IOWN (/aɪən/: Innovative Optical and Wireless Network) concept, which is a future communication infrastructure that uses leading-edge optical and information processing technologies to create a smart world. Beyond the limits of existing infrastructure, it will also enable the creation of an affluent and diverse society. Together with Intel and Sony, NTT established the IOWN Global Forum to promote IOWN jointly with partners from various industries who have extensive knowledge and insight.

Keywords: IOWN, All-Photonics Network, Digital Twin Computing, Cognitive Foundation

1. Toward a new world

Important innovations, such as the Internet and smartphones, have changed our society dramatically. As a result, people's values have also been affected such as *from ownership to usership*. As computerization and informatization in our society accelerates, the use of artificial intelligence (AI) and Internet of Things (IoT) will increase, such as for new financial services with ICT (information and communication technology) and automated driving through AI. It is conceivable that our lives will change drastically and that diverse values will emerge [1].

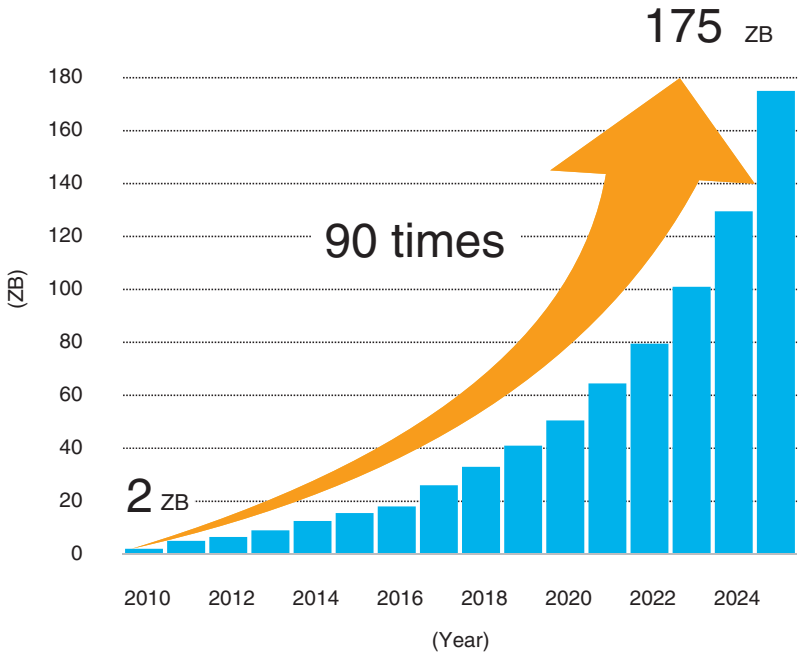
1.1 Responding to diversity

What makes this new world diverse is the understanding of others. To deepen such understanding, it is very helpful to see information and sensibilities from the perspective of others. To build this world through technology, it is necessary not only to obtain more information by developing high-definition and highly sensitive sensors but also to process information by taking into account the sensibility and subjectivity of others. It is necessary to incorporate not only science and technology but also the humanities and social sciences. We use the term *natural* for the condition that arises when humans enjoy the results of technology without stress. We also use the term *natural harmonic* for a world where people and the environment are in harmony. These will be our objectives.

1.2 Transcending the limits of the Internet

In such a world, transmitting and processing a huge amount of information is required, and current information and communication systems cannot handle such information. It is estimated that the amount of Internet traffic in Japan will increase 190 fold from 2006 to 2026 (From 637 Gbit/s to 121 Tbit/s) and global data volume will increase 5.3 fold in just 7 years (33 ZB in 2018 to 175 ZB in 2025) (**Fig. 1**).

If we try to mitigate such a situation using only current information communication systems, we will face serious problems such as further increase in communication volume, further complication of networks, and increase in delay due to congestion.



Source: IDC, "November 2018 The Digitization of the World From Edge to Core"

Fig. 1. Global data growth.

1.3 Overcoming increases in power consumption

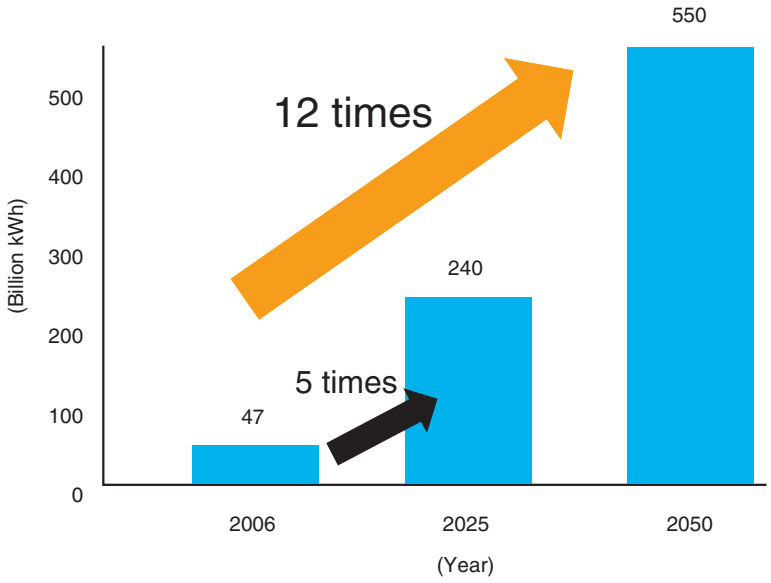
The explosive increase in the number of connected devices due to advances in IoT not only increases network load but also raises serious concerns about energy consumption (**Fig. 2**). The increase in power consumption of datacenters, which are essential for providing cloud services, has become a global problem.

We are now facing the density limit of integrated circuits. The degree of integration has been reduced to nanometers, and manufacturing is running up against physical limits. As power consumption increases, the temperature increase in integrated circuits due to an increase in the rate of heat dissipation is becoming evident, and the limit of processor clock frequency is starting to be noticed.

2. Innovative Optical and Wireless Network (IOWN)

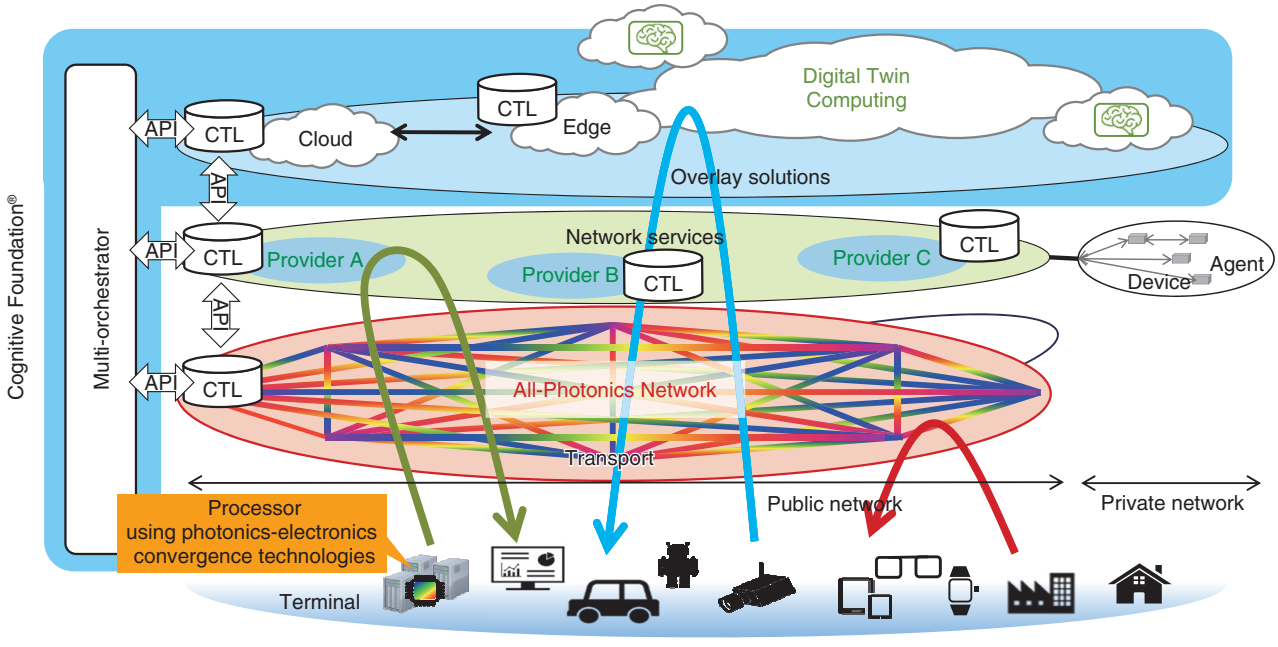
To create an affluent and diverse society, NTT has proposed the Innovative Optical and Wireless Network (IOWN) concept, which is a new communication infrastructure that can provide high-speed broadband communication and enormous computing resources by using innovative technologies including optical technologies. NTT also believes that these innovative technologies can optimize society as a whole and individuals using all types of information. IOWN uses three elements, All-Photonics Network, Digital Twin Computing, and Cognitive Foundation® to create a smart world, as shown below (**Fig. 3**).

- Dramatic reduction in power consumption and broadening of communication bandwidth can provide enormous processing capacity for the explosive increase in computational complexity.
- By increasing the capacity and reducing the delay of communications, it is possible to share in real time huge amounts of information collected from various sensors, exceeding the five senses.
- Dedicated use of optical wavelengths provides a high level of confidentiality and stability and can be used for mission-critical services.
- Multi-orchestration capabilities for centralized management of various resources, enabling resource utilization across industrial and regional domains
- The creation of a cyberspace that replicates and expands the real world by combining various digital twins and human models



Source: "Green IT Initiative" by the Ministry of Economy, Trade and Industry (Dec. 2007)

Fig. 2. Power consumption of IT (information technology) equipment.



API: application programming interface
CTL: controller

Fig. 3. Elements of IOWN.

2.1 All-Photonics Network

As the number of people and things connected to a network increase, advanced, complex, and large-scale information processing such as for AI will

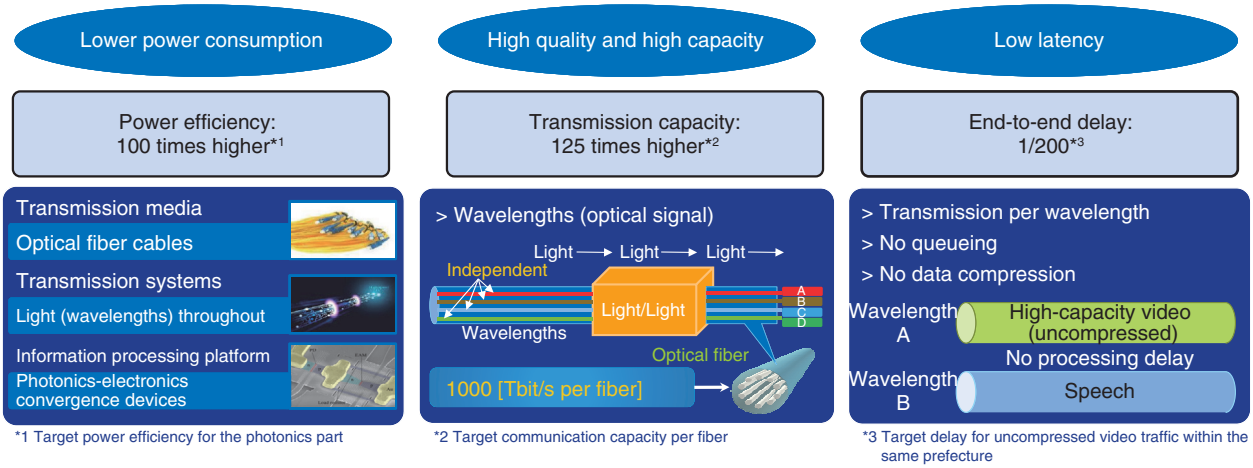


Fig. 4. Target performance of All-Photonics Network.

require a vast amount of power consumption. To reduce such power consumption and meet mission critical service requirements, NTT applies photonics technologies to end-to-end environments for achieving ultra-low-power consumption, large-capacity, and low-delay networks. For example, NTT aims to increase power efficiency 100 fold by developing transmission devices that control optical wavelengths and photonics-electronics convergence devices. NTT also aims to expand transmission capacity 125 fold by increasing multiplexing in optical fibers and expanding multicores in a fiber (**Fig. 4**).

2.2 Digital Twin Computing

A digital twin is an image of real-world objects, such as production machines, aircraft engines, and automobiles in factories, by mapping their shapes, conditions, and functions into cyberspace and expressing them accurately. Using digital twins enables us to analyze the current situation, predict the future, and simulate objects in cyberspace.

Digital Twin Computing is a new computing paradigm that makes it possible to reproduce and simulate the interaction between things and people freely in cyberspace by conducting computations such as exchange, fusion, duplication, and synthesis for many digital twins representing the real world [2].

2.3 Cognitive Foundation®

To achieve low-power-consumption, high-capacity, high-quality communication networks and large-scale interactions between people and objects, it is necessary to select and use various resources appropriately. The Cognitive Foundation is an infrastructure that provides a set of functions necessary to build and operate services by using various methods of collecting, processing, storing, and communicating data scattered throughout various locations.

3. Establishment of IOWN Global Forum

To enable IOWN, it is necessary not only to create and combine many innovative technologies but also promote these technologies for widespread use. Major changes in information processing, communication, and network infrastructure are required, and extensive knowledge and insight is needed. NTT Group alone cannot achieve this.

Accordingly, NTT, Intel, and Sony established the IOWN Global Forum to achieve IOWN, and will invite partners with a wide range of knowledge and insight from various industries [3]. The purpose of this forum is to promote IOWN by creating and publishing specifications, frameworks, and reference architectures of new technologies in the following fields.

- Photonics-related research and development using advanced photonics-electronics convergence technology
- Research and development related to distributed computing
- Use cases and best practices to create a smart world and research and development to achieve them

In the future, NTT, Intel, and Sony will select initial board members to jointly operate the forum, establish

a working group, and work with a wide range of partners to achieve IOWN.

We introduced NTT's activities to enable the IOWN concept and the efforts of the IOWN Global Forum, in which various partners will collaborate. We will create a new smart world by combining innovative technologies cultivated by NTT laboratories with technologies and knowledge from various partners.

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Self-folded Three-dimensional Graphene for Biointerfaces

Tetsuhiko Teshima, Koji Sakai, Hiroshi Nakashima, and Yuko Ueno

Abstract

Three-dimensional (3D) graphene-based electrodes have been gaining much interest regarding applications in flexible electronics and biointerfaces. We propose a simple method of transforming two-dimensional (2D) monolayer graphene into 3D structures that interface with biological samples. We found that the transferred monolayer graphene tightly adheres to the polymer surface via π-π stacking forces, resulting in the spontaneous folding of graphene/polymer bilayers (self-folding). Owing to the high biocompatibility of the materials and self-folding procedures, the self-folded bilayer films provide a hollow and non-toxic environment to encapsulate and culture cells. The cells embedded in the rolled-up architectures spontaneously form cellular 3D constructs with the intrinsic morphologies and functions of living tissues. For instance, we demonstrate that neuronal constructs with 3D geometry contribute to the construction of brain-like functional tissues such as functional integration with surrounding neuronal networks via their extended axons. Our method can be used to potentially provide 3D biointerfaces necessary for the reconstruction and assembly of functional tissues and implantable tissue grafts.

Keywords: self-folding, graphene, neural engineering, tissue regeneration

1. Introduction

Given its non-cytotoxicity, electrical/thermal conductivity, and mechanical strength, graphene is one of the most promising two-dimensional (2D) materials for applications in flexible bioelectronics [1]. Specifically, its large open-surface enables ions, molecules, and cells to be anchored and desorbed, showing its relevance to electro-chemical sensing [2]. For practical application, the inherently planar geometries of graphene are curved, folded, and wrinkled to assemble three-dimensional (3D) structures and interface with 3D objects. Conventionally, these 3D geometries of graphene have been assembled by loading on flexible templates and applying external mechanical forces [3]. However, this manual process results in technical difficulties in constructing dimensionally well-controlled 3D structures. In addition, the relatively poor adhesion of the transferred graphene leads to detachment and delamination from the substrates, resulting in difficulty in creating 3D graphene architectures.

We propose a method for rapid and easy formation of microscopic 3D graphene structures by using origami-inspired self-rolling bilayer films [4]. We use poly(*p*-xylylene) (parylene) as a flexible template that tightly adheres to graphene due to π-π stacking sp^2 hybridization. We discover the self-assembly principle in which the graphene behaves as the driving force behind the transformation of parylene films into tubular and spherical shapes termed a *micro-rolls*. Simply transferred monolayer graphene forms graphene-laden bilayer films with heterogeneous mechanical properties. Consequently, the differential strain gradients inside the films trigger spontaneous transformation into micro-rolls. To demonstrate the biocompatible 3D graphene interfaces, we used this graphene-laden self-folded cylindrical structure as an interface with neurons [5]. The self-folding graphene film encapsulates neurons inside its folded cylindrical structure, reconstitutes the intrinsic cellular morphologies and functions, and forms functional connections

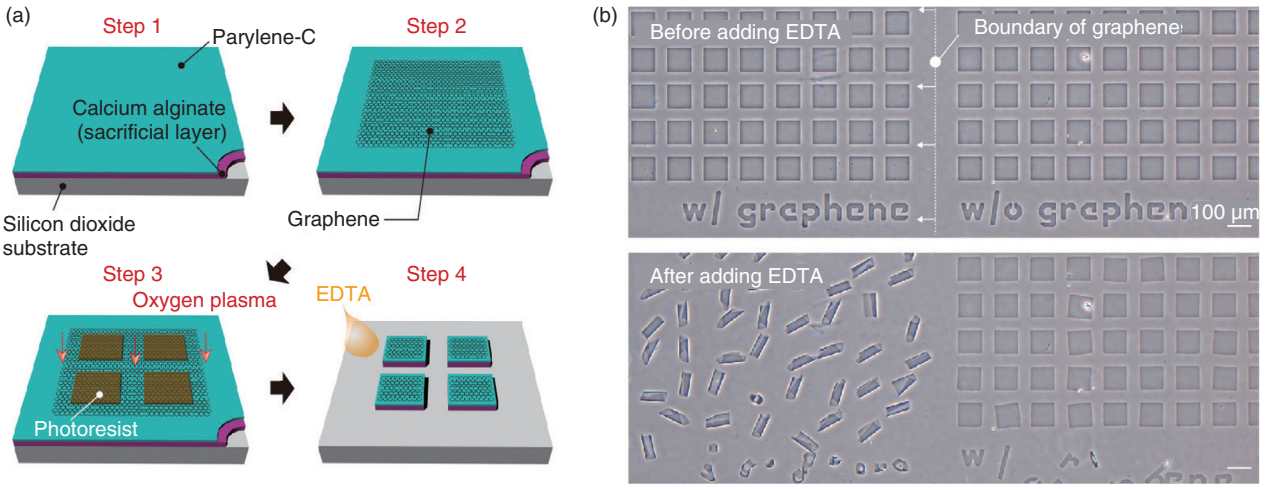

Fig. 1. (a) Fabrication process of self-foldable thin film. Three layers of graphene, parylene, and Ca-alginate gel are laminated then processed using lithography to form an arbitrary 2D micro-pattern. (b) Self-folding process of graphene/parylene bilayers. The Ca-alginate gel layer is removed with EDTA to release the thin film from the substrate.

with surrounding neurons. This is potentially applicable to creating 3D bioelectrodes and biointerfaces for applications such as the reconstruction of functional tissues and implantable tissue grafts.

2. Materials and experimental methods

2.1 Preparation of materials

Owing to tight π-π adhesion with graphene, we used poly(chloro-*p*-xylylene) (parylene-C) as a mechanically stable, biocompatible, and aromatic ring-rich polymer [6–8]. We adhered the multi-layered films composed of parylene, polycrystalline / single-crystal monolayer graphene, to the underlying sacrificial layer. While polycrystalline monolayer graphene chemical vapor deposition (CVD)-grown on copper (Cu) foils was purchased from Graphene Platform Corp., large-scale single-crystal graphene was synthesized on the Cu foils with an atmospheric pressure CVD process by using a mixture gas of methane (CH_4) and hydrogen (H_2) [9]. The sacrificial layer consists of calcium (Ca) alginate hydrogel that is dissolved instantly by adding chelating agents such as ethylenediaminetetraacetic acid (EDTA) or sodium citrate solution. To examine the biocompatibility of self-folded structures, we used primary hippocampal neurons that were dissociated from the hippocampi of Wistar rat embryos.

2.2 Device fabrication and cell encapsulation

Figure 1(a) shows the process used to fabricate micro-patterned graphene/parylene bilayers. After Ca alginate was spin-coated on silicon dioxide (SiO_2) substrates, both single-crystalline and polycrystalline monolayer graphene were transferred using the conventional poly(methyl methacrylate)-assisted method. Subsequently, parylene-C was deposited using a CVD process and covered with photolithographically micro-patterned photoresist. The triple-layered film was finally etched with oxygen plasma to create a micro-patterned film array. After suspending the neurons, an array of micro-patterned films was released from the substrate by dissolving Ca-alginate sacrificial layers via immersion in EDTA solution.

3. Results

3.1 Self-folding of 3D graphene-polymer architectures

The dissolution of the sacrificial Ca-alginate layer with EDTA resulted in simultaneous batch self-folding of the graphene-laden parylene bilayers into cylindrical micro-rolls (**Fig. 1(b)**). Interestingly, the bilayer was bent in the direction of the substrates while maintaining the bottom parylene on the inward side. At this time, the loaded graphene appeared to be exposed to tensile force; thus, causing it to cover the inner parylene from the outside. We confirmed that the curvature of the micro-rolls is controllable with

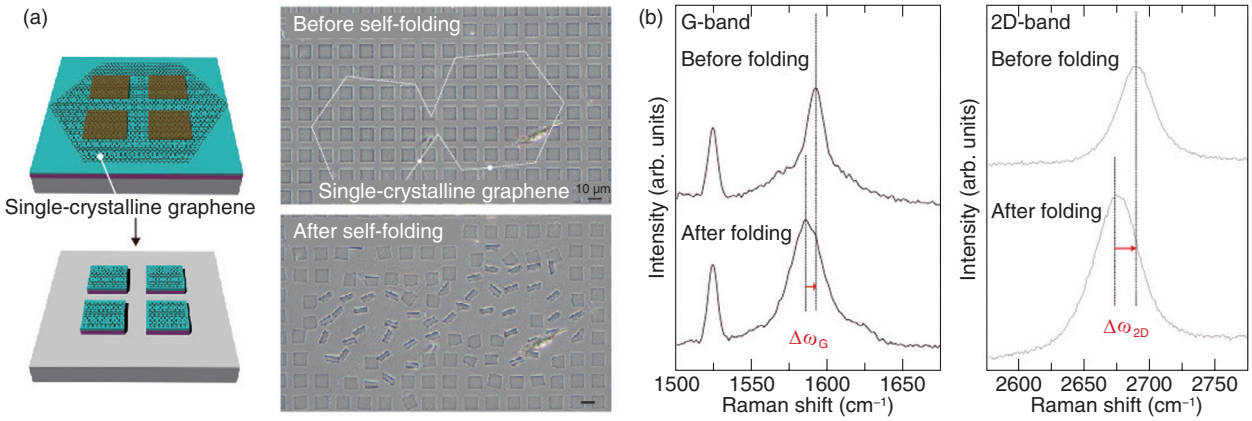

Fig. 2. (a) Schematic of transferring and micropatterning for generating single-crystalline graphene-laden micro-rolls (left), and snapshots highlighting the bilayer films of single-crystalline graphene and parylene in the flat and folded states (right). White dotted lines indicate the grain boundaries of hexagonally shaped graphene. (b) Raman spectra of monolayer graphene-laden micro-rolls before and after self-folding. Enlarged G and 2D peak regions for graphene.

the thicknesses of parylene (t_p) and the number of graphene layers (t_g). Given the transferred monolayer graphene, a thinner t_p leads to a smaller micro-roll; stacking multi-layered graphene makes the micro-rolls much tighter when t_p is constant. Both reducing the thickness of the parylene layer and sequentially stacking multi-layered graphene decreases the bending rigidity, thereby improving machining controllability of a fine 3D structure. These results indicate that the underlying mechanism of self-folding is the stiffness mismatch in the bilayer, following the trend predicted by the bimorph beam theory [10].

While the self-folding orientation of polycrystalline graphene-laden bilayers was random, one of the single-crystalline graphene-laden bilayers was relatively uniform. **Figure 2(a)** shows that two adjacent hexagonally shaped-single graphene domains caused the subsequent unidirectional self-folding to form a tubular shape with a uniform curvature. This difference is attributed to a patchwork of relatively smaller single-crystalline grains separated by grain boundaries within the polycrystalline graphene. Since one might expect a single domain of graphene to have the same elastic energy, which induces an isotropic tensile force for folding, the uncontrollable folding orientation originates from domains inside the CVD-grown graphene [11]. In contrast, when the domain size is larger than one sheet of micro-patterned film, the crystalline orientation of graphene would certainly affect the orientation of self-folding.

3.2 Electrical properties

The strain in outer graphene during self-folding was estimated by characterizing shifts in G peaks (ΔG) and 2D peaks (Δ2D) from the original modes with Raman spectroscopy (**Fig. 2(b)**). The blue-shifts in both ΔG (~8 cm^{-1}) and ΔG (~16 cm^{-1}) stem from the distorted graphene lattice and altered interatomic distance, which determines the strain of 0.18%. This estimated strain within the graphene is almost in agreement with the predicted value in the 0.16–0.18% range that is theoretically rationalized with the bimorph-beam theory [10]. Therefore, graphene loaded on parylene will not only longitudinally elongate but also contract transversely with uniaxial tension.

The structural alteration of hexagonal-shaped graphene is critical in terms of changing the electronic structure. Therefore, we newly micro-patterned bilayers that were hinged and partially pinned down and measured their drain current (I_d)–voltage (V_d) characteristics before and after self-folding at room temperature. While flat graphene exhibits linear behavior, the self-folding process greatly alters the electrical property of loaded graphene to non-linear (**Fig. 3(a)**). The resistance increased from 17.9 to 38.0 kΩ when measured at 0 mV. When applying back-gate voltages (V_g), both positive and negative back-gate voltages modulated the non-linear resistance of micro-rolls (**Fig. 3(b)**). This result indicates that the self-folding process never leads to the exfoliation or rupture of graphene and behaviors as a p-type semiconductor in both flat and folded states. We attribute the altered

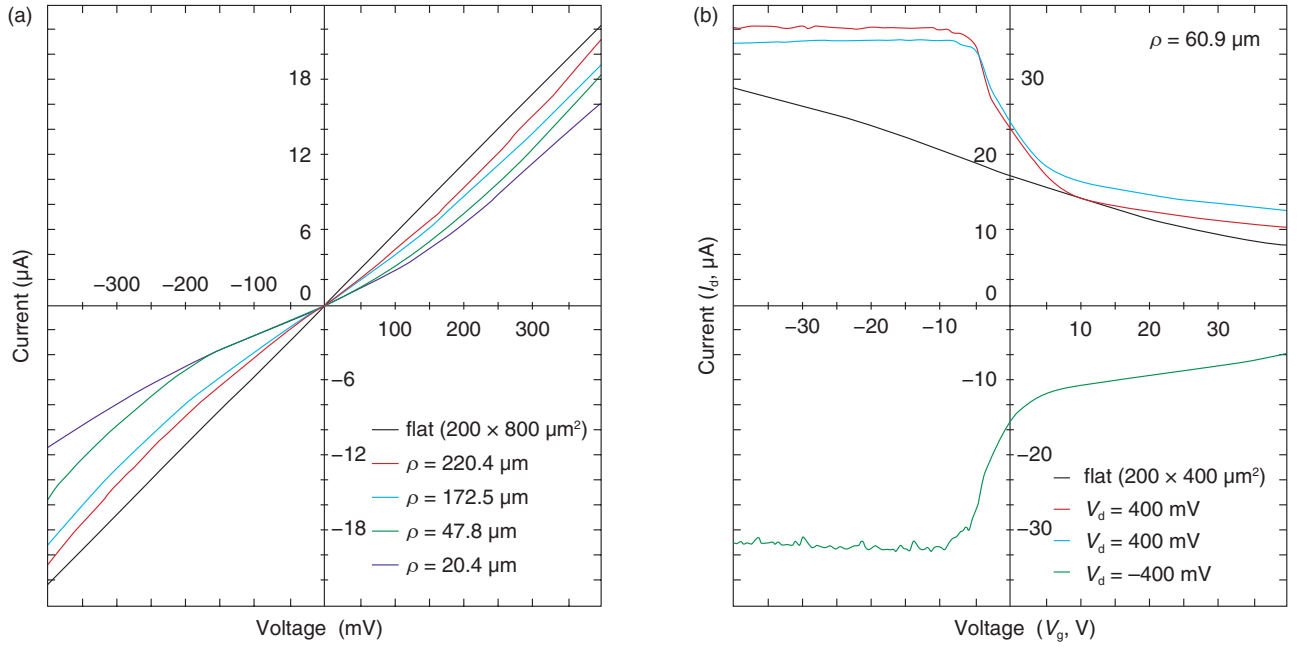

Fig. 3. Electrical properties of graphene-laden micro-rolls. (a) Non-linear I_d–V_d curves of self-folded 200×800 I_d–V_d m^2 films with different curvature radii, ρ. (b) Corresponding non-linear I_d–V_d curves of self-folded 200×400 I_d–V_d m^2 films where ρ = 60.9 μm by varying V_g.

charge carrier densities even at room temperature to the uniformly compressed graphene-unit hexagonal cell. This modulatable property makes it possible to develop switching transistors.

3.3 Encapsulation of cells in porous micro-rolls

To apply graphene micro-rolls to biointerfaces, we investigated their biocompatibility by encapsulating the primary hippocampal neurons inside them [5]. After exposure to EDTA, the cells on the 2D film surface were encapsulated inside the micro-rolls through the self-folding of the bilayer (**Fig. 4(a)**). Both self-folding and encapsulation were sufficiently gentle to avoid cell damage, which allows the encapsulated cells to migrate inside the micro-rolls during incubation. Since the curvature radius and length of the micro-rolls are controllable, the number of encapsulated cells can be easily controlled with the cell density and volume of the micro-rolls. The high biocompatibility and transparency of the micro-rolls enable stable culturing of encapsulated cells.

To enable long-term cell culture, we incorporated the tiny pores with several different diameters to facilitate reagent delivery to the encapsulated cells. Importantly, these numerous pores inside the bilayer have no effect on the curvature radius of the micro-rolls. The pores have two additional characteristics to enable long-term cell culture. First, they allow the neurites to grow across them and extend outside the micro-roll. Time-lapse images of neuron-laden micro-rolls over 5 days show that the neurites from a porous micro-roll protruded beyond the micro-roll 2 h after folding and became longer with an average growth rate of approximately 3 μm/h (**Fig. 4(b)**). Second, they enable us to load biological probes and pharmacologically stimulate the encapsulated cells. Although a major advantage of cell encapsulation is homogenous cell distribution, long-term culture causes changes in the distribution depending on the cell type and its adhesive and migration properties. The results indicate that porous micro-rolls help encapsulated cells maintain their positions with homogeneous distribution.

To further investigate the morphology, the neuron-laden micro-rolls were characterized with immunocytochemistry by using two neuronal markers: MAP2 (dendrite/cell body marker; red) and tau1 (axon/cell body marker; green). **Figure 4(c)** shows that MAP2-positive neuronal cell bodies were sustainably located in porous micro-rolls and greatly extended their axons (tau1-positive) around the micro-rolls (Φ = 3 μm). We verified that porous self-folding film

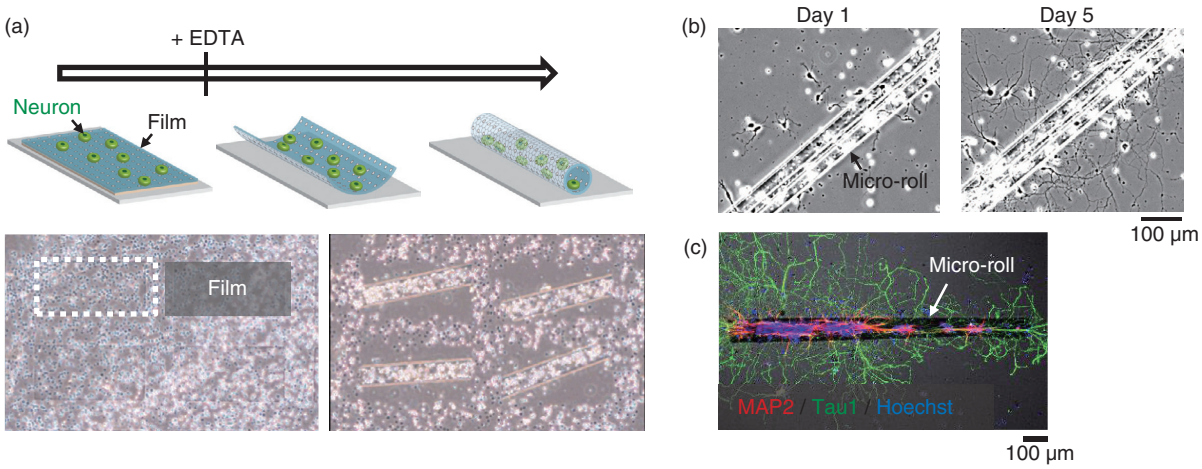

Fig. 4. (a) Schematic and snapshot images of cell encapsulation. Dissociated cells are seeded on the self-folding film. The folded film encapsulates seeded cells and forms a cell-laden micro-roll. (b) Time-lapse images of neurons encapsulated within micro-rolls with ϕ = 5 μm pores for 5 days. Neurons extend their axons (black and white arrowheads) around the micro-roll. (c) Immunocytochemical images of neuron-laden micro-rolls with ϕ = 3 μm pores. The cultures are stained with antibodies for the dendrite/neuronal cell body marker MAP2 (red) and the axon/neuronal cell body marker tau1 (green) for 6 days *in vitro*. Nuclei are visualized using Hoechst staining (blue).

enables us to isolate axons from neuronal cell bodies cultured in a 3D tubular structure. It is well recognized that a 3D tubular structure is useful for guiding neurite outgrowth. When neurons are encapsulated, the confined structure not only arranges neurons but also guides axons in the single direction as the long axis. Also, incorporated pores on the surface allow both control over the cell distribution and axon guidance in multiple directions. Thanks to the axon guidance in multiple directions, a porous neuron-laden micro-roll can potentially be used as a building block for constructing a complex neuronal network and creating a brain-like network.

3.4 Reconstruction of functional tissue-like structures

The key challenge with cell-laden micro-rolls is to fabricate tissue-mimicking tubular structures and confirm their cellular function [12]. To demonstrate that pores provide functional integration of neuron-laden micro-rolls into a surrounding neuronal network, a culture was labelled with anti-beta3-tubulin (neuronal marker; green) and anti-synapsin I (synapse marker; red) to assess the morphology and synapse formations around the pores. Confocal microscopic images indicate that beta3-tubulin-positive cells inside and outside the micro-roll were connected by neurites that pass through a pore (**Fig. 5(a)**). Furthermore, synapsin I was expressed in the neurons, forming synapse puncta along their neurites. Importantly, synapsin I puncta were detected along the neurites passing through the pores (white arrowhead), suggesting the formation of synaptic connections between encapsulated and surrounding neurons.

To determine whether a functional synaptic connection is formed, we investigated the synchronization of spontaneous activities within the neuronal network by monitoring intracellular calcium ions (Ca^{2+}). **Figure 5(b)** shows that spontaneous Ca^{2+} increases in the neurons attached within and around the micro-rolls. The spontaneous Ca^{2+} oscillations are highly synchronized between encapsulated and surrounding neurons. Given that synchronized spontaneous activity is typically mediated by glutamate synaptic transmissions in the hippocampal neuronal network, the synchronized Ca^{2+} oscillations indicate the formation of functional synaptic connections. Hence, the encapsulated neurons were functionally integrated into surrounding neuronal networks by extending their axons through the pores.

It is generally believed that the functional integration of transplanted neurons into existing circuitry is required for neural transplantation leading to brain repair. Although cell encapsulation is a useful method for 3D tissue formation and cell delivery, the confined structure limits the formation of neuronal connections with surrounding tissues. Cell encapsulation using a porous film allows encapsulated neurons to

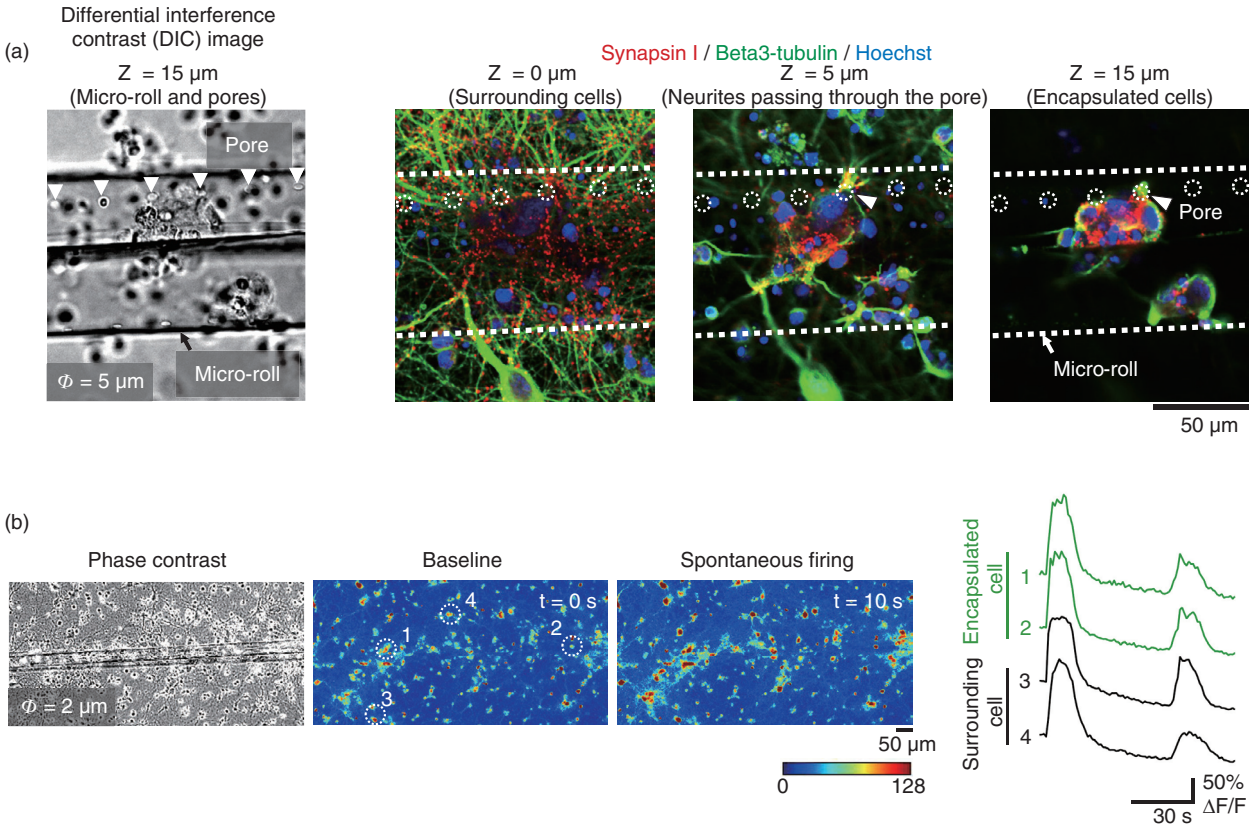

Fig. 5. (a) Images acquired at different z-positions around the micro-roll with a differential interference contrast microscope. The micro-rolls on the neuronal network are immunostained with the synapse marker anti-synapsin I (red), neuronal marker anti-beta3-tubulin (green), and Hoechst (blue) over 6 days *in vitro*. White dotted circles indicate pores on the micro-roll surface. The white arrowheads show axons passing through a pore. (b) Heat maps of spontaneous activities in neurons (left) and intensity traces of the calcium indicator in regions of interest (ROIs) (right). The traces are normalized to the initial fluorescence intensity ($\Delta F/F$). The scale bars indicate 100 μm.

extend their axons across the pores and form functional synaptic connections with surrounding neurons. These results highlight the potential for using a neuron-laden micro-roll with pores as a platform for constructing functional neural tissue with highly precise 3D geometry. Furthermore, the graphene surrounding a micro-roll will be used as an electrode for electrophysiological recording and the stimulation of neuronal activity.

4. Summary

We proposed a simple method of transforming a monolayer graphene-laden polymeric film (parylene) into a programmed 3D configuration that depends on 2D geometry. The adhesion between graphene and parylene is mainly attributable to intermolecular force including π-π stacking, which ensures a conformal and stable contact within bilayers. The strain gradient in homogeneous films initiates self-folding into micro-rolls. Remarkably, micro-scale curved graphene exhibits previously unachievable non-linear electrical behavior without any fracturing or insulation. In addition, both the fabrication process and materials of micro-rolls never require cytotoxic etchant, allowing for batch encapsulation of multiple cells. The biocompatibility of graphene and parylene also ensure the encapsulation and long-term culturing of more than one month of encapsulated cells without cytotoxicity.

Notably, the higher elasticity of graphene and parylene enables the embedded cell to develop a fiber-shaped construct. In particular, a porous graphene/parylene bilayer can encapsulate neurons and allow these neurons to interact with their surroundings. The pores facilitate the diffusion of reagents to encapsulated

neurons for the dye loading and stimulation essential for the analysis of neuronal circuits. As a result, the encapsulated neurons can be functionally integrated into surrounding neuronal networks by extending their axons through the pores. Thus, the porous self-folding film allows us to construct neuronal tissues connecting to surrounding tissues with a precisely controlled cell distribution. This method could be expanded for use with many other adherent cell lines for reconstructing fiber-shaped functional tissues that mimic muscle fibers, blood vessels, and nerve networks *in vitro*.

5. Future prospects

From the perspective of material science, in combination with the 3D reconfigurable structure with electrical conductivity, this method could be extensively used for the multi-functional integrated circuits needed for flexible electronics and field effect devices in which the electrical conductivity of graphene is tunable with self-folded geometries. Furthermore, the ability to fold the atomically thin sheet into 3D shapes allows the formation of multi-functional micro-rolls with diverse chemical, electrical, spintronic, and optical characteristics. From the biological perspectives, the method can also be used to form scaffolding structures toward regenerative medicine and the behavior analysis of single cells. This method could be expanded to reconstruct tissues with various shapes *in vitro* that are suitable for exploring single-cell assays, tissue engineering, and implantable *ex vivo* tissue grafts. In addition, a graphene electrode can be implanted in the brain surface for long-term electrophysiological recording. Therefore, if graphene can be attached to both the inner and outer face, it will be possible to record neuronal activities in encapsulated and surrounding tissue independently and investigate the establishment of functional connections. We believe that the incorporation of the electrical functionality of graphene will have great potential in terms of developing an integrated platform for both cell transplantation and electrophysiological recording.

Acknowledgments

We are grateful to Dr. Makoto Takamura, Dr. Yui Ogawa, and Dr. Shengnan Wang for providing monolayer CVD graphene samples and fruitful discussions regarding graphene characterization. We are also grateful to Dr. Yoshiaki Kashimura and Yuriko Furukawa for their help with the microscopic observation, characterization of electrical property, and assistance regarding cell culture. This work was partially supported by Grants-in-Aid for Scientific Research (JP17H02759) from the Japan Society for the Promotion of Science.

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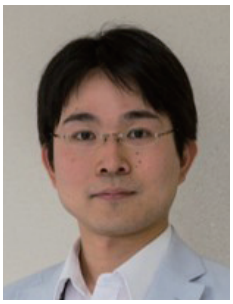

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Report on Fourth ITU-T Telecommunication Standardization Advisory Group (TSAG) Meeting

Hideyuki Iwata

Abstract

The fourth meeting of the Telecommunication Standardization Advisory Group (TSAG) of the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) was held on September 22–26, 2019 at the ITU headquarters in Geneva, Switzerland. It was attended by approximately 140 delegates from 38 countries. This article introduces the proceedings of the meeting.

Keywords: TSAG, quantum information technology, artificial intelligence

1. Introduction

The fourth meeting of the Telecommunication Standardization Advisory Group (TSAG) of the International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) was held on September 22–26, 2019 at the ITU headquarters in Geneva, Switzerland. It was attended by approximately 140 delegates from 38 countries. The delegation from Japan was headed by personnel from the ICT Standardization Division, Global Strategy Bureau, Ministry of Internal Affairs and Communications and included eight locally stationed delegates from Japanese enterprises and organizations (National Institute of Information and Communications Technology (NICT), NTT, NEC, Fujitsu, Hitachi, and Mitsubishi Electric). Japan proposed a method of identifying the relationship between ITU-T study group (SG) standardization questions and the United Nations' Sustainable Development Goals (SDGs) and the addition of criteria for evaluating standardization activities of SGs. The meeting also deliberated on the establishment of two new focus groups (FGs): "Quantum Information Technology for Networks (QIT4N)" and "AI and Data Commons."

2. Rapporteur group meetings

Each rapporteur group (RG) had the following discussions.

2.1 RG on Standardization Strategy

Didier Berthoumieux (Nokia, Finland) served as the RG chair for this meeting. The contributions from Japan proposed developing mapping between ITU-T SG questions and 17 SDGs. They also argued that, when determining new study items for each SG, it is important to identify SDGs to which each study item can contribute. It was decided to continue studying these issues and accelerate such studies by holding interim e-meetings ahead of the next meeting. Japan also proposed adding the number of participants and number of contributions in SG questions to the criteria for evaluating standardization activities of the SGs. This proposal was well supported by the participants. Detailed study on the addition of these criteria will be carried out in cooperation with Telecommunication Standardization Bureau (TSB) personnel of the ITU-T Secretariat ahead of the next TSAG meeting. The RG chair for the fifth TSAG meeting will be Rim Belhassine-Cherif (Tunisia Telecom, Tunisia).

2.2 RG on Work Programme and Structure

Reiner Liebler (Federal Network Agency, Germany) served as the rapporteur. This meeting approved the creation of a new question, QA/SG9 (Accessibility to cable systems and services), revision of Q6/SG9 (Functional requirements for residential gateway and set-top box for the reception of advanced content distribution services), integration of Q18/SG12 (Measurement and control of the end-to-end quality of service (QoS) for advanced television technologies, from image acquisition to rendering, in contribution, primary distribution, and secondary distribution networks) into Q19/SG12 (Objective and subjective methods for evaluating perceptual audiovisual quality in multimedia and television services), creation of Q12/SG16 (Visual surveillance systems and services), and revision of Q2/SG17 (Security architecture and framework). This RG also held a joint meeting with the RG on Standardization Strategy to ensure that the SG restructuring will reflect the priority questions selected in this standardization strategy.

2.3 RG on Working Methods

Stephen Trowbridge (Nokia, USA) served as the rapporteur. The RG considered and approved revisions to Recommendation (Rec.) ITU-T A.1 "Working methods for study groups of the ITU Telecommunication Standardization Sector" and Rec. ITU-T A.13 "Non-normative ITU-T publications, including supplements to ITU-T Recommendations." This RG will continue to study revisions to Rec. ITU-T A.7, which concerns FGs, and Rec. ITU-T A.8, which is related to an alternative approval process.

2.4 RG on Strengthening Cooperation/ Collaboration

Glenn Parsons (Ericsson, Canada) served as the rapporteur. The RG considered and approved revisions to Rec. ITU-T A.5 "Generic procedures for including references to documents of other organizations in ITU-T Recommendations" and Rec. A.25 "Generic procedures for incorporating text between ITU-T and other organizations."

2.5 RG on Creation, Participation and Termination of Regional Groups

Kwame Baah-Acheamfuor (National Communications Authority, Ghana) served as the rapporteur. The RG considered criteria for creation, participation, and disbandment of regional groups, which will be established by ITU-T SGs, an issue related to Rec. 8 approved by the ITU Plenipotentiary Conference 2018 (PP-18).

2.6 RG on Review of WTSA Resolutions

Vladimir Minkin (National Wireless Communication Laboratory, Russia) served as the rapporteur. The RG reviewed the progress of resolutions adopted by the World Telecommunication Standardization Assembly (WTSA).

3. New standardization items

Three new items for standardization were discussed: quantum information technology, artificial intelligence (AI), and a new-Internet protocol (IP)-based future network.

3.1 Quantum information technology

In the previous meeting, China proposed that an FG on Quantum Information Technology for Networks be established, but it was considered to be too early to establish it. In this meeting, China again made this proposal. Discussions were held by narrowing the study scope of the proposed FG.

Initially, some countries were opposed to the establishment of the FG because they thought it was too early. They also argued that the study on quantum communication by the proposed FG could duplicate those of other ITU-T organizations and standardization organizations, pointing out that ITU-T SG13 and SG17 had been making progress in the standardization of network architecture and security for quantum key distribution (QKD). However, establishment of the FG was agreed to on condition that its study area will not overlap that of the existing studies on QKD, that the FG focus on quantum information technologies (QIT), which is a broad concept for quantum information processing, including quantum communication, quantum computer, and quantum sensor, subjects not covered by QKD, and that the FG will operate for only one year with priority given to the study on QIT-related terms and use cases. It was recognized that it is vital for the FG to collaborate with European Telecommunications Standards Institute (ETSI) Industry Specification Group on QKD, ETSI Technical Committee Cyber, Institute of Electrical and Electronics Engineers (IEEE), International Organization for Standardization/ International Electrotechnical Commission Joint Technical Committee 1 (ISO/IEC JTC 1) Subcommittee 27/Working Group 3, ISO/IEC JTC 1 Advisory Group 4, Internet Engineering Task Force (IETF), Internet Research Task

Force (IRTF), etc. on the study of quantum communication and provide a global forum for collaboration between ITU-T and those organizations.

3.2 AI Commons

Since 2017, ITU has been holding AI for Good Global Summit (hereafter, the AI Summit) meetings (most recently on May 28–31, 2019). In the AI Summit meetings, AI experts recognized that it is necessary to have a standardized method of assessing how useful AI is for solving problems in order to develop secure and transparent AI solutions. Thus, they proposed the establishment of "Commons," a forum for global cooperation in which AI experts can share their experience and knowledge on problem-solving. Against a backdrop of increased interest in this idea at the AI Summit, it was proposed in this TSAG meeting to establish an FG dedicated to the role of *AI Commons* (FG on AI and Data Commons) as a pre-standardization activity to pave the way for future international standardization. The proposal was mainly prepared by the program chair (USA) of the Global Summit and researchers of the AI research institute of the University of Montreal, Canada, which is a leading AI research organization. A list of organizations interested in the establishment of the FG was announced and included Google, Facebook, Intel, Symantec, Element AI, and China Telecom. A tutorial presentation on AI Commons was given in the TSAG meeting, followed by discussions in an ad hoc meeting on the establishment of the FG. The ad hoc meeting saw considerable support for the establishment of the FG. However, some government delegates expressed their opposition, asserting that the scope of the FG was too wide and that it was too early to agree on establishment in that TSAG meeting because it will take a long time before the intent of the FG is widely understood. Since the discussion time ran out, the proposal was passed over.

3.3 New-IP-based future network

Chinese organizations, including Huawei Technologies, China Mobile, China Unicom, and China Academy of Information and Communications Technology (CAICT), submitted a contribution titled "New IP, Shaping Future Network," proposing to *analyze the current challenges and provide a development path for the future network for the next decade*. It proposed a strategic study on a future network, including development of a new IP that will replace the conventional Transmission Control Protocol (TCP)/IP. The purpose is to make possible various e-services, such as Internet of Things and industry Internet, and to achieve an ultrahigh-capacity, low-latency network for hologram transmission. This proposal was remitted to the relevant SG liaison, and feedback will be received in the next or a subsequent meeting.

4. Next meeting

The next TSAG meeting (fifth meeting) will be held in Geneva on February 10–14, 2020. The SDG-related issue proposed by Japan was discussed in interim e-meetings of the RG on Standardization Strategy, which were held in November 2019 and January 2020.

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He has been a delegate of IEC Subcommittee 86A (optical fiber and cable) since 1998 and of ITU-T TSAG since 2003. He is a vice-chair of the Working Group on Policy and Strategic Coordination and the Expert Group on Bridging the Standardization Gap in the Asia-Pacific Telecommunity Standardization Program (ASTAP). He received an award from the IEC Activities Promotion Committee of Japan in 2004, the ITU Association of Japan (ITU-AJ) International Activity Encouragement Award in 2005, an ITU-AJ International Cooperation Award in 2012, an award for contributions to an ICT development project at the Asia-Pacific Telecommunity (APT) ICT Ministerial Meeting in 2014, the ITU-AJ Accomplishment Award in 2018, and the Telecommunication Technology Committee (TTC) Chairman's Prize in 2019.

A New Method for Repairing Steel Lifting Conduits

Technical Assistance and Support Center, NTT EAST

Abstract

This article introduces a simple and low-cost repair method applied to damaged lifting conduits and presents the results of its technical verification. This is the fifty-sixth article in a series on telecommunication technologies.

Keywords: lifting conduit, corrosion, repair method

1. Introduction

The telecommunication cables connecting a NTT telecommunication central office and customer premises run through underground facilities before being carried by overhead facilities to the customer premises. When a cable leaves an underground facility and is taken up to an overhead facility, it is housed in a steel pipe called a lifting conduit installed alongside a telephone pole (**Fig. 1**). The function of the lifting conduit is to protect the cable (**Fig. 2**). Since lifting conduits are exposed when coming into contact with the ground, they are typically treated with anti-corrosion materials such as zinc-plating and painting.

In the joint portion of the conduit (**Fig. 3**) and the portion close to the ground (**Fig. 4**), rainwater or damage due to external factors such as impact by vehicles will cause surface corrosion of those portions, and the surface corrosion will lead to the formation of holes (perforations). As the perforation progresses, the conduit may be further damaged, e.g., cracking. As a result, as well as the appearance of the conduit being deteriorated, the cable may become exposed outside the conduit and became further damaged by external factors such as impact by vehicles, which could be lead to telecommunication service interruption.

It is thus necessary to appropriately repair damaged lifting conduits. The repair method described in this article was originally developed by Yokohama Service Center of NTT EAST-Minamikanto Corporation, and the Technical Assistance and Support Center (TASC), NTT EAST, verified and validated on the basis of in-house standard method. The TASC conducted technical verification of this repair method (in terms of weather resistance, etc.) for damaged lifting conduits. This article introduces noteworthy features on this repair method and presents the results of its technical verification.

2. Current methods for repairing lifting conduits

When a lifting conduit is damaged by corrosion it is desirable to repair it on site, rather than to replace the whole of lifting conduit. The repair method is selected according to the size of the holes formed in the conduit and the degree of corrosion. Examples of conventional repair methods [1] are listed below.

(1) Half-cut-conduit method

The corroded lifting conduit is cut vertically using an exclusive tool to remove the corroded section, and two pieces of half-cut conduit are attached to the original conduit and fixed with several clips to cover the cables (**Fig. 5**).

(2) Over-cleat method

The existing lifting conduit does not need to be cut.

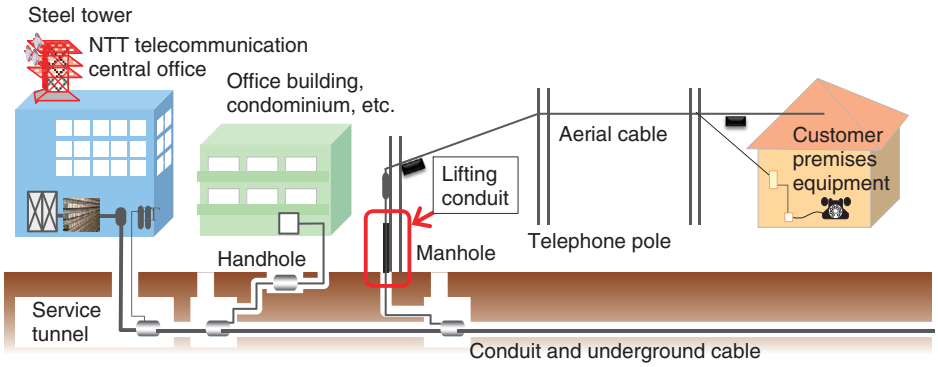

Fig. 1. Overview of telecommunication facility.

Fig. 2. Lifting conduits installed alongside a telephone pole.

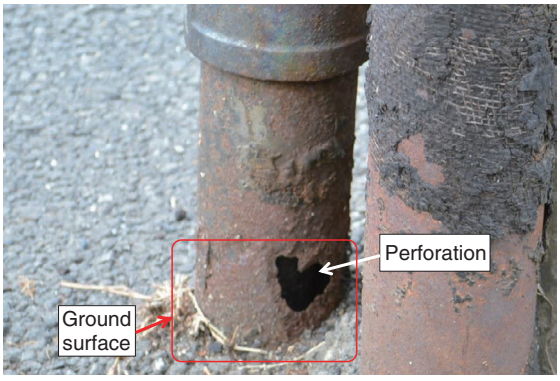

Fig. 4. Lifting conduit with perforation (due to corrosion) near the ground.

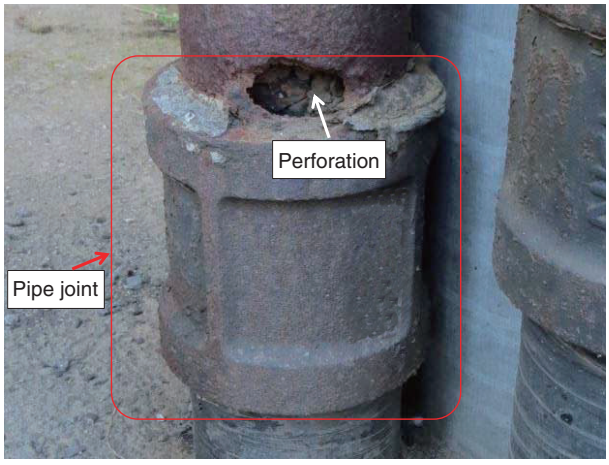

Fig. 3. Lifting conduit with perforation (due to corrosion) in the upper part of the joint.

First, the corroded section is removed and primed with resin, which is used to bond stainless-steel repair plates around that section. After that, resin intermediate coating, glass-cloth winding, a resin top coating, and anti-corrosion paint are coated.

The most representative method for repairing lifting conduits is the half-cut-conduit method. This method has the advantage that even a conduit with large corrosion holes can be repaired; however, it is necessary to cut the conduit and remove parts of it. Accordingly, care must be taken to avoid accidentally damaging the cable during repair work. The over-cleat method, with which the steel lifting conduit is not cut, has two problems: (i) repair work takes a long time and (ii) repair work requires a specialist; thus, a damaged lifting conduit cannot be easily repaired. In consideration of these problems with such conventional methods, NTT EAST-Minamikanto developed a new method for easily repairing steel lifting conduits.

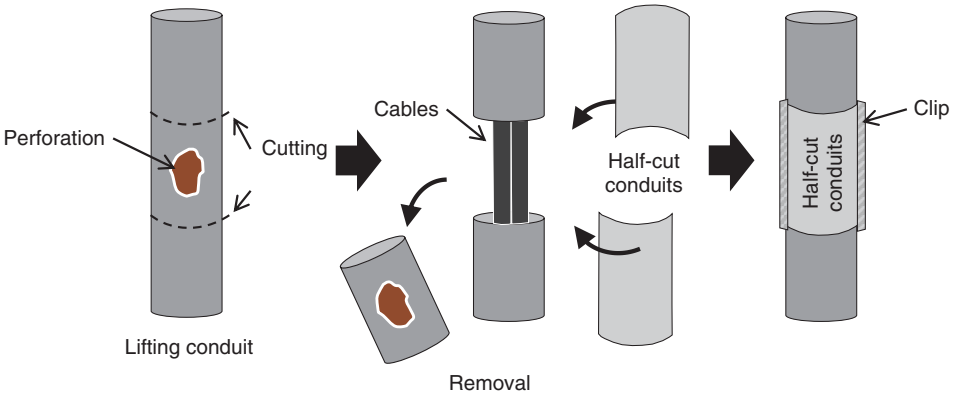

Fig. 5. Repair of lifting conduit with half-cut-conduit method.

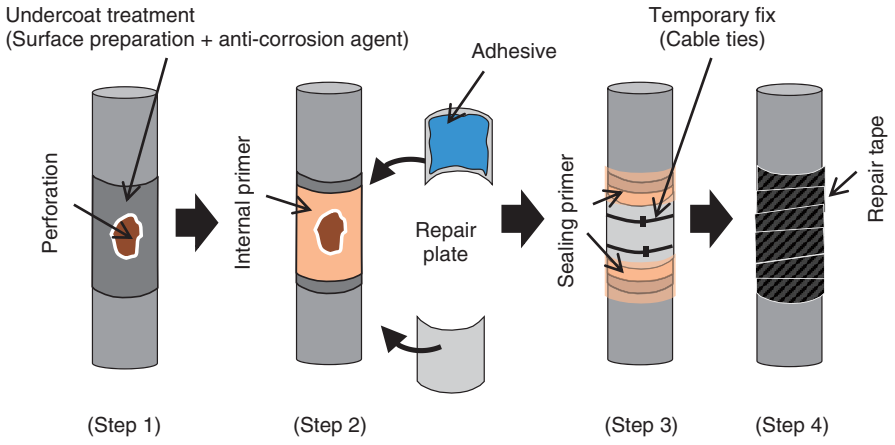

Fig. 6. New method for repairing lifting conduits.

3. New method for repairing lifting conduits

The new repair method mainly consists of four steps: (i) undercoat treatment, (ii) coating of an internal primer and attachment of repair plates, (iii) coating of a sealing primer, and (iv) wrapping with glass-fiber tape (**Fig. 6**).

(1) Step 1: Undercoat treatment

A metal brush or sandpaper is used to remove the rust around the areas where coatings have peeled off (hereafter referred to as repair area). An anti-corrosion agent is then coated by brush to the repair area and dried.

(2) Step 2: Coating and curing of internal primer and attachment of repair plates

A photo-curing resin (internal primer) is uniformly coated to the inside of the repair plates (within the repair area) and cured with natural or ultraviolet (UV) light. The internal primer prevents contact corrosion of a dissimilar metal between the lifting conduit (steel) and repair plates (stainless steel). Adhesive is then applied to the repair plates, which are then adhered to the repair area.

(3) Step 3: Coating and curing of sealing primer

A photo-curing resin (sealing primer) is applied evenly to the gaps between the conduit and the repair plates as well as to areas where the existing anti-corrosion agent peeled off. The repair area is then irradiated with natural or black light for curing.

(4) Step 4: Wrapping with glass-fiber tape

Glass-fiber tape (hereinafter, repair tape) is wound around the repair area while pulling it tight so that there is no looseness in the repair area or above and below the widths of the repair tape. By wrapping the

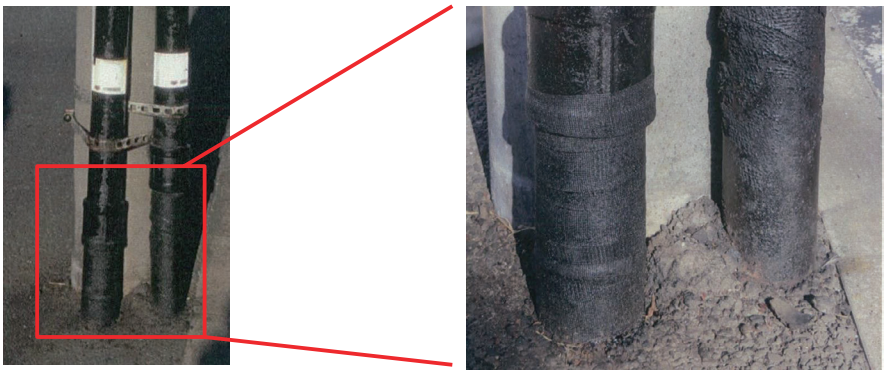

Fig. 7. Lifting conduits repaired with the new method.

Table 1. Outline of test.

Test item	Test details	Summary of test results
Weather resistance	UV irradiation	No change in peeling or cracking
Heat resistance	Heat cycle between high temperature and low temperature	No change in peeling or cracking
Corrosion resistance	Salt-water spray	No change in rusting

repair tape in a manner called *half-overlapped one-return lap*, the overlapping tapes complement each other and prevent adhesion from decreasing. By straddling the boundary between the anti-corrosive area and area coated with sealing primer and by ensuring the repair tape completely covers that entire area, it is possible to prevent rusting on the portion without the applied sealing primer (tape end).

The materials used for the repairs are commercial products and therefore easy to obtain. Moreover, the new method has the advantage that repair work can be easily completed in a short time (about two hours). Photographs of two steel lifting conduits after repair are shown in **Fig. 7**. The surfaces of the repair areas are covered with repair tape, and the required strength is assured by the repair plates fitted inside, and rusting is prevented by coating the primer.

4. Verification of durability of lifting conduit repaired with new method

Lifting conduits repaired with the new repair method would deteriorate under complexed conditions such as UV rays, wind and rain, temperature change, and sea salt. Accordingly, the TASC fabricated a test piece applied with the new method and verified its weather resistance, heat resistance, corrosion resistance, etc. in a simulation of an actual environment. The verification results were evaluated on the basis of standards defined in the specifications for repairing lifting conduits. The details of the verification test are listed in **Table 1**.

In the test, the new method was applied to repair a steel conduit with a simulated hole. According to the results of the test, NTT's specifications, such as no visible change in rust state and no peeling of repair tape (Table 1), were satisfied. Photographs taken before and after the corrosion-resistance test are shown in **Fig. 8**.

The results presented in Table 1 indicate that the stipulated specifications were satisfied; thus, we confirmed that this new repair method can be employed for practical use.

5. Concluding remarks

The new repair method uses commercially available materials and do not require specialized technology for repair work, which can be completed in a short time (about two hours). Accordingly, in comparison with conventional methods, the new method enables lower repair costs while maintaining quality. In fiscal year 2019, NTT EAST will add this repair method to current repair methods for steel lifting

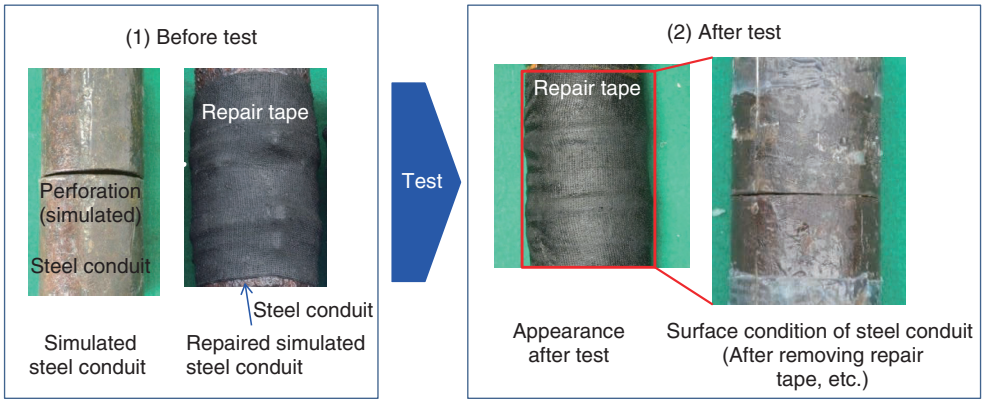

Fig. 8. External appearance of simulated steel conduit before and after corrosion test.

conduits.

The TASC will continue to promote technical cooperation activities aimed at solving on-site issues and contribute to improving the quality and reliability of telecommunication facilities.

Reference

[1] Technical Assistance and Support Center, NTT EAST, "Q&A Concerning On-site Troubleshooting with Telecommunication Equipment," 3rd edition, pp. 508–510, The Telecommunication Association, Tokyo, Japan, 2016 (in Japanese).

Report on NTT R&D Forum 2019

Tomohisa Hosoda, Yasushi Matsuno, Takayoshi Mochizuki, Hideo Kato, Tomota Ieyasu, Masaki Hisada, Kentaro Hotta, and Norio Sakaida

Abstract

NTT R&D Forum 2019 was held at the NTT Musashino Research and Development Center on November 11–15, 2019 (November 11 and 12 were set aside solely for the press and NTT Group employees). This article provides an overall of the forum.

Keywords: R&D forum, IOWN, smart world

1. Forum overview

The NTT Group is seeking to resolve social issues as *Your Value Partner*. In May 2019, it announced the Innovative Optical and Wireless Network (IOWN), a photonics-based concept aimed at providing a high-capacity, low-latency, and energy-efficient information communication infrastructure capable of supporting sustainable growth. NTT R&D Forum 2019 introduced the latest results of research activities carried out based on this concept through lectures and exhibits presented under the theme of "What's IOWN? - Change the World."

2. Lectures and workshops

On November 13, NTT president and CEO Jun Sawada gave a keynote lecture entitled "Towards the Era of IOWN" (**Photo 1**). By comparing and contrasting a recycling society developed during the Edo Period in Japan with European societies during the Industrial Revolution, which was designed to encourage economic growth, he stated that NTT is seeking a society in which innovations bridge today's social divisions arising from differences in civilization or thinking. Increasing consumption of electrical energy represents a technical constraint on sustainable development. The technical foundation of IOWN is the extremely energy-efficient photonics-electronics convergence technology that NTT is developing. Based on this technology, NTT is developing the All-Photonics Network, which will also pave the way for an ultimate future network that incorporates quantum communication and quantum encryption. As Digital Twin Computing advances, interactions within the cyberworld will become possible. When the real space works in concert with the new cyberspace, how will social institutions, the purpose of and joy in life, ethics, and responsibility manifest themselves? NTT will collaborate with Kyoto University in studying these questions, which represent a new way of looking at the world. Mr. Sawada also described Cognitive Foundation®, which automatically links various information and communication technology (ICT) resources to enable a network to evolve autonomously, and introduced NTT's involvement in the Smart City project in Las Vegas as an example.

Looking towards the future of communication, NTT, Intel, and Sony announced the establishment of the IOWN Global Forum, an international forum that promotes photonics-related research and development (R&D) based on photonics-electronics convergence. Sixty-five companies, the majority of which are from outside Japan, are currently considering to participate in it. Mr. Sawada ended his address by inviting partners to participate in NTT projects

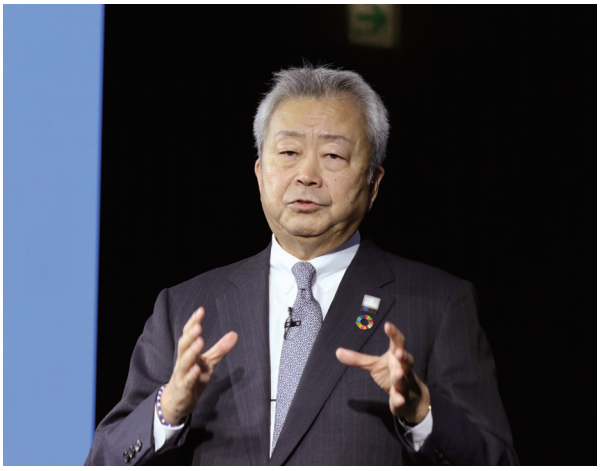

Photo 1. Keynote lecture by Jun Sawada, president and CEO, NTT.

aimed at creating a smart world.

The president's keynote lecture was followed by a presentation by Katsuhiko Kawazoe, NTT senior vice president and head of the Research and Development Planning Department, entitled "What's IOWN? - Change the World." The vision of IOWN is to create an innovative information processing base that will carry out vastly expanded information processing and make it possible to break through conventional technical constraints such as power consumption. IOWN consists of three elements: All-Photonics Network, which dramatically enhances the potential of the information processing base; Digital Twin Computing, which opens a new horizon for services and applications.; and Cognitive Foundation, which optimally harmonizes all ICT resources. Wireless access technology in IOWN will also penetrate everywhere, e.g., under the sea, in the air, or in outer space, resulting in a world of *connected everywhere*. NTT's activities towards this goal include world-leading high-capacity wireless transmission, undersea wireless communication, and wireless transmission in outer space, with the latter being undertaken as a joint research project with Japan Aerospace Exploration Agency (JAXA).

To illustrate a world made possible by IOWN, Mr. Kawazoe introduced a project involving a company, academic institution, and local government, i.e., NTT, Hokkaido University, and Iwamizawa City in Hokkaido. The aim of this project is to promote world-leading smart agriculture using cutting-edge agricultural robot technology and ICT. He concluded his presentation with a declaration that those involved in NTT R&D are committed to thinking outside the box and pursuing the welfare and prosperity of humankind propelled by a tremendous zeal for technical innovation given the urgent need to protect the global environment and ensure sustainable development.

Two special sessions were held on November 14, and four on November 15. In the first session on November 14, Kazuhiro Gomi, president and CEO of NTT Research, Inc., introduced the innovation strategy of NTT Research, which is responsible for the globalization of NTT R&D, and its positioning in the IOWN initiative under the title of "Upgrade Reality - Reality in IOWN Concept." In the second session, the directors of the three laboratories that make up NTT Research gave an overview of their respective activities. Tatsuaki Okamoto, director of Cryptography & Information Security Laboratories (CIS Labs), reported that their aim is to create a world-leading encryption laboratory and that they already have a pool of top researchers, who they hope will form a *dream team* in the areas of cryptography theory and blockchain. For this purpose, they will collaborate with NTT Security Platform Laboratories. Hitonobu Tomoike, director of Medical & Health Informatics Laboratories (MEI Labs), said that they are focusing on precision medicine as it enables diagnosis and healthcare to be tuned to the characteristics of each individual. For this purpose, they will apply artificial intelligence (AI), the Internet of Things (IoT), and data science in their research on health and diseases while placing the highest priority on patients. Next, Yoshihisa Yamamoto, director of Physics & Informatics Laboratories (PHI Labs), presented the challenge of fusing the principles of quantum mechanics and brain-based information processing with light. Their long-term research target is to understand how humans carry out advanced information processing, such as recognition and decision-making, as well as the nature of consciousness, by analyzing the relationships between these two principles. Lastly, a panel discussion was held with Director Okamoto of CIS Labs, Director Tomoike of MEI Labs, and Deputy Director Satoshi Kako of PHI Labs as panelists and with President Gomi acting as the moderator (**Photo 2**). They discussed the advantages that Silicon Valley, where NTT Research is located, offers, such as the availability of top-notch and highly motivated experts and interdisciplinary environments, and their determination to advance their research capabilities on the basis of NTT's traditions.

Photo 2. Panel discussion.

Photo 3. Special session by Professor Noboru Noguchi, Hokkaido University.

On November 15, Professor Noboru Noguchi, program director of Fundamental Agriscience Research, Research Faculty of Agriculture, Hokkaido University, gave a presentation entitled "Smart Agriculture toward Society 5.0." He spoke of a smart agriculture project that uses cutting-edge agricultural robot technology and ICT. This project is being undertaken based on an agreement involving NTT, Hokkaido University, and Iwamizawa City (**Photo 3**). Then, Ryutaro Kawamura, director of NTT Service Innovation Laboratory Group, gave a talk entitled "The Digital World of Humans and Society – Digital Twin Computing." He envisioned how the acceleration of digitalization will change the world and identified key technologies that will make this change possible. This was followed by a presentation, entitled "Innovative Network Focused on 2030 (Beyond 2020)," by Arata Itoh, director of NTT Information Network Laboratory Group. He introduced the Group's research initiatives undertaken within the context of the IOWN concept and the latest research cases. Lastly, Tetsuomi Sogawa, director of NTT Science and Core Technology Laboratory Group, presented a lecture entitled "Basic Research Supporting All-Photonics Network." He elaborated on photonics-electronics convergence devices that make high-speed and ultra-power-efficient operation possible; innovative photonics devices that support high-capacity optical transmission; LASOLV™, a new physical computer based on optical communication technologies; and an optical lattice clock network that serves as a next-generation frequency/time reference infrastructure.

3. Showcasing research results

In this forum, 106 examples of the latest research results were on display and divided into seven categories: [Special category] IOWN for Smart World; media and devices/robotics; networks; AI; data collection, management and analysis; security; and basic research. Technologies being investigated by the NTT Group and outcomes resulting from collaboration with partner companies were also presented. There were also nascent projects that went beyond the exhibition theme, such as "Action for 2020 and Beyond" and "SDG-based Assessment of ICT Solution Services." Thus, the exhibition covered a wide range of research findings from basic research to already commercialized technologies.

To enable visitors to see the results of R&D more effectively, there were not only exhibition sites devoted to specific topics but also dedicated exhibition rooms and outdoor sites depending on the nature of the topics presented. There was also a special exhibition site that introduced activities related to the special category: IOWN for Smart World (**Photo 4**). At these sites, visitors could view well-designed demonstrations and exhibits.

3.1 IOWN for Smart World

(1) IOWN use cases

Use cases of IOWN for Smart World depict a world that will be made possible by IOWN. As a use case of Digital Twin Computing, decision-making through consultation with multiple selves (digital twins) that

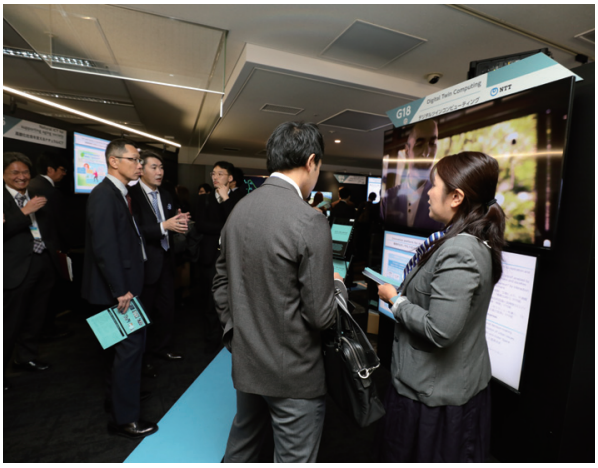

Photo 4. IOWN for Smart World.

Photo 5. Media and devices/robotics.

have different abilities was demonstrated. A conceptual model of a mobility society at the time when vehicles are completely self-driven showed how people, vehicles, and roads will cooperate and interact at an advanced level.

(2) Distinctive technologies for IOWN

The latest R&D results for implementing IOWN were introduced and classified as Post-Moore, All-Photonics Network/Beyond 5G, Advanced Research, and Point of Atmosphere. Specifically, the following distinctive technologies for IOWN were introduced: nano-photonic acceleration and on-board/chip optical network, both based on photonics-electronics convergence information-processing technology, which makes high-performance and low-power operation possible; terabit-level transmission technology for building a high-capacity network for IOWN; and high-frequency-band analog radio-over-fiber (RoF) technology that separates signal processing from an antenna and/or radio frequency to enhance the degree of flexibility in determining wireless areas.

3.2 Media and devices/robotics

(1) Media technologies that provide the novel experience of transcending time and space

A theater-type exhibition presented a concept of the future in which "IOWN × Entertainment" integrates real and virtual worlds to create a transcendent experience. The following distinctive technologies were also exhibited: three-dimensional (3D) video presentation technology that allows a choice between 2D and 3D viewing (**Photo 5**); glasses-free 3D technology that makes 3D viewing from any angle (360°) possible; acoustic field control technology that delivers sound to only a specific area; zero-latency media technology that uses predictive expression to achieve communication that transcends time and space; and user experience (UX) technology that creates a heightened sense of reality by manipulating temperature and air.

(2) Human-machine interface technologies that expand human potential

In a demonstration of technology that turns visual and auditory senses into a haptic sense, visitors were able to experience a virtual skateboard ride while sensing vibrations along with a video. Also on display were a new hands-free, stress-free, and focus-free visual sensing device; behavior-design technology that uses AI to understand a person from multiple perspectives and enables him/her to approach his/her ideal well-being; and self-transformation interaction technology that uses surrounding devices to impart how professionals use their expertise and prompts an individual to transform into someone he/she wants to be.

3.3 Networks

(1) Optical and wireless technologies for an innovative network

A wide range of optical and wireless technologies, each dedicated to a specific function, were introduced. They will make it possible to build an innovative network that will serve as a smart social infrastructure that can meet diverse and complex needs. They included technology that controls the network

Photo 6. Networks.

Photo 7. AI.

so that it can adapt to the quality requirements of individual applications and technology for underwater communication.

(2) Control and orchestration technologies for flexibility and intelligence

A diverse range of network control and orchestration technologies were on display. They included AI-based advanced operation technology; technology for detecting fault locations, diagnosing faults, and achieving early recovery; and technology for real-time presentation of traffic in a virtual environment (**Photo 6**).

(3) Use cases using network features

Use cases of the following technologies were introduced: technology for low-latency transmission of a live 4K video; video-streaming architecture achieved through cooperative interactions with video-delivery providers; and network-information infrastructure technology for efficiently collecting, processing, and delivering the information needed to provide mobility as a service (MaaS).

3.4 AI

The NTT Group's AI-related technologies, corevo®, which co-exist with people to co-create new values to enrich people's lives, were introduced according to the following classifications.

(1) AI supporting people

The following AIs were introduced: technology that uses a sequence-to-sequence model to convert the voice quality and prosody of a person into those of another person of his/her choice; chat-dialogue technology for enabling conversations with unique characters; technology for identifying events from speech to achieve context-adapted dialogue; English-pronunciation training technology that uses auditory sense-based feedback; voice and acoustic emotion-processing technology that will facilitate the evolution of connected cars; technology for estimating the locations of roadside display devices for map enrichment; technology for reading non-verbally expressed emotions to improve communication quality; and an AI solution that automatically responds to visitors using audio and video.

(2) AI supporting society

The exhibited AIs included Smart Plant that digitizes the five human senses to improve productivity and operation rates; technology for relieving congestion during a large-scale event in real time by forecasting and guiding visitor flows; technology for automating responses to reporting of faults; angle-free object detection technology that uses image recognition to identify diverse products to reduce the need for retail assistants in shops and that becomes smarter the more it is used; and rescue-team operation-optimization technology that uses AI and urban data to shorten the time needed for ambulances to arrive at emergency scenes and transport patients to hospitals (**Photo 7**).

(3) AI infrastructure technologies

On display were technology that produces highly accurate translation at a TOEIC®* score level of 960 (highest possible score being 990); technology that

* TOEIC® is a registered trademark of Educational Testing Service (ETS). This product is not endorsed or approved by ETS.

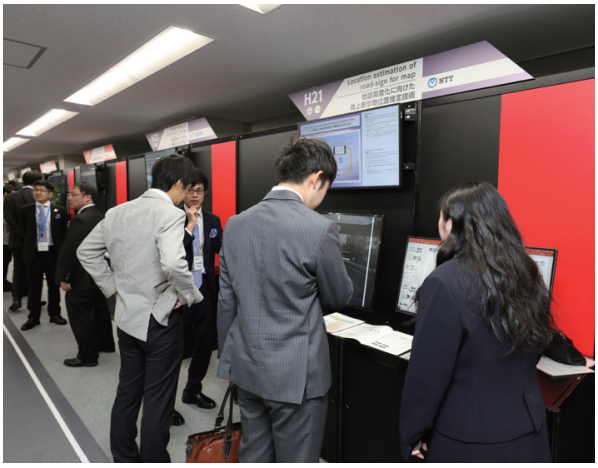

Photo 8. Data collection, management, and analysis.

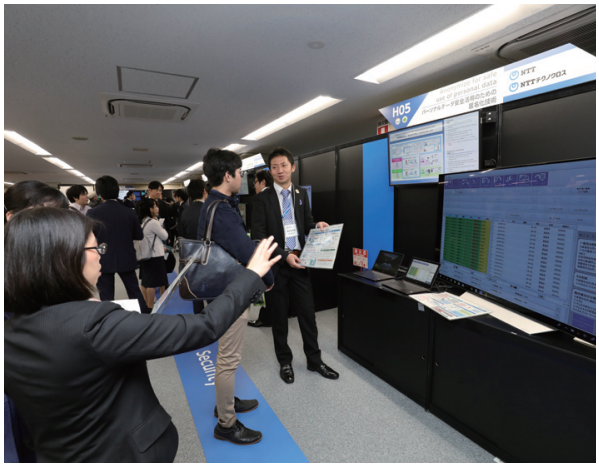

Photo 9. Security.

reduces the cost of creating chatbot scripts; technology that compresses space-information data to improve data-reading speed, making it easy to handle a large volume of human activity data; and pattern-recognition technology that uses sparse operation in media processing and ensures end-to-end security.

3.5 Data collection, management, and analysis

(1) Innovation of system construction and operational services

The following technologies were on display: technology that analyzes a code and tests it automatically and quickly focusing on the changes made in it; technology that enables rapid handling of faults by sharing expertise obtained from the analysis of the fault logs of multiple systems; and an international standard-compliant IoT data-sharing platform.

(2) Real-time analysis of camera and space-sensor data

Introduced were an image-recognition service lowering AI creation costs (**Photo 8**); a public-safety solution by exploiting incident and sensor data in public areas; and the "Hikari Deep Learning" (Carrier Cloud for Deep Learning) inference platform that carries out AI analysis of numerous video streams.

(3) Core technologies that support future connected vehicles

Two technologies were on display. The first is for collecting data from numerous connected cars and simulating road environments in clouds. The second is Global Navigation Satellite System (GNSS) positioning technology that uses cloud processing to achieve centimeter-level positioning.

3.6 Security

(1) Security for protecting Smart World

Technologies for countering cyberattacks that are becoming increasingly sophisticated were presented. Technology for detecting fake sensor data makes it possible to protect social systems that rely on numerous sensors from attack. Secure technology for Society 5.0 detects falsification of data in OT (operational technology)/IoT devices installed throughout a supply chain. Data collection technology protects people from social engineering attacks that exploit their psychological vulnerabilities.

(2) Security for creating Smart World

Applications of encryption technology and technologies that create new value using cutting-edge security technology were introduced. Anonymizing technology supports the creation of highly useful anonymized information and makes secure use of personal data possible (**Photo 9**). A secure information-communication platform makes it possible to conduct advanced data analysis while protecting privacy and commercially sensitive information.

3.7 Basic research

Basic research projects that are revolutionizing society were presented. They included innovative information-processing technology in the Post-Moore era, advanced medical care, and advanced materials.

Cutting-edge basic research projects that are aimed at the creation of new principles and concepts for the future were also presented. They included Danswing paper, which uses illusion to make it appear that

Photo 10. Basic research.

printed materials are moving; a transparent battery that can be used to make devices virtually invisible (**Photo 10**); optical meta-surface, which conveys information of invisible light to AI; and middleware for LASOLV, which solves challenging problems at an extraordinary speed.

4. Conclusion of the forum

We were able to welcome more than 17,000 visitors, including those from abroad. We believe that this large number reflects the expectations of NTT Group employees and our customers for the first NTT R&D Forum after the announcement of the IOWN concept. Visitors to the exhibit sites and those who took the questionnaire survey or sent us inquiries after the forum clearly expressed their high expectations for NTT R&D. To live up to these high expectations, we will redouble our efforts in all areas from basic research to the development and deployment of new technologies.

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External Awards

CSS2019 Encouragement Award
Winner: Ibuki Mishina, Koki Hamada, and Dai Ikarashi, NTT Secure Platform Laboratories
Date: October 23, 2019
Organization: Information Processing Society of Japan

For "Realization of Practical Secure Deep Learning."
Published as: I. Mishina, K. Hamada, and D. Ikarashi, "Realization of Practical Secure Deep Learning," Computer Security Symposium 2019, Nagasaki, Japan, Oct. 2019 (in Japanese).

CSS2019 Encouragement Award
Winner: Koki Hamada, Dai Ikarashi, Ibuki Mishina, and Ryo Kikuchi, NTT Secure Platform Laboratories
Date: October 23, 2019
Organization: Information Processing Society of Japan

For "A Secure Batch Function Evaluation Algorithm and Its Application to Secure Logistic Regression Algorithm with High Accuracy."
Published as: K. Hamada, D. Ikarashi, I. Mishina, and R. Kikuchi, "A Secure Batch Function Evaluation Algorithm and Its Application to Secure Logistic Regression Algorithm with High Accuracy," Computer Security Symposium 2019, Nagasaki, Japan, Oct. 2019 (in Japanese).

CSS2019 Encouragement Award
Winner: Dai Ikarashi, NTT Secure Platform Laboratories
Date: October 23, 2019
Organization: Information Processing Society of Japan

For "Secure Real Number Operations for Secure AI –O(|p|)-bit Communication and O(1)-round Right Shift Protocol–."
Published as: D. Ikarashi, "Secure Real Number Operations for Secure AI –O(|p|)-bit Communication and O(1)-round Right Shift Protocol–," Computer Security Symposium 2019, Nagasaki, Japan, Oct. 2019 (in Japanese).

CSS2019 Outstanding Paper Award
Winner: Toshinori Usui, NTT Secure Platform Laboratories/Institute of Industrial Science, The University of Tokyo; Kazuki Furukawa, The University of Electro-Communications; Yuto Otsuki, Tomonori Ikuse, Yuhei Kawakoya, Makoto Iwamura, Jun Miyoshi, NTT Secure Platform Laboratories; Kanta Matsuura, Institute of Industrial Science, The University of Tokyo
Date: October 23, 2019
Organization: Information Processing Society of Japan

For "Automatically Appending Multi-path Execution Functionality to Vanilla Script Engines."
Published as: T. Usui, K. Furukawa, Y. Otsuki, T. Ikuse, Y. Kawakoya, M. Iwamura, J. Miyoshi, and K. Matsuura, "Automatically Appending Multi-path Execution Functionality to Vanilla Script Engines," Computer Security Symposium 2019, Nagasaki, Japan, Oct. 2019 (in Japanese).

Papers Published in Technical Journals and Conference Proceedings

Comparative Study on Layered Light-field Displays and Optimization Methods
K. Maruyama, K. Takahashi, T. Fujii, M. Date, and H. Kimata
Proc. of the International Display Workshops (IDW) 2019, pp. 1073–1076, Sapporo, Japan, November 2019.

We focus on two factors that affect the performance of layered light-field displays: the layer device and optimization method. We quantitatively compared the performances of different architectures of layered light-field displays (liquid crystal panel (LCD), holographic optical element (HOE), and super-in plane switching LCD) and their optimization methods (analytical and CNN-based methods).

Depth-range Control in Visually Equivalent Light Field 3D (VELF3D) Display
M. Date, S. Shimizu, and H. Kimata
Proc. of IDW 2019, pp. 65–68, Sapporo, Japan, November 2019.

Light field displays have limited display depth range, which is a serious issue in supporting live action content. Though generating depth maps and re-rendering is a solution, it incurs huge computational cost. In this paper, we discuss achieving depth-range compression simply by calculating the weighted average of multi-camera images.

Privacy-preserving Support-vector-machine Computing Using Random Unitary Transformation

T. Maekawa, A. Kawamura, T. Nakachi, and H. Kiya

IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences, Vol. E102-A, No. 12, pp. 1849–1855, December 2019.

We propose a privacy-preserving support vector machine (SVM) computing scheme is proposed. Cloud computing has been spreading in many fields. However, cloud computing has serious issues for end users, such as the unauthorized use of cloud services, data leaks, and privacy being compromised. Accordingly, we propose a privacy-preserving SVM computing scheme. We focus on protecting visual information of images by using a random unitary transformation and discuss some of the properties of the protected images. The proposed scheme enables us not only to protect images but also to experience the same performance as that of unprotected images even when using typical kernel functions such as the linear kernel, radial basis function kernel, and polynomial kernel. The scheme can also be directly carried out using well-known SVM algorithms without the need to prepare any algorithms specialized for secure SVM computing. In an experiment, we applied the proposed scheme to a face-based authentication algorithm with SVM classifiers to confirm its effectiveness.

OEM Finder: Hunting Vulnerable OEM IoT Devices at Scale

A. Nakajima

BlackHat Europe 2019, London, UK, December 2019.

Many consumer Internet of Things (IoT) vendors now use an original equipment manufacturer (OEM) production model. They purchase IoT devices from OEM suppliers then customize and sell those devices under their own brands. While this production model can reduce device manufacturing costs, it could lead to high-security risks such as when the original device is vulnerable, the OEM device (re-branded device) is also vulnerable. The survey conducted by IPVM in 2017 concluded that the vulnerability found in the Hikvision's (OEM supplier's) network camera was propagated to its various OEM devices, which are sold by over 80 vendors.

Including the above case, we found that vulnerability databases (e.g., National Vulnerability Database (NVD), Common Vulnerabilities and Exposures (CVE)) do not include or announce OEM devices as affected by vulnerabilities. One of the probable causes is that there is still no means to find OEM devices other than asking OEM suppliers or inspecting each device manually.

To address this supply chain risk, we developed a tool called OEM Finder, which can automatically detect OEM device candidates based on the similarity of its appearance between OEM and original devices. To achieve fast, automatic, and precise OEM device detection, we adopt an object-recognition algorithm (KAZE) with k-NN and use graph kernels.

With our tool, we found more than 180 unique vulnerable OEM device candidates from over 50,000 IoT device images, which we collected from e-commerce websites. We also analyzed the latest firmware images of some of these OEM device candidates, which are distributed by OEM vendors (not OEM suppliers), and confirmed that the devices detected with our tool are indeed OEM devices. We also found that the OEM firmware images are still vulnerable.

At the end of the talk, we will publish this tool as an online search engine. By uploading a photo of vulnerable IoT devices, this web service can list the OEM device candidates that potentially contain identical vulnerabilities. We believe that our web service will help in finding vulnerable OEM devices and mitigate security risks.
