NTT Technical Review

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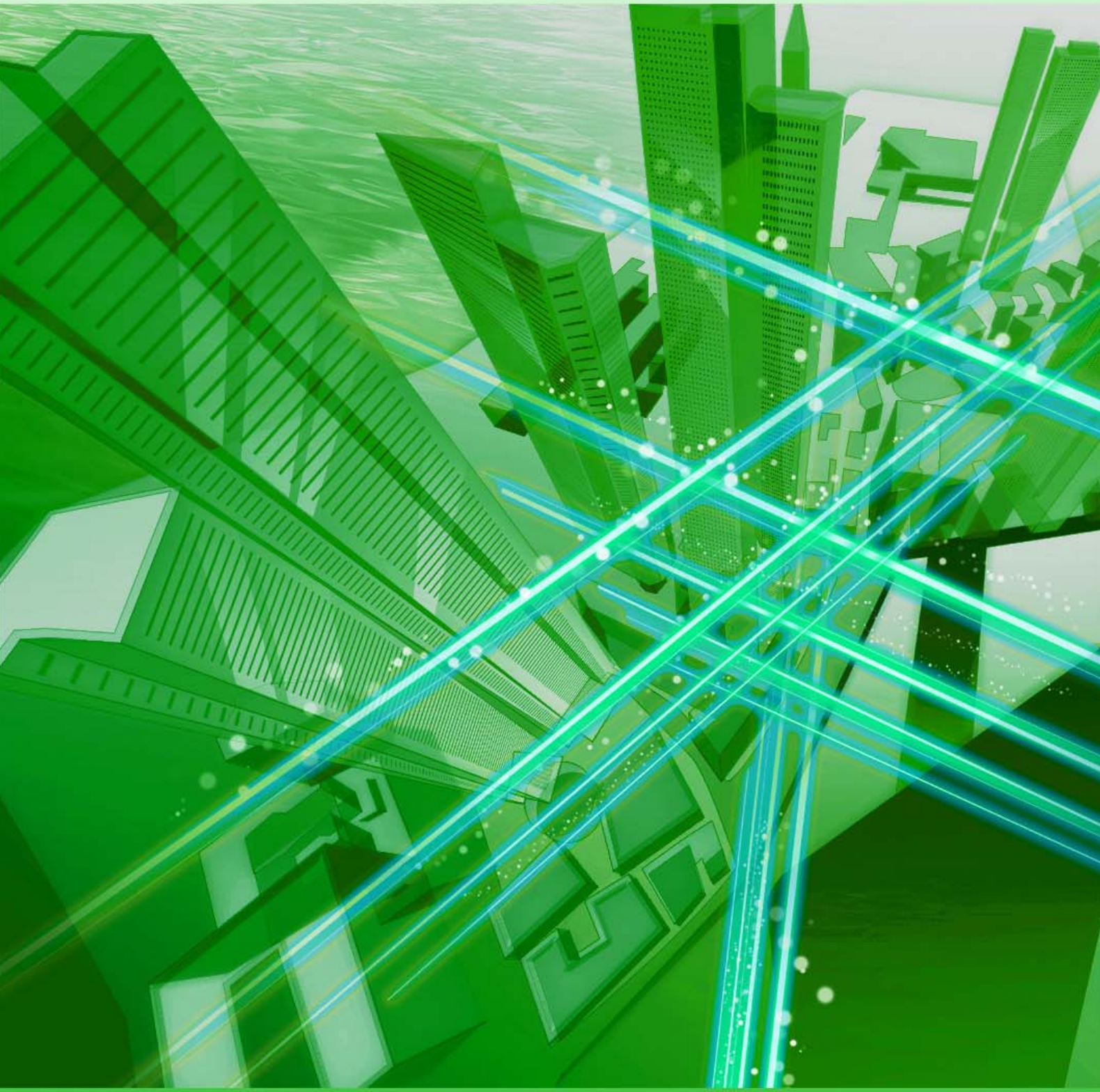

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Even If Facing Difficulties, Create New Value While Building on the Achievements of Your Predecessors

Akira Fujiwara
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Abstract

The missions of NTT Basic Research Laboratories are to promote advances in science that will ultimately benefit humankind and contribute to NTT's business. Researchers at the laboratories have published numerous achievements in the fields of materials science, physical science, and optical science. Akira Fujiwara, a senior distinguished researcher, is researching silicon single-electron devices to enable accurate operation and detection of single electrons, which are expected to be applied to quantum electrical standards, high-sensitivity sensors, and quantum qubits. We asked him about the progress of his research activities and attitude as a leading researcher.

Keywords: silicon single-electron device, electric-current standard, quantum metrology triangle

Taking the challenge of applying silicon single-electron devices to high-accuracy electric-current standards

—Could you give an overview of your current research for the readers?

My current research is focused on (i) developing *ultimate electronics* on the basis of high-precision and high-speed charge manipulation, detection, and control of electrons using silicon-based semiconductor nanodevices and (ii) applying this technology to high-accuracy electric-current standards, ultra-low-energy information processing, ultra-sensitive sensing, and quantum technology (**Fig. 1**).

Computers and smartphones, which have become everyday tools, use semiconductor circuits made of silicon. By passing an electric current through a semiconductor circuit or applying a voltage across it, the current can be amplified or switched on/off. The current flowing through the semiconductor circuit consists of moving electrons, which are tiny particles with a negative charge. In my research, I am testing the limits of how far we can control and manipulate each electron in a silicon semiconductor. Such control and manipulation of single electrons will be applicable to ultra-low-energy information processing and ultra-sensitive sensing. Units such as the meter (m) for length and kilogram (kg) for mass are defined as basic international standards for weights and measures. Regarding the ampere (A), which is the unit for electric current, we are aiming to establish

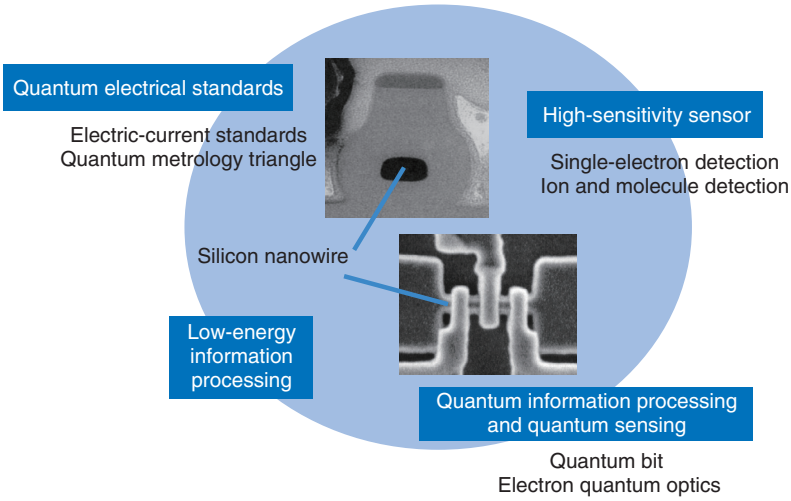


Fig. 1. Ultimate electronics using silicon nanodevices.

a quantum electrical standard on the basis of an accurate current generated by a silicon single-electron device.

—What triggered you to target a new international standard for electric current?

In 2003, when I was a visiting researcher at the National Institute of Standards and Technology (NIST, Gaithersburg, USA) and evaluating the characteristics of a silicon single-electron device developed by NTT, I realized that the field of standards—which pursues extreme accuracy—is the most suitable application of the device. After ten years of persistent research, I began to receive interest from Europe as well.

The technology I am pursuing was not adopted when the International System of Units (SI) was revised in 2019 as well as the definition of the ampere. However, believing that it will be adopted in the future, I am continuing my research while working hard with researchers around the world. Being recognized for such efforts, I was honored to be elevated to an IEEE (Institute of Electrical and Electronics Engineers) Fellow in 2018 and JSAP (Japan Society of Applied Physics) Fellow in 2020. I am glad that I did not give up on my research.

I am currently working on establishing high-accuracy single-electron current standards and achieving the quantum metrology triangle, which is an experiment to verify the consistency of quantum electrical standards. Specifically, I am working on (i) the characteristic evaluation of devices fabricated at NTT using a semiconductor-manufacturing line for research purposes and (ii) computational analysis of such devices using a device simulator, which we developed when we were teleworking during the novel coronavirus pandemic (**Fig. 2**). Following the revision of the definition of the ampere in 2019, electric current is now defined as the number of electrons that constitute the current carried per second, and we are currently focusing on how to transfer one electron accurately and quickly while minimizing as much error as possible. Silicon single-electron devices also have the potential to be applied to quantum computers, which is a hot topic of research; however, it is very difficult to produce many identical devices because of their extremely small size. Therefore, I believe that it is important for us to focus on applying such a device in electric-current standards in which one device will be good enough to demonstrate its usefulness.

Collaboration is a vital part of this research. About five years ago, we issued a press release about the results of our joint research with the National Physical Laboratory (NPL) in the UK, announcing that we could generate accurate currents at the world's fastest operating speed [1]. We have also begun joint research with the National Institute of Advanced Industrial Science and Technology (AIST), which manages Japan's national standards.

For practical use of a high-accuracy current standard that will enable the revised "new ampere," we will have to further improve the accuracy of the

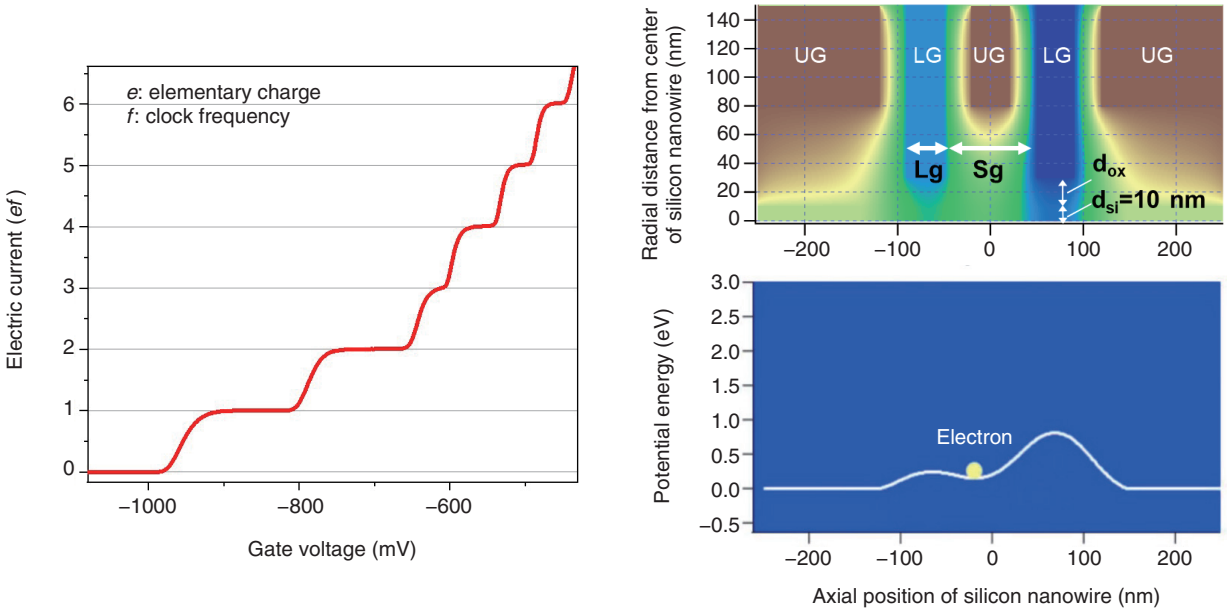


Fig. 2. Characteristics of silicon single-electron current standards (experimental results) and potential analysis using a device simulator.

currents generated by a silicon single-electron device. To break the world record and take the global lead, we are working with AIST and other teams to complete the quantum metrology triangle using single-electron current standards.

Verify your research fairly

—Is it important for researchers to take up the challenge of being the best in the world?

Research, whether basic or applied, is carried out as a community, and in each community, many competitors aim to be the best in the world. I believe that this situation is good for all because by competing together, even if one of us loses, we can all learn. Such friendly rivalry will lead to contributions to the field as well as society. The development of the research community may lead to not only the commercialization and implementation of our products in society but also the creation of new research themes and business.

I sometimes naturally feel disappointed when I am competing with overseas researchers. Although Japan is excellent in the field of science, the United States and Europe, the birthplace of modern science, are even better and have more resources, including a deeper pool of researchers. I even have moments when I feel that Japan is losing and accept that fact with humility, but I am also sometimes frustrated with my lack of ability.

Under these circumstances, I try to evaluate and verify my own research fairly. For example, you can judge the quality of your research results, their significance, and their contribution to the community by the response from the community and leading researchers. Of course, it is important to have your own beliefs, but I try not to be complacent and evaluate myself objectively so that I can grow further.

I have been active as a researcher for a long time and feel that the environment surrounding research is becoming more difficult every year. In Europe and the United States, the competition is very fierce, and it is a tough environment in which you have to keep producing outstanding results to survive under severe competition for acquiring research funds and human resources. In quite a few cases, people leave their home countries in search of a research environment and place in which they can be themselves and live their lives as researchers. China is producing good results with its large organizations and resources; even so, I have heard that in some cases, young researchers are only allowed to work as research assistants. Compared with those countries, Japan is a good environment for creating new ideas in a harmonious relationship among researchers but lacks the

intensity as in other countries. Still, it is difficult to obtain employment as a researcher in Japan, and, as has been reported in the media, it is also difficult for young researchers to find an academic post at a university.

Under these circumstances, the choice of a research theme can be a fork in the road for researchers. For example, research in a popular field is, in a sense, secured by the fact that it is needed by society, so a certain number of posts are available. Working on research in such a field that is currently needed or popular is one meaningful choice; however, you run the risk of being carried away by superficial trends and your research not becoming significant enough. In the case of basic research, it is important to take a more long-term perspective and read the trends. If you find a field in which you can use your strengths or a theme that only you can tackle and has the potential to make you a leading researcher, you should compete in that field, even if it is a narrow one.

I am conducting research on electric-current standards with this mindset, and striving to make the most of my skills, one step at a time. For the rest of my research life, I want to pursue what only I can do while evaluating my research fairly from time to time so that I do not become complacent.

—You have been pursuing the issues that will impact future society rather than the issues facing us today, right?

Science is a process of knowledge accumulation, so even if my research is not useful right now, I want to conduct research that prompts people to say things like, "This is really new." and "This is one step forward." I believe that it is very important to aim for research that is valued by the research community.

I think that my research has been successful to some extent by having this attitude, therefore I cherish the research community and colleagues. If you understand what has been done in the community by your predecessors, you will come to respect them. If you focus on adding something new to the community, the community will grow and the researchers who belong to the community will be able to continue their research, creating a virtuous cycle. It is important to build up the community and become a valued member so that you can exchange useful information and obtain the cooperation of other researchers. To that end, I want to continue to engage in friendly rivalry with world-class researchers. It is vital to have people around you with whom you can have serious discussions about your research and continue learning from the results of those discussions, and I am happy to have such a community around me now. I work in an environment in which I can form collaborative teams with my colleagues and have come to realize the importance of collaborative research.

I think that the culture of Japanese companies and the mindset of researchers still have a strong tendency to do everything on their own. Japanese researchers have a strong respect for craftsmanship and are willing to do work with their hands in every aspect, including everyday maintenance of experimental equipment. Although I think that mindset is commendable, in Europe, the work of technicians is separate from that of researchers, and many companies seem to think that what they don't have in-house, they can obtain from outside. Partly due to cultural differences, international companies are probably more accustomed to doing things collaboratively. Both domestic and international companies have advantages and disadvantages, but if you can produce good results and new value by complementing what you don't have with what others do have, I think joint research is essential.

I used to be less than enthusiastic about collaborating. It was the advice from Tetsuomi Sogawa, head of the NTT Science and Core Technology Laboratory Group (who was then head of NTT Basic Research Laboratories), that changed my mind. Regarding the joint research with NPL on electric-current standards I mentioned earlier, he encouraged me to, "Not only work within our lab but also collaborate with outside parties to give your research a visible presence." I am also encouraging mid-career and young researchers to follow that advice. Joint research involves a lot of tasks due to intellectual property issues and piles of paperwork, but I transfer the necessary skills to these researchers and assure them that they can go ahead and form collaborations without hesitation if they need to. That said, I try not to say too much or be too forceful so as not to put too much pressure on our young researchers; in other words, I just try to make sure that my advice is one of their options.

Research mottos: "friendly rivalry," "take advantage of every opportunity," and "dig deep"

—What has been important to you in your research activities?

I believe that basic research is not immediately useful or helpful to anyone; however, even if you face

difficulties, create something new and valuable while building on the achievements of your predecessors.

With that belief in mind, I continue my research activities with the mottos of "friendly rivalry," which I have mentioned several times already, as well as "take advantage of every opportunity," and "dig deep." I believe that research is about learning from your failures, and even though I have had many failures, I have tried to learn from them. When I was young, sometimes the devices I created did not work as expected, but as I searched for the cause of the problem, I discovered new phenomena. At that time, I remember how happy I was when one of my senior colleagues said to me, "Mr. Fujiwara, even if you fall, you get up and learn from your failure."

Research is often described as "digging deep and wide." It is important to dig deeper and deeper into your topic. You need to understand more about the topic than anyone else to come up with new ideas. It is also very important to dig horizontally and cultivate the area surrounding your research topic. Doing so will help you understand the position of the research you are working on, and you will learn that it actually has a close relationship with unknown fields. That's why I often tell young researchers to take both approaches. If you only dig deep, you will become complacent, and if you only dig horizontally, you will end up with research without depth. I'm also trying to find a good balance between digging deep and digging horizontally.

—Finally, do you have any advice for young researchers on how to interact with leading researchers?

I think it is quite intimidating for a young researcher to suddenly meet a "big name" in their field. It may sound like a cliché, but the first thing you should do is try to get people to remember your face. It is also important to ask questions and make impactful presentations at international conferences. When you get the opportunity to make a presentation, I hope you will practice hard and impress the audience in such a manner that they will think, "What an impressive young person!"

If you feel uncomfortable asking a leading researcher a question, ask a talented person of your generation first or someone who is more approachable. In that sense, coffee breaks at a conference are valuable times to meet and ask questions. In fact, quite important information about research is exchanged at such meetings, so don't drink coffee alone because you are tired; instead, listen to the detailed stories that you couldn't hear at the presentations and the stories about the presenters' difficulties. All top researchers have such lively exchanges of information during coffee breaks.

At times, I feel that I am not yet part of that circle, even though I am saying things that sound great. At other times, I find it difficult having conversations with native speakers of English and feel that I am still in the process of learning. Therefore, let's take the challenge and get into such conversations without hesitation. You tend to be hesitant if you think you're not good enough or don't understand what's being said. Well, that's just the way I am. Instead of hesitating, it's okay to say, "I don't really understand the topic, but may I join the conversation anyway?" You don't have to pretend to know more than you do.

Reference

[1] Press release issued by NTT, "World-record accuracy of gigahertz high-speed single-electron transfer – An important step toward a high-accuracy current standard –," July 5, 2016. https://group.ntt/en/newsrelease/2016/07/05/160705a.html

■ **Interviewee profile**

Akira Fujiwara received a B.E., M.E., and Ph.D. in applied physics from The University of Tokyo in 1989, 1991, and 1994. He joined NTT LSI Laboratories in 1994 and moved to NTT Basic Research Laboratories in 1996. Since 1994, he has been engaged in research on silicon nanostructures and their application to single-electron devices. He was a guest researcher at the National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA from 2003 to 2004. He was a director of the Japanese Society of Applied Physics (JSAP) in 2010 and 2011 and a visiting professor of Hokkaido University in 2013. He was appointed as a distinguished scientist of NTT in 2007 and senior distinguished scientist of NTT in 2015. He received the International Conference on Solid State Devices and Materials (SSDM) Young Researcher Award in 1998, SSDM Paper Award in 1999, and Japanese Journal of Applied Physics (JJAP) Paper Awards in 2003, 2006, and 2013. He was awarded the Young Scientist Award in 2006 and Prizes for Science and Technology in 2017 from the Minister of the Ministry of Education, Culture, Sports, Science, and Technology. He was supported by the funding program for Next Generation World-Leading Researchers (NEXT Program), Japan Society for the Promotion of Science (JSPS) from 2011 to 2014. He is now a principal investigator of the 2018–2022 JSPS KAKENHI S (Quantum Standards and Ultimate Precision Measurements Based on Single Electrons). He is a JSAP Fellow, a member of Science Council of Japan, and an IEEE Fellow.

Research into Ultra-high-speed Full Software Access Networks that Virtualize the Physical Layer Functionality of Communications Networks

Kim Sangyuep
Distinguished Researcher, NTT Access Network Service Systems Laboratories

Abstract

Virtualization is progressing in a variety of areas, including networking, servers, and storage. In this issue, we speak with Distinguished Researcher Kim Sangyuep about the virtualization of the physical functionality (high-speed transmission interfaces) of communications networks, something which is very difficult to do with conventional technologies.

Keywords: virtualization, softwarization, logic algorithms

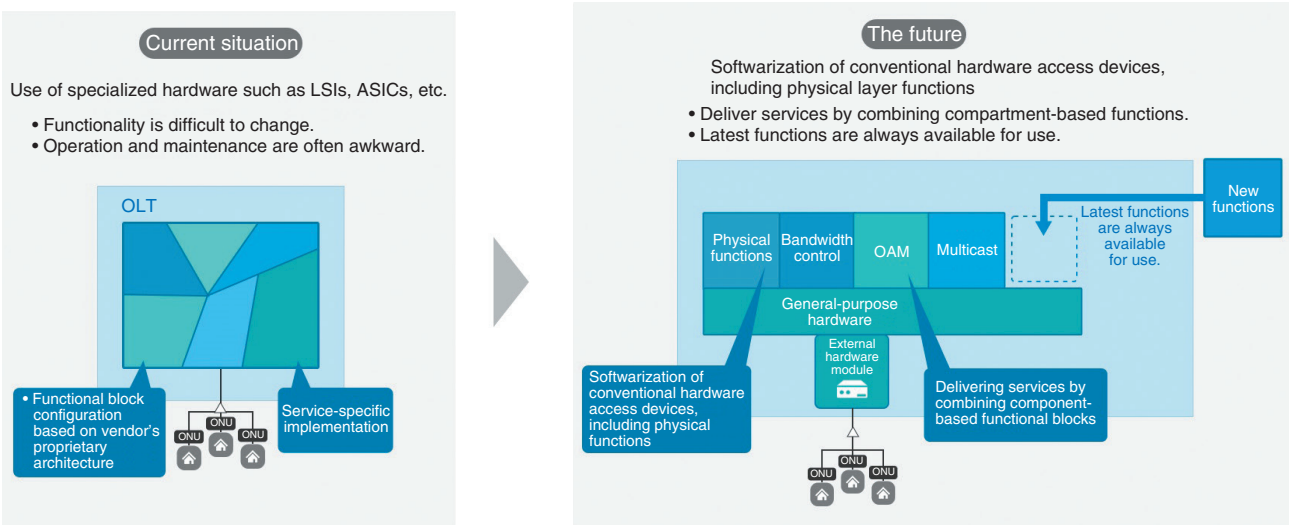
Aiming to provide flexible services without being tied to dedicated hardware

—What exactly does research into ultra-high-speed full software access networks entail?

The optical access lines we have today need to provide services to user devices that each has different requirements when it comes to communications speed, latency, security, and so forth. What's more, communications traffic rapidly increases as those services become more sophisticated and complex. In order to meet these requirements, each service provider uses access devices that consist of dedicated devices such as large-scale integration (LSI) and application-specific integrated circuits (ASICs) that are customized to the service's specifications.

However, there are also some drawbacks to using hardware based on these dedicated devices (i.e., dedicated hardware). First of all, the nature of dedicated hardware is such that once it has been manufactured and implemented, its functionality cannot be changed. This makes it difficult to respond flexibly to additions or changes to the service, and tends to make operation and maintenance tasks awkward.

We therefore expect to see software-based networks become a reality. These are networks where the functions of all the constituent devices are softwarized and can be freely combined on servers and offered as services. This would allow quick responses to security emergencies, as hardware changes would not be required when new services are needed, and



OAM: operations, administration, maintenance
ONU: optical network unit

Fig. 1. Research into ultra-high-speed full software access networks.

the latest functionality would always be available. If software-based networks become a reality, they will enable support for a variety of services, such as services for next-generation mobile devices, edge computing, and the Internet of Things.

To achieve this, I have been focusing on the softwarization of the physical layer functionality of communications networks—something that has typically posed a challenge. I am currently working on research into the full softwarization of the physical layer—in other words, the transmission interface—that performs the lower-layer processing in optical access equipment that has so far been handled by hardware such as optical line terminals (OLTs). To put it more technically, I am working on the softwarization of digital coherent modulation and demodulation systems.

I am planning to use general-purpose server central processing units (CPUs), graphics processing units (GPUs), and other processors to handle these processes using programming, coding, and other techniques (**Fig. 1**).

—What are the challenges of softwarization?

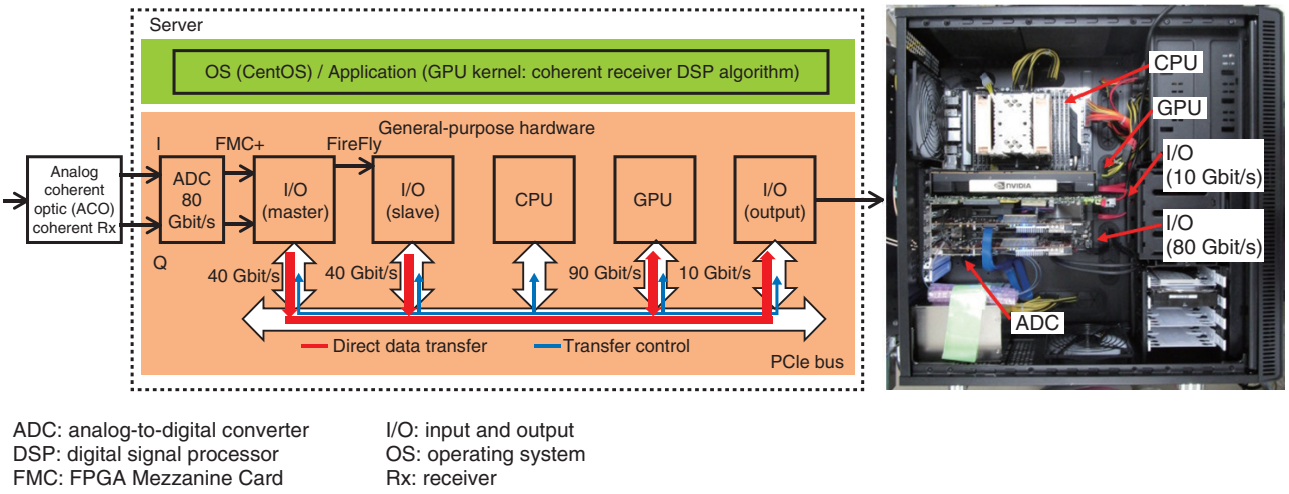
When you take into account 6G (sixth-generation mobile communications system), the mobile communications standard that will succeed 5G (fifth-generation mobile communications system), and future communications between datacenters, we will eventually end up needing overwhelming speeds of 100 Gbit/s. However, increasing speeds using general-purpose processors is very challenging due to fundamental limitations, such as constraints in the semiconductor manufacturing process.

There are already fully softwarized networks, but their speeds are still only at about 100 Mbit/s at present. That's a mere 1/1000th of the 100 Gbit/s I am aiming for—quite an astounding difference in speeds. Therefore, in this research I am trying to overcome this problem by focusing on devising logic algorithms optimized for general-purpose processors such as CPUs, coprocessors, GPUs, and field programmable gate arrays (FPGAs). Increasing the speed is potentially the biggest challenge in making software-based networks a reality in the future.

—What progress has been made to date?

In 2018, a proof of concept of a software-coherent platform using differential phase shift keying achieved a world-first 5 Gbit/s, and was accepted as a top-scoring paper at the Optical Fiber Communication (OFC) Conference, a prestigious international conference in the field of optical communications.

In 2021, another world-first speed of 10 Gbit/s was achieved—double that achieved in 2018—using a proprietary carrier phase-locking algorithm. This



ADC: analog-to-digital converter
DSP: digital signal processor
FMC: FPGA Mezzanine Card
I/O: input and output
OS: operating system
Rx: receiver

Fig. 2. 10-Gbit/s software-coherent platform.

accomplishment was also presented in a paper at the European Conference on Optical Communication, a similarly prestigious international conference in the field of optical communications.

This increase in communications speed from 5 Gbit/s to 10 Gbit/s is mainly due to improvements in logic algorithms. Increasing the bit rate, or communications speed, naturally increases the amount of data transmitted per unit of time. For example, the amount of data per unit of time doubles with an increase from 5 Gbit/s to 10 Gbit/s. First, that doubled data have to be input to the server and processed by the CPU, GPU, and other processors. There are already established logic algorithms for data processing, but as the volume of data increases, real-time processing is no longer able to keep up. This is why logic algorithms have so far been optimized for CPUs and GPUs in order to increase speed. If we express the target of 100 Gbit/s as 100%, then we can say that at this point we have achieved about 10% of this target (**Fig. 2**).

Aiming to develop software-based access networks in the future

—What outcomes could this research produce?

Communications services have evolved from Integrated Services Digital Network to asymmetric digital subscriber lines, and then to optical access (fiber to the home). Communications speeds have also evolved—from 100 Mbit/s to 1 Gbit/s, and then to services reaching 10 Gbit/s in 2020. In the mobile field in particular, the focus of the discussion is shifting from 5G to 6G, and I feel that the role of access-segment communications—the foundation that supports these technologies—is growing. This research will likely prove beneficial in creating mechanisms that adapt flexibly to and provide support in this area.

In addition, relatively inexpensive general-purpose hardware will become able to support a variety of future service requirements, such as for high-speed wired optical communications and next-generation mobile communications. This will dramatically expand the diversity and flexibility of optical access and is anticipated to reduce equipment installation, operation, and maintenance costs. There are still many hurdles to overcome in terms of practical use, but I believe this will contribute to the Innovative Optical and Wireless Network (IOWN) vision, which I expect to see implemented in society in the future.

—Can you tell us about future developments in this research?

The approach of this research is to optimize software algorithms to increase speeds. However, the key focus of this is creating new algorithms to improve speeds, rather than improving current algorithms. I hope to make new breakthroughs and achieve our target speed of 100 Gbit/s or faster. Furthermore, by integrating the softwarized physical layer with the application layer, I intend to build a new ecosystem that will increase the number of my fellow collaborators from different fields and industries.

—What kind of initiatives will be needed to further advance this research?

I hope to advance this research effectively through the establishment of strategic collaboration frameworks with advanced research organizations in relevant fields. General-purpose processors, of course, have inferior performance compared to that of processors customized for a specific function. However, they do offer advantages such as flexibility, so there will surely be a need for algorithms that are tailored to suit them. For this reason, it would certainly be beneficial to work with people who have a good knowledge of general-purpose processors.

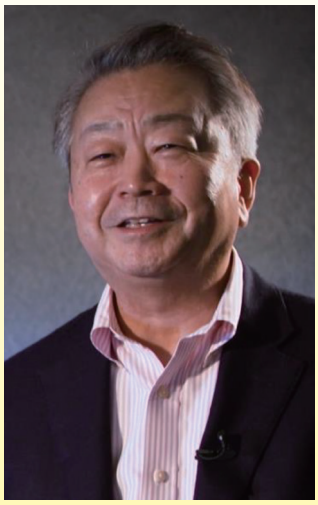
In addition, this research requires not only digital programming skills, but also knowledge of electrical circuits, server hardware, and a variety of other things, so I also envision establishing strategic collaboration frameworks with companies that develop server hardware. I know Japanese companies have been developing server-related hardware for years with an extremely high level of focus, so I hope to be of use in that area, as well as accelerating my research. For example, I can envision working together with businesses that develop hardware, software, and other solutions for datacenters. It will also be possible to integrate applications into the softwarized physical layer, which could be beneficial for connecting with businesses that develop and provide services. Furthermore, as data transfer speeds increase, so too does the need for large volumes of data to be sent within the server. That being the case, it would be good if I could establish collaboration frameworks with anyone familiar with data transfer, i.e., speeding up interfaces such as Peripheral Component Interconnect and transferring data to the server's memory.

■ **Interviewee profile**

Kim Sangyuep joined NTT in January 2008, where he has been engaged in research into ultra-high-speed full software access networks at NTT Access Network Service Systems Laboratories. He received the Best Paper Award in Selected Areas in the Communications Access Networks and Systems Track at the 2016 IEEE Global Communications Conference (GLOBECOM). He was a subcommittee member of the Optoelectronics and Communications Conference (OECC) 2018 and has been a subcommittee member of the OFC Conference and Exhibition for 2020–2022.

What is IOWN?

Jun Sawada
President and Chief Executive Officer, NTT



Abstract

This article introduces initiatives to expand the use of the Innovative Optical and Wireless Network (IOWN) called the "Road to IOWN." It is based on the keynote speech given by Jun Sawada, president and chief executive officer of NTT, at the "NTT R&D Forum—Road to IOWN 2021" held from November 16th to 19th, 2021.

Keywords: IOWN, All-Photonics Network, bio digital twin

1. Road to IOWN

Let me today introduce our initiatives to expand the use of the Innovative Optical and Wireless Network (IOWN) called the "Road to IOWN." Before that, I would like to reflect on recent natural disasters, which have become much more severe than in the past. In the summer of 2021, a disastrous landslide occurred in Atami City, Shizuoka Prefecture in Japan, and in Germany, about 200 people died in torrential rains and floods. There were also the earthquake in Haiti and wildfires in California. On top of all that, the threat of the novel coronavirus (COVID-19) pandemic has changed our lives dramatically over the last two years.

The pandemic has made remote work (work from home) more widespread and has made it difficult for people to meet in person. Along with the world becoming more connected through the Internet, problems such as crimes related to the Internet and overflow of information with varying quality called "infodemic" have been increasing. From a different viewpoint, a lesson learned from natural disasters and pandemics is, "Nature is full of unexpected things." We should be aware that unexpected things are happening all the time and are out of our control. Therefore, what conclusions can be reached when the situation is so unexpected and uncontrollable? The means of trying to explain the world using natural science is called "naturalism." As the idea of naturalism alone cannot deal with natural disasters, it is necessary to take a broader view of preparation that goes beyond what is scientifically understood.

The world cannot be explained by logic alone. Jakob von Uexküll, a German biologist and philosopher, thought about this problem in a different way and came up with the concept of the "umwelt" ("environment" or "self-centered world" in English) (**Fig. 1**). Umwelt may not have received much attention in current academic circles. However, we may need to apply this concept of umwelt when we think about unexpected things as the scale of natural

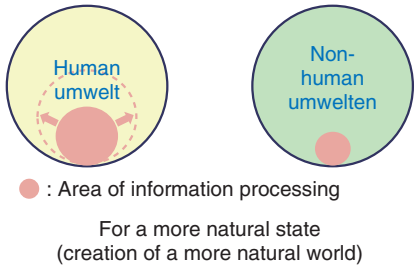


Fig. 1. Human umwelt—Enlarge areas of information processing.

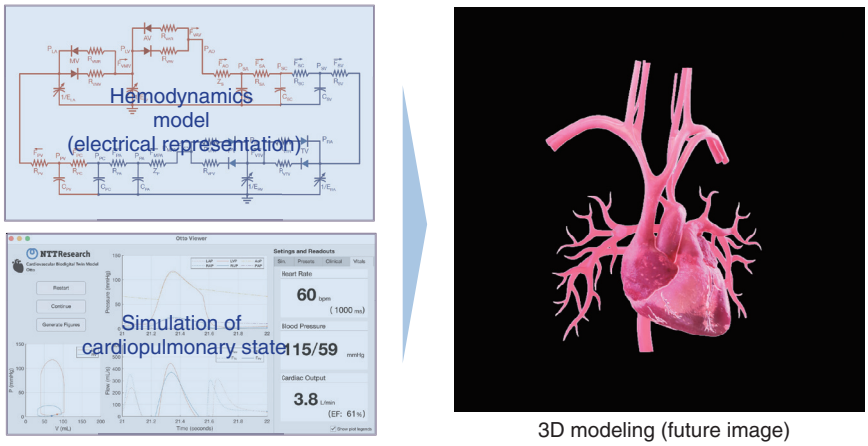


Fig. 2. Bio digital twin.

disasters is increasing and people tend to be more easily divided due to the development of social networking services (SNSs), etc. By applying this concept to the direction in which technology should advance, we aim to expand the area in the human umwelt occupied by information processing, which is currently very small. In other words, the goal is to achieve a situation closer to nature. For example, broadband enables high-speed, high-capacity data transmission. This technology is based on the idea of recreating a situation close to nature. Meanwhile, our communication devices have evolved from fixed-line telephones to smartphones, and at each evolution, we need to learn how to use new devices, which results in putting load on humans. This situation is far from natural. Technology, which can naturally support the human desire to communicate and convey our thoughts, will lead our world to greater happiness.

2. Bio digital twin

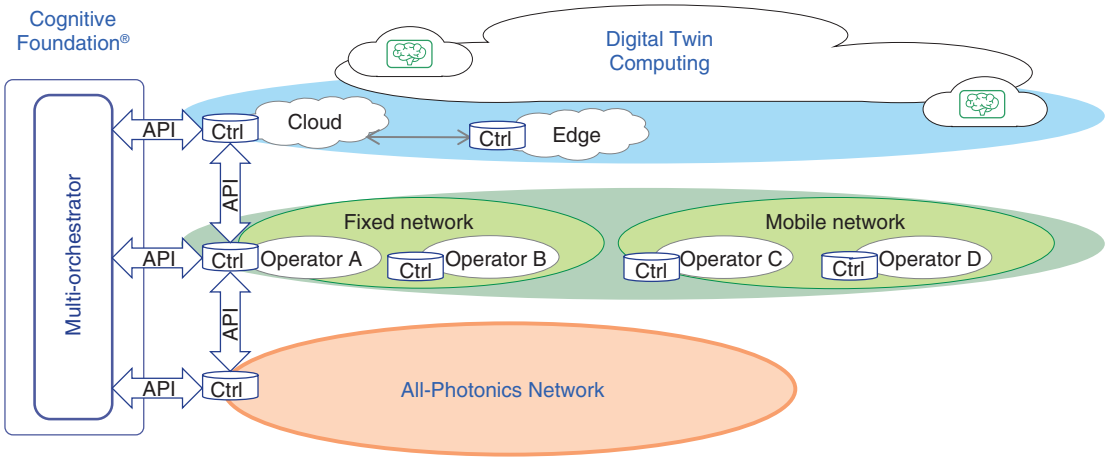
Researchers at NTT Research, Inc. in the United States are working on reproducing the physical and psychological states of humans in cyberspace (**Fig. 2**). They are currently focusing on modeling the heart. This research will support treatment based on predictions by modeling and simulating hemodynamics from blood-flow data and visualizing the cardiopulmonary state. They have also started contributing to preventive medicine for illnesses such as heart disease and failure. Bio digital twin is another example for making information processing closer to nature.

2.1 Using non-human umwelten

The world perceived by humans with our five senses, or six senses, differs from that perceived by insects, fish, animals, and other organisms. As I mentioned in the previous NTT R&D Forum, birds and bees see things in ultraviolet light, while humans do so in visible light. If we could see things in ultraviolet light, a whole new world would be opened up. That is to say, we would make our world closer to nature.

For example, dolphins emit ultrasonic waves (at a frequency of about 150 kHz) by shaking folds at the back of their throat near their vocal cords, while humans can only hear sounds up to about 20 kHz. This means that dolphins can communicate via very-high-frequency sounds compared with humans. Dolphins also have a bump on their forehead called the "melon organ," which has a mechanism for effectively transmitting and receiving ultrasonic waves in the targeted direction. While humans do not have such a mechanism, NTT laboratories developed a method of listening to music and other sounds called the "personalized sound zone" by using the mechanisms, technologies, and principles inspired from dolphins. We established a company called NTT sonority, Inc. in September 2021 and are currently developing new products. Turning space into information to make people more comfortable will improve well-being and bring information from a different umwelt to that of humans.

While the umwelt is traditionally characterized by species, human communities are more than ever characterized by only information they are comfortable with as we now live in a divided world. That is, we are



API: application programming interface
Ctrl: controller

Fig. 3. IOWN framework.

entering an era of fragmentation, in which several umwelten are created in human communities. We need to figure out how to connect them, and I believe that the Innovative Optical and Wireless Network (IOWN) will be the medium to connect each umwelt to make information processing in the human umwelt closer to nature, apply the mechanisms of non-human umwelten to the human umwelt, and close the communication gap between people.

3. All-Photonics Network

The framework of IOWN consists of three major layers and four functions. The first layer is the All-Photonics Network (**Fig. 3**). The idea behind the All-Photonics Network is to use optical fiber across the entire network, replace the semiconductors that process information with optical technology, and use optical computers. The All-Photonics Network will support high-capacity, low-latency, and low-power-consumption communication. A data-driven society generates huge amounts of packets and information data. The datacenters that store, transform, and process such data generate heat like a toaster and are currently cooled inefficiently by using fans. Optical technology will change this situation by reducing heat generation drastically. Such technological revolution should bring about breakthrough innovations.

On top of the All-Photonics Network are the fixed and mobile networks as the second layer, in which many companies provide services around the world. Fifth-generation mobile communication networks (5G) are now being offered, and after that comes the era of 6G. The third layer is Digital Twin Computing. In this layer, objects in real space are reproduced in cyberspace such as a bio digital twin as described previously. These three layers are connected via a multi-orchestrator, and the entire structure is called Cognitive Foundation®. We will live in a world in which various businesses will compete and cooperate with each other, and Cognitive Foundation® will be the key to promoting such competition. IOWN is formed by the elements of interconnection and interoperation. Several use cases of the All-Photonics Network have started in 2021.

3.1 Avatar robot café DAWN Ver.β

I'll introduce the comment by Yoshifumi Shiiba, director and chief technology officer of OryLab Inc.

"DAWN is a café where people with physical disabilities can use the power of the Internet and technology to work in the same manner as able-bodied people (**Fig. 4**). We are conducting a series of experiments to determine how moving an avatar robot [OriHime-D] in a low-latency network condition affects actual tasks. Thanks to the high-speed communication provided by IOWN, the robot can move smoothly along narrow routes and get to its desired destination reliably even if that location is not predetermined, which was not possible when using the ordinary Internet.

It is not human-like to move along a predetermined

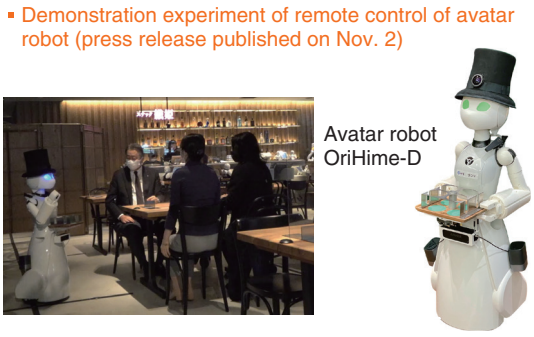


Fig. 4. Case 1 : Avatar robot café "DAWN" Ver.β.

route, in a predetermined form, and in a predetermined order. Unfortunately, OriHime-D operating over the ordinary Internet cannot act exactly the same as able-bodied people such as flexibly handling unplanned tasks and oral requests on the spot.

If high-speed networks could be expanded, all five senses could be transmitted to the customer's location, and people with disabilities could work as if they were at that location. As a result, they would have a wider range of tasks they could handle, and many things would become feasible for them. I also believe that the differences between disabled and non-disabled people would become less. I would be pleased if we could create such an environment."

I had talked about this avatar robot café with Kentaro Yoshifuji, CEO of OryLab Inc. six or seven years ago. People like us, who work in communication industry, thought that "interactivity" was the basis of communication. For example, when we develop communication services, we assume that they will be able to communicate in both directions, but OriHime can only communicate one-way. It uses unidirectional video to communicate, so only the pilot—a person with disabilities—can see a customer but the customer cannot see the pilot. Therefore, it does not convey information in two directions; rather, it conveys its presence in one direction. Such two-way and one-way communication systems will probably exist naturally in the future. When such systems are controlled remotely, latency often becomes a problem. In this demonstration experiment with OriHime, we were able to connect NTT Musashino R&D Center in western Tokyo to Nihonbashi in central Tokyo and move the robot with a delay of less than 20 ms. Since such remote control is normally operated in about a 400-ms delay, we were able to achieve remote control with 1/20 the normal delay.

3.2 Cloud-based e-sports events

One of the most effective use cases of the All-Photonics Network is in cloud-based fighting games. In such games, it is important to stream 8K video with a delay of less than 20 ms. When we compare the environment of a few milliseconds delay and 20–30-ms delay, we can clearly recognize the timing gap of two game characters' actions. In an environment where the timing of kicks does not match due to the delay, it is difficult to play. While the delay is still 20 ms in the case of OriHime mentioned above, we are now working to reduce it to a few milliseconds. We are also currently researching and developing a system that can synchronize actions of game characters by controlling the delay in the order of microseconds.

3.3 Security in the age of quantum computing

Another use case of the All-Photonics Network is security. We developed an encryption method by combining conventional methods (e.g. RSA (Rivest–Shamir–Adleman) cryptography) with a cipher method called NTRU (Nth Degree Truncated Polynomial Ring Unit) (**Fig. 5**) on the basis of the computational difficulty of the lattice problem. Commercialization of this encryption method is currently underway. The information processed with this encryption method cannot be deciphered even with quantum computers.

In the All-Photonics Network, the delay time can be evaluated in advance. As the delay time changes when somebody eavesdrops or accesses without authorization, it is possible to instantly detect whether there was an external access. Even though NTRU prevents the information from being deciphered whenever the network is eavesdropped, we aim to make the network capable of detecting eavesdropping as well.

4. Advances in photonics-electronics-converged devices

Current semiconductors generate a large amount of heat as they are operated by electrons (**Fig. 6**). To address this issue, we are researching and developing a photonics-electronics-converged device that will enable inter-chip optical transmission and plan to announce it at Expo 2025 in Osaka, Japan. By 2030, we aim to make a photonics-electronics-converged device that enables both inter-chip and intra-chip optical transmission.

In the era of IOWN, various elements will be combined to form a single system. For example, in the late

<New encryption method>

	Basic encryption	Tolerance for traditional computer	Tolerance for quantum computer
Conventional method (RSA encryption etc.)	Prime factor decomposition	✓	×
Post-quantum cryptography proposed by NTT (NTRU encryption)	Lattice problem	✓	✓

<New monitoring method>
- Delay time is almost constant on the All-Photonics Network due to end-to-end optical connection
- Detect attacks or anomalies by detecting fluctuation of delay time triggered by wiretapping

Fig. 5. Case 3: Security for quantum computing.

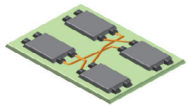
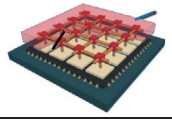
	2021	2025	2030
			
Inter-chip	Electrical	Optical	Optical
Intra-chip	Electrical	Electrical	Optical

Fig. 6. Evolution of photonics-electronics-converged devices.

2020s, photonics-electronics-converged chips will be applied to mobile communication facilities. In addition, a new optical interconnect device (called super white box) that transcends the traditional concept of the server is planned to be introduced.

5. Toward achieving carbon neutrality

In 2013, NTT Group emitted about 1% of Japan's greenhouse gas emissions, which was about 4.65 million tons per year (**Fig. 7**). To reduce greenhouse gas emissions, we will promote energy conservation and use renewable energy. However, the amount of greenhouse gas emissions will still increase if we only take these measures without any other solutions since the amount of electricity usage increases in conjunction with the increase in information processing. To achieve carbon neutrality, we need to leverage the power of IOWN.

We aim to achieve carbon neutrality in the datacenter and mobile sectors by 2030 and throughout the entire NTT Group by 2040. We must solve environmental problems through innovation and drive economic growth simultaneously. While these goals are contradictory, we will tackle them with a *paraconsistent* approach. We believe that we can contribute to reducing the environmental impact of the entire society through the introduction and expansion of IOWN.

6. How to transform NTT Group

We are currently focusing on three pillars to transform NTT Group (**Fig. 8**). The first pillar aims to strengthen our domestic and global businesses as digitalization and digital transformation (DX) spreads around the world. Regarding the second pillar, in both "corona" and "post corona" societies, we need to introduce a new management style to cope with the transition as we move toward a decentralized society. The third pillar is to increase our corporate value through ESG (environmental, social, and corporate governance) and other initiatives to maximize

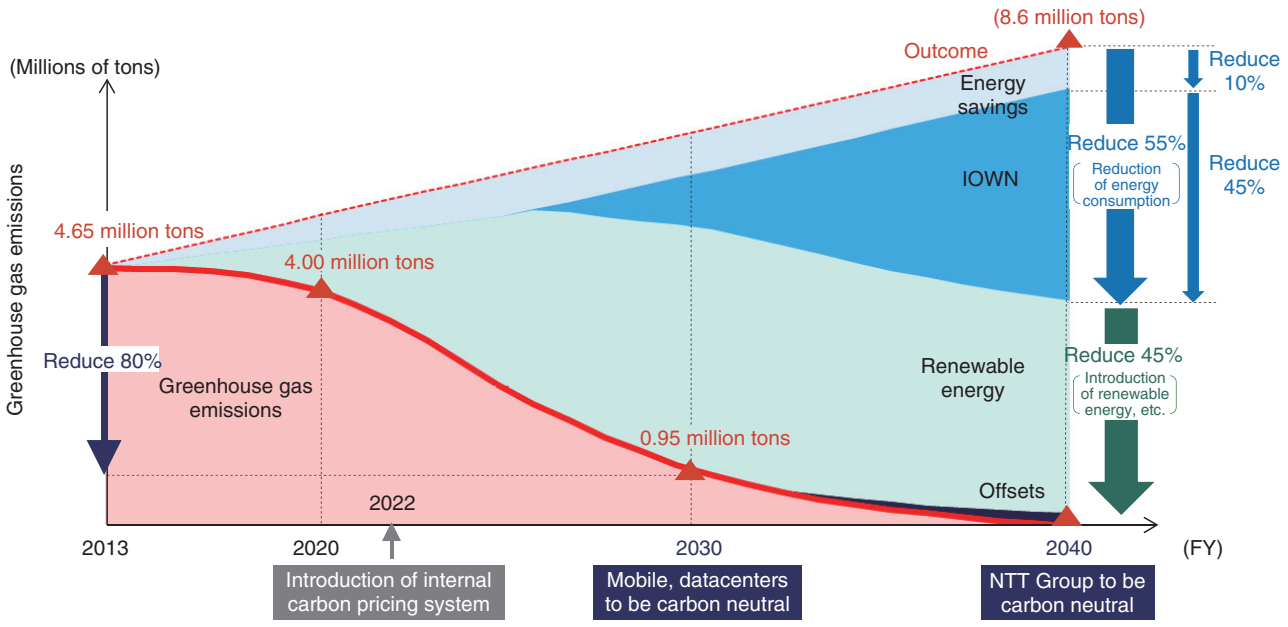


Fig. 7. Activities for achieving carbon neutrality.

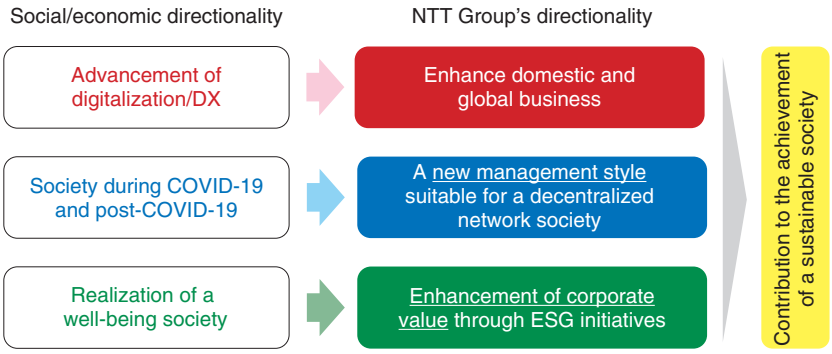


Fig. 8. Directionality of NTT Group's transformation.

the well-being of our society. Through the initiatives of these three pillars, we aim to contribute to creating a sustainable society.

7. Transformation to a new management style

With regard to the reform of our management style, we have continued and strengthened remote working during the COVID-19 pandemic. As a result, employee satisfaction, especially among those raising children, has improved. This fact shows that remote working can mitigate some of the issues brought by childcare and both parents working. Looking ahead to the future, we would like to further promote a "work-in-life" (health management) approach (**Fig. 9**).

8. Sustainable society

Let us think about what kind of sustainable society we aim for. First, it is a society that cannot be understood by dualism. Next, as the word "diversity" implies, it is a society that simultaneously embraces and puts into practice various viewpoints and ideas. To achieve this sustainable society, the concept of "Self as We" becomes the basic philosophy (**Fig. 10**).

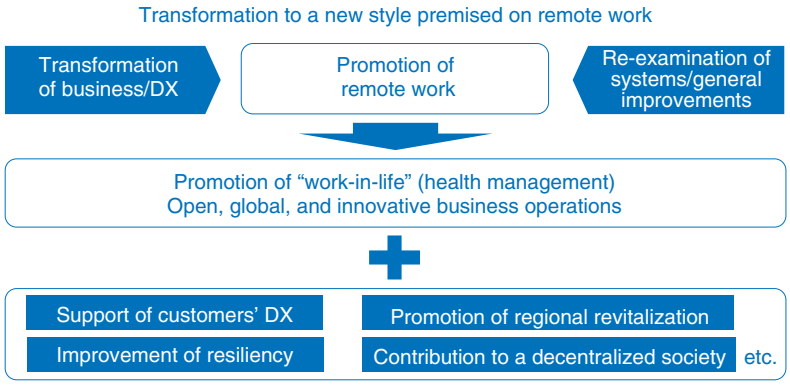


Fig. 9. Transformation to a new management style.

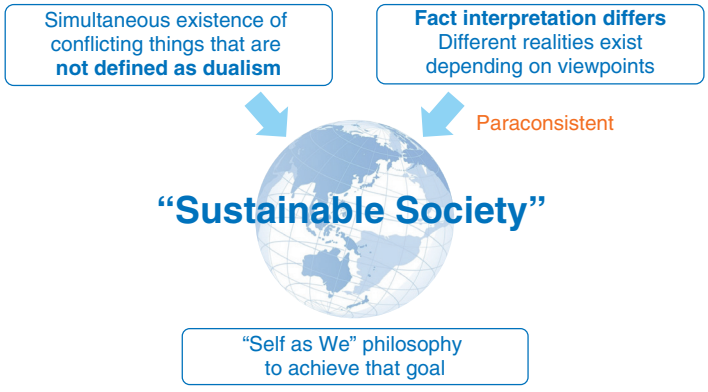


Fig. 10. Sustainable society.

Our society has generally been operating under the concept of "Self as I"—which is about valuing the individual. According to biologist Dr. Shinichi Fukuoka, no organism can transcend its species. However, humans have overcome the idea that only they and their offspring are important. In other words, humans have developed as individuals who are not limited to genetics.

For example, only humans can have the concept of inclusion of members of the LGBTQ (lesbian, gay, bisexual, transgender, queer) community. If we look further into the next era, our alter egos will extend to cyberspace. In cyberspace, you will also be able to have your own family, friends, and community. This world is also based on "Self as We," rather than "Self as I." I believe we should adopt such a philosophy.

The concept of "Self as We" is that;

i) nature is an altruistic force and we are a part of it,
ii) culture and society are secured by connecting us through ethics, and
iii) one's happiness and other peoples' happiness coexist (altruistic coexistence).

Accepting the concept of "Self as We," we set the following three themes to achieve a sustainable society;

1) ensure the coexistence of nature and humanity,
2) improve prosperity for all people and cultures, and
3) maximize well-being for all (**Fig. 11**).

We established NTT Group Global Sustainability Charter on the basis of the above-mentioned "Self as We" concept and three themes. Along with this charter, we specified our Environment and Energy Vision, New Management Style, and Human Rights Policy, which were shared within entire NTT Group globally [1].

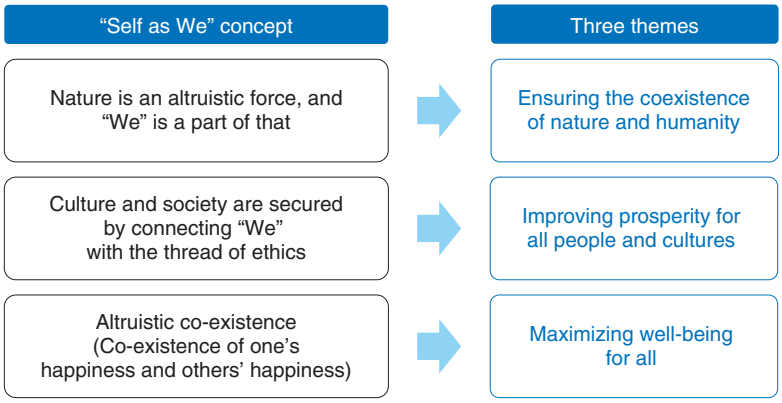


Fig. 11. Three themes for a sustainable society.

9. Concluding remarks

I have talked a lot today, and my book, “Paraconsistent World,” which is about to be published, covers more details through discussion with various experts. I hope you will find an opportunity to read it.

Reference

[1] Press release issued by NTT, “Establishment of NTT Group Global Sustainability Charter - Towards a Sustainable Society -,” Nov. 10, 2021. https://group.ntt/en/newsrelease/2021/11/10/211110d.html

Road to IOWN 2021

Katsuhiko Kawazoe
Executive Vice President, Head of Research and Development Planning Department, NTT

Abstract

This article presents a lecture given by Dr. Katsuhiko Kawazoe, NTT Executive Vice President, Head of Research and Development Planning Department, at NTT R&D Forum 2021—Road to IOWN 2021 held from November 16th to 19th, 2021.

Keywords: IOWN, connection of Umwelten, concatenated loop topology, photonic disaggregated computing, Cradio®, 4D digital platform™, infinite clustering, NTT Green Innovation toward 2040

1. Introduction

We announced the concept of the Innovative Optical and Wireless Network (IOWN) in May 2019. At NTT R&D Forum in 2019 and 2020, I spoke about its goals, objectives, and base technologies. This is the third year of the IOWN initiative, so I would like to focus on its progress and expansion. Since some of you may be hearing about IOWN for the first time, let me start with the concept.

2. Negative aspects of human development

The concept of IOWN stems from the current situation of humanity and technology. Humanity has made various technological innovations that have brought about a more affluent world. However, the novel coronavirus (COVID-19) has made all of us realize that we are now faced with unprecedented challenges and that our current technology is not sufficient to solve them. We need to improve our approach to innovation drastically. However, the current approach to technological innovation has had serious negative effects, i.e., the depletion of resources, biodiversity loss, environmental destruction, and global warming (**Fig. 1**). I feel that if this trend continues, the Earth and all living beings on it will be overburdened, and both humanity and all other living beings may perish. It is believed that the environmental destruction of Easter Island, famous for its Moai statues, was caused by deforestation stemming from a population explosion. This caused the soil to drain into the sea, depleting resources and causing conflicts over resources. Our current technological infrastructure is surrounded by these contradictions and paraconsistencies; economic development and environmental protection, industrial production and resource conservation, and information and communication technology (ICT) development and power consumption.

3. What kind of innovation do we need?

What kind of innovation do we need to create a sustainable society? The answer is innovation that achieves a significant performance improvement of the technological infrastructure without placing a burden on the Earth. Our conclusion is that we should not focus only on humans, but also recognize and implement innovations for all living beings and the

Fig. 1. Negative aspects of human development.

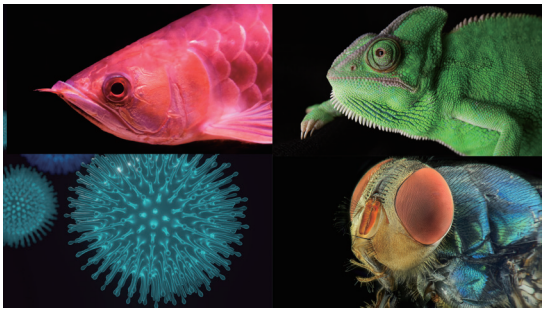


Fig. 2. The "connection of Umwelten" to use the wisdom and value of all Umwelten.

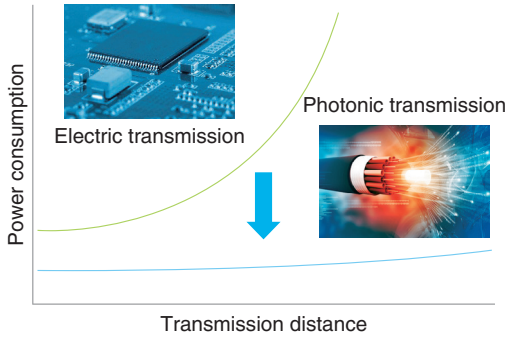


Fig. 3. Advantage of photonic transmission.

entire Earth as a whole system. We should do our best to widely adopt the technologies that will have the least impact on Earth.

4. How to do it?

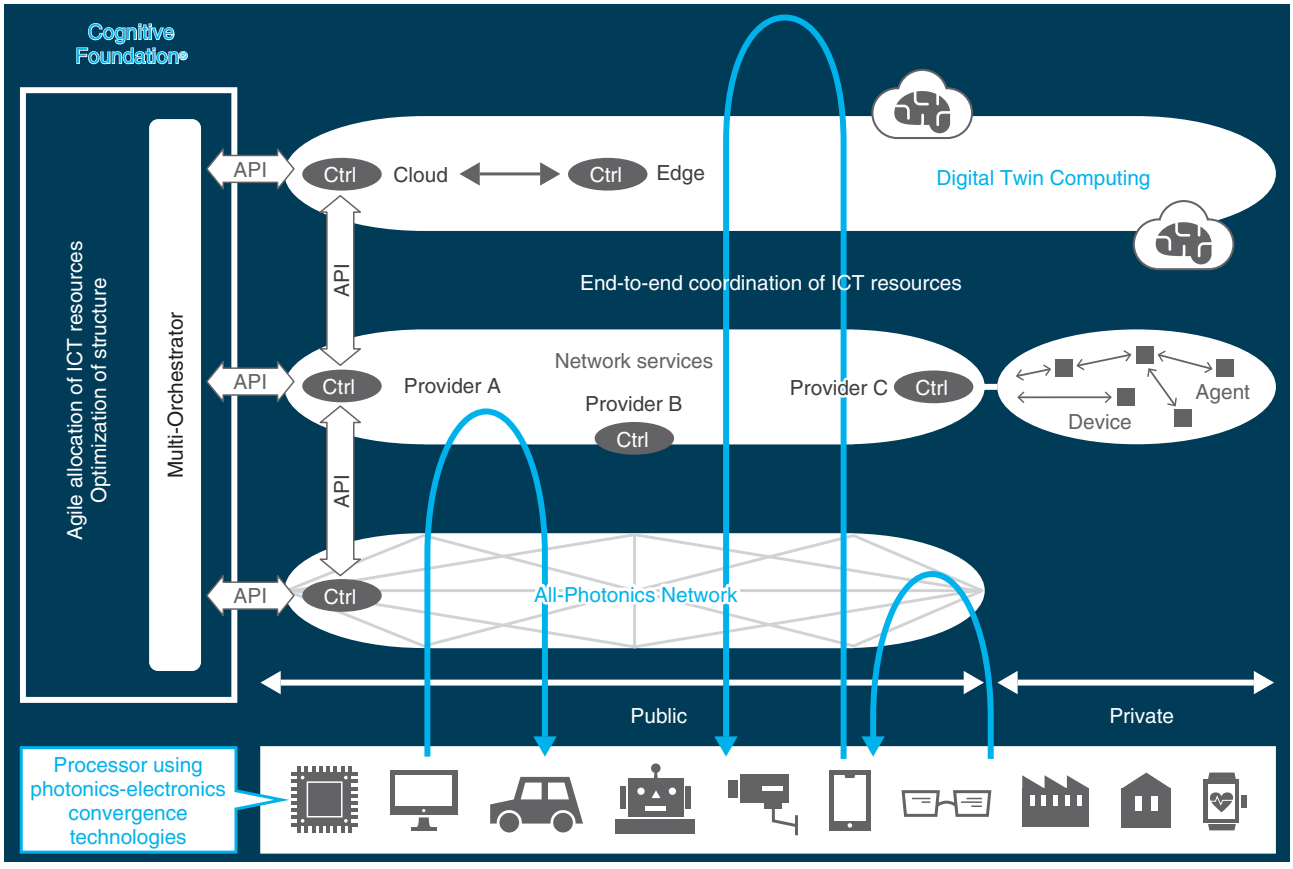
What we have been proposing as an effective strategy for recognizing and using the total system is the "connection of Umwelten" (**Fig. 2**). The world as we humans perceive it is not all there is. Various Umwelten exist around us, for example, the Umwelten of insects, reptiles, and fish. Perhaps even non-living things, such as viruses, have their own Umwelten. To understand the world made up of various Umwelten, we need to use the wisdom and value of each of them. This is the "connection of Umwelten." To do this, we need to overcome two barriers.

5. Barriers

The first barrier is the understanding all Umwelten. In the past, humankind has learned from nature to enhance wisdom and promote innovation. However, this is very limited. There are still many Umwelten that have yet to be approached. Bioengineering and biotechnology are truly academic disciplines that discover the characteristics of various living beings and apply them to our society. It will be necessary to learn not only from the Umwelten of living beings but also from those of non-living things such as viruses. As you all know, viruses are not living organisms, but they have a great impact on humanity. If we can understand the mutation process of viruses, we can bring a ray of hope to many people.

The second barrier is the technological infrastructure for connecting Umwelten. We need to go beyond humanity's Umwelt and choose those that are useful for improving well-being and create a connection that does not place a burden on the Earth. This requires information processing more complex and extensive than ever before. We believe that the expansion of optical technology can help solve this problem.

Optical technology has been mainly applied to the transmission of information via optical fiber. This has created a significant increase in transmission speed and capacity. Compared with electricity, light has great potential in terms of energy consumption (**Fig. 3**). Therefore, we need to overcome technology barriers and extend optical technology from transmission to information processing.



API: application programming interface
Ctrl: controller

Fig. 4. IOWN concept.

6. Concept of IOWN

NTT has been conducting extensive research and development of optical technology since the 1960s. This is extending from information transmission to information processing. In information transmission, optical technology has progressed mainly through the evolution of optical fibers and technological innovations in transmission processing technology, such as digital signal processors. In information processing, we have been unable to create a breakthrough technology that surpasses electronics technology. In April 2019, however, NTT succeeded in inventing the world's first optical transistor [1]. This is the origin of the concept of IOWN (**Fig. 4**). Since then, we have succeeded in inventing a variety of optical devices and found a means of extending optical technology to information processing.

In artificial intelligence (AI), for example, research and development is currently underway worldwide to improve its capabilities. We believe that we can make progress with a completely different approach. Current AI research is believed to be a technology to achieve the goals set by humanity. However, as I mentioned, we need to find yet unknown Umwelten and understand them. The increase or decrease in the number of people infected with COVID-19 may be one such subject. A future AI needs to know the unknown. As I have said repeatedly, this AI must not burden planet Earth but should instead lead to the well-being of the whole planet. To create such a world, the NTT Group is focused on the concept of "Self as We."

Self as We refers to the concept of "I" as "we." It is the idea that my existence is supported by connections with all types of entities, including people, things, and technologies. Therefore, we need to maximize the well-being of "us" through altruistic

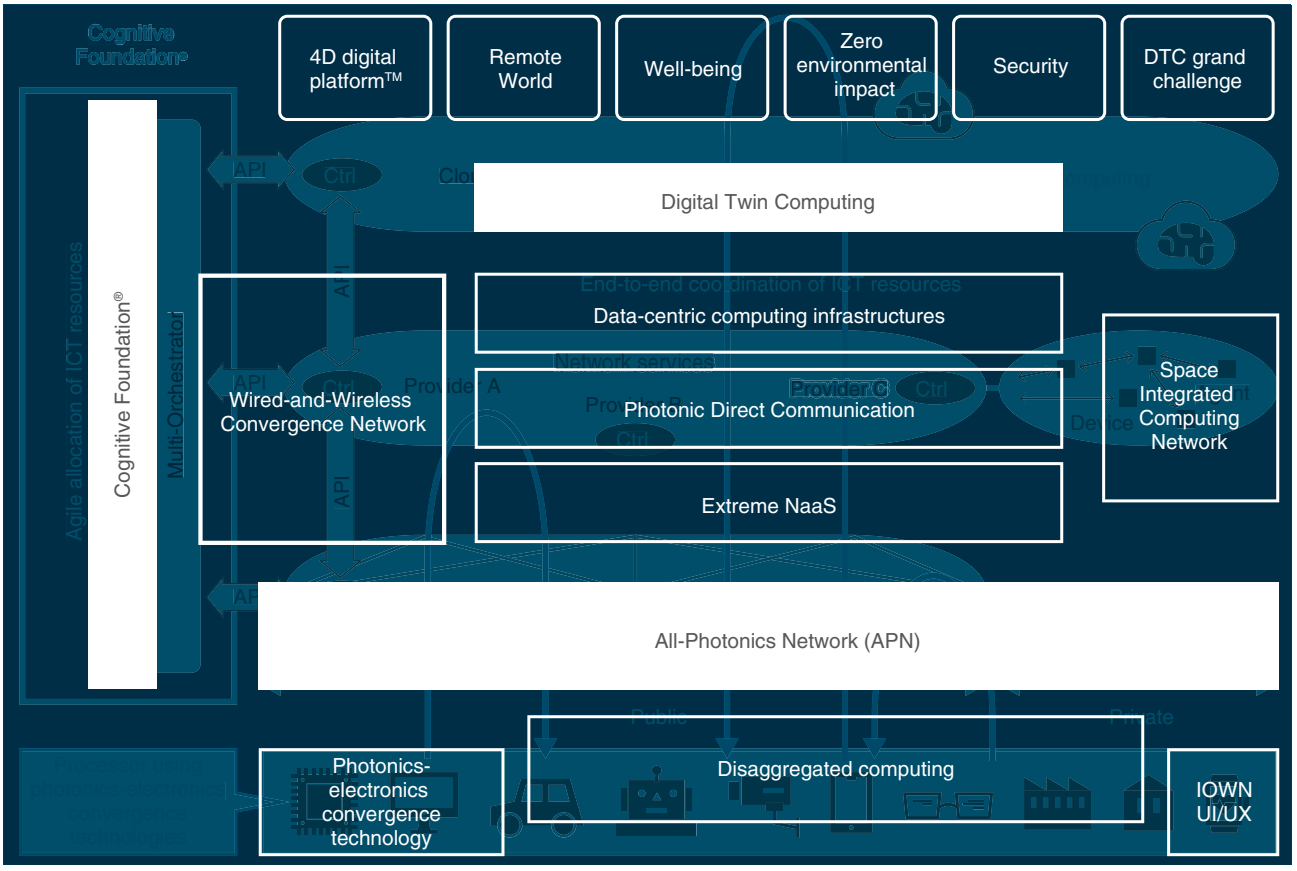


Fig. 5. Research areas under the IOWN initiative.

coexistence. Since nature is altruistic and we are a part of it, we need to live in harmony with nature. Through the concept of IOWN, we will promote initiatives to achieve a sustainable society by simultaneously achieving growth and solving social issues.

7. Latest progress in the IOWN initiative

I will now discuss the latest progress in the IOWN initiative. This started with the invention of the optical transistor by one of NTT's research laboratories and has now spread to the entire NTT Group and beyond—to a global level. I will explain the progress in the technologies that have already been announced, as well as 15 new technologies that will be announced for the first time (**Fig. 5**).

7.1 All-Photonics Network (optical access network design based on concatenated loop topology)

The first technology is our new access network, the optical access network design based on concatenated loop topology, which is a component of the All-Photonics Network (APN) introduced in 2021 [2]. To create a smart society in areas such as telemedicine and automated driving, the APN will provide a reliable and flexible infrastructure-of-infrastructure.

The new IOWN optical access network will evolve significantly in three areas, i.e., reliability, tolerance for fluctuation of service demand (flexibility), and optical-path selectivity (scalability).

To achieve these goals, we established the optical access network design based on concatenated loop topology (**Fig. 6**). Circular optical fiber primary loops spread from the NTT building (central office), and secondary loops are connected to them via fiber cross connections. Mobile base stations are connected to secondary loops. This configuration improves reliability because there are multiple routes between the NTT building and mobile base station. The number of core lines can also be flexibly allocated according to demand, and unexpected increases in demand can be

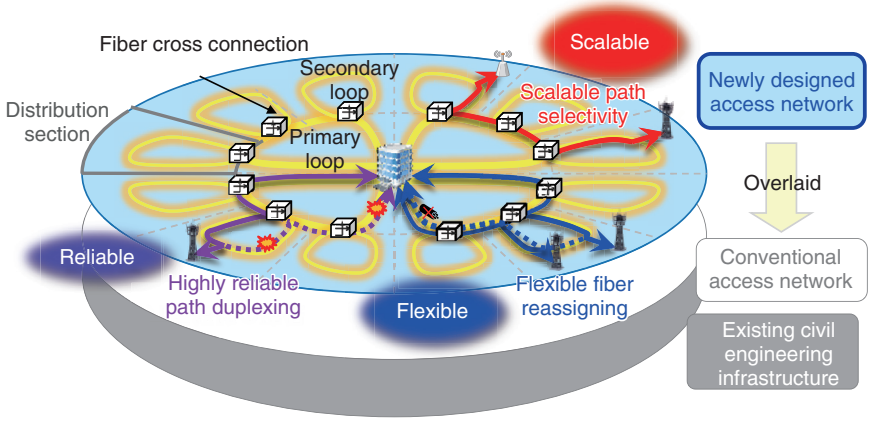


Fig. 6. Optical access network design based on concatenated loop topology.

quickly accommodated. Neighboring mobile base stations can also be connected to each other without having to go through the NTT building.

We also clarified the appropriate value of design indicators for this new network through theoretical calculations based on reliability engineering and probability theory. We developed a remote optical-path-switching node that does not require commercial power supply and confirmed the principle of the variable optical branching ratio.

We will continue to promote research and development of this technology for practical use.

7.2 Distance Zero

The second technology is Distance Zero, a technology to overcome the physical distance brought about by the APN. We succeeded in reducing network-latency fluctuation to the microsecond level, which is close to the physical limit between locations, for communication of more than 100 Gbit/s per wavelength [3]. By installing an IOWN adapter at the user's location, we can provide a 100-Gbit/s communication path to a user's device with no latency fluctuation. IOWN adapters enable overheadless 1000-km long-distance transmission by transporting uncompressed or slightly-compressed HDMI (high-definition multimedia interface)/DisplayPort and USB (universal serial bus) signals through over-100-Gbit/s optical paths of the APN. Even with the APN, which can provide overwhelmingly low latency compared with conventional Internet Protocol (IP) networks, there are physical limitations such as the speed of light and occurrence of network latency depending on the communication distance. We developed a technology that enables the APN to automatically compensate for the delay difference.

Distance Zero will enable e-sports events to be held in various cities under fair conditions, i.e., the same delay difference among various cities. We will continue to improve this technology by taking advantage of the APN's high-capacity, low-latency, and zero-fluctuation performance. Our aim is to create a future where users can easily participate in e-sports without a game console.

7.3 Bidirectional wireless transmission using a Van Atta array in Beyond 5G

I'll now talk about new innovations in IOWN's W, i.e., wireless, which is connected to the APN. Many of the technologies related to IOWN are based on simple principles. The wireless technology I am about to talk about is also simple but greatly effective. There is no need for complex processing. We focused on the principle of the Van Atta array antenna, which is based on retroreflection, a method of engineering radio waves so that they are reflected directly back to the source no matter from what direction they hit. By adopting the Van Atta array, it is possible to construct antennas with retroreflective properties in the most compact and simple way possible. For drastic performance improvement of wireless systems, we, with the Tokyo Institute of Technology, successfully demonstrated the world's first bidirectional wireless transmission using a Van Atta array [4].

In wireless communication using high-frequency bands, such as millimeter or terahertz waves, which will be used in beyond fifth-generation mobile communication systems (Beyond 5G), it is necessary to

form a sharp directivity by controlling the phase of each element of the arrayed multi-element antennas and always direct the antenna towards the communication partner because the propagation loss of the signal is large. This requires complex signal processing and directivity control mechanisms to track the moving communication partner.

The Van Atta reflector array antenna we demonstrated can be applied to telecommunication, reflect radio waves in the direction of incidence without complicated signal processing and control, and further reduce power consumption by eliminating the complicated functions of beam selection and antenna directivity control that conventional wireless base stations and terminals have.

We will promote the practical application of this technology in a wide range of wireless systems.

7.4 Wired-and-Wireless Convergence Network technology

In preparation for Beyond 5G, the NTT Group has begun considering the Wired-and-Wireless Convergence Network. In the next generation after 5G, features of mobile and fixed networks are expected to be merged to create unprecedented services, and you will not notice the difference.

The Wired-and-Wireless Convergence Network consists of function dedicated networks (FDNs) for each virtual endpoint function. By placing virtual endpoints as communication endpoints on the computing infrastructure, and connecting them with an FDN for each function, seamless communication can be provided at the end of the network without users noticing the access or terminal. With this network-fusion technology, the fusion of cyberspace and real space, as well as computers and networks, will be further developed. Not only humans, but also a wide variety of objects will be able to communicate without being restricted by communication environment, location, or terminal type, enabling the creation of a new generation of services that require high stability and reliability.

7.5 Disaggregated computing: memory-centric architecture

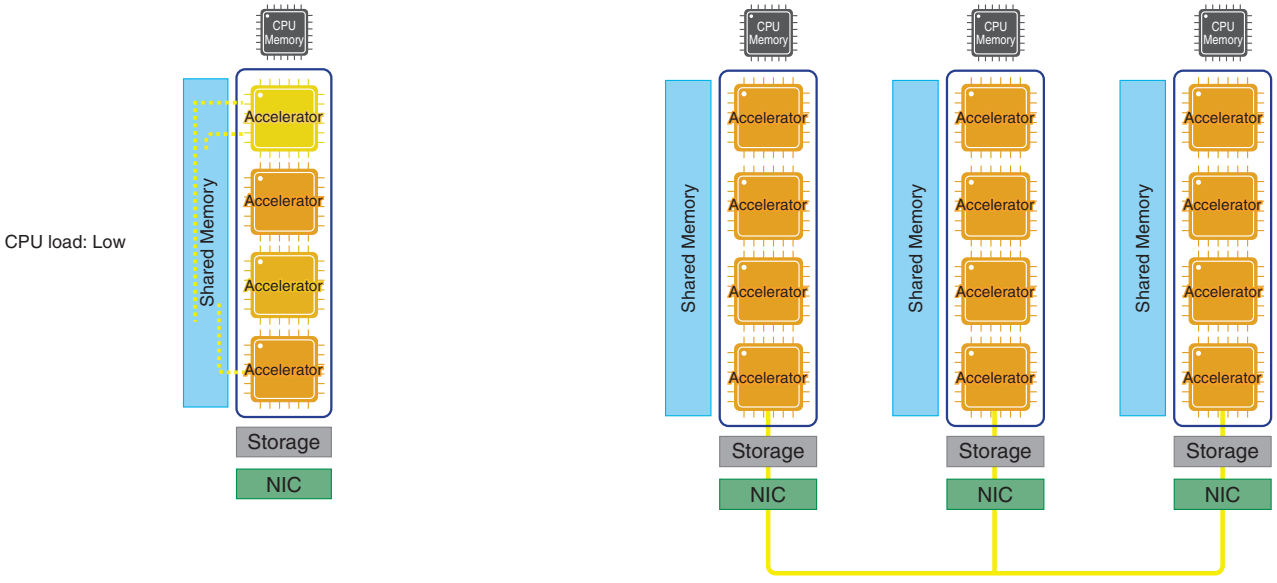
I will now talk about the progress in disaggregated computing in which distributed computing devices are connected by light. The computational efficiency of accelerators, such as graphics processing units (GPUs) and field-programmable gate arrays (FPGAs), has dramatically improved compared with that of central processing units (CPUs), which are general-purpose processors. However, when sharing and passing data between accelerators, the CPU is involved, which reduces efficiency in terms of processing speed and power consumption. To solve this problem, NTT has devised a computer architecture in which the accelerators are equipped with optical communication functions, allowing them to communicate directly with the memory using light (**Fig. 7(a)**). This dramatically improves the processing performance of the computer and reduces the CPU load and power consumption. The architecture consists of a scalable pool of accelerators that can be combined a la carte in accordance with the application, enabling a highly scalable and efficient computing infrastructure (**Fig. 7(b)**). We call this new computing architecture the memory-centric architecture.

We developed a prototype of the memory-centric architecture using a conventional device and verified its effectiveness using video-based AI inference as a test case. We confirmed that it reduces power consumption by about half compared with the conventional architecture. We estimate that power consumption will eventually be reduced to about 1/20 that of the conventional architecture through the evolution of photonics-electronics convergence technology and further development of this architecture using this technology.

7.6 Security-transparency-assurance technology

The next technology I will discuss is the security-transparency-assurance technology, which uses IOWN's photonics-electronics convergence technology to solve the security problems of decentralized computer devices. Decentralization increases the risk of malicious software and hardware. Therefore, visibility and inspection of the hardware and software is necessary to improve security transparency. NTT is developing this technology in collaboration with NEC Corporation [5].

I will now introduce the elemental technologies of the security-transparency-assurance technology, i.e., a technology for analyzing the software configuration of telecommunication equipment and a backdoor inspection technology for detecting illegal functions in software. To externally inspect communication equipment, we match device-specification data with device-operation data to detect out-of-specification behavior. We achieved the detection of out-of-specification code that does not normally run by directly analyzing the binary code inside a device. This technology will allow for versatile, high-performance and secure white boxes consisting of software and



(a) To reduce CPU load and power consumption by directly communicating with a memory using light

(b) A scalable pool of accelerators that can be combined a la carte in accordance with the application

NIC: network interface cards

Fig. 7. Progress in disaggregated computing (memory-centric architecture).

hardware devices supplied by multiple vendors to become the next generation of communication devices. NTT calls such super high-performance general-purpose devices *super white boxes*, which will be applied to various IOWN communication-infrastructure devices.

7.7 Post-quantum cryptography

I'll talk about cryptography for the IOWN era, the era of quantum computers. Quantum computers are expected to be applied to various fields, but if they are put to practical use, there is a possibility that existing cryptography, which ensures a secure communication infrastructure, will be broken. Research on the next generation cryptography post-quantum cryptography (PQC), which cannot be broken even by quantum computers, is being conducted worldwide. The NTRU (Nth Degree Truncated Polynomial Ring Unit) cryptography developed by NTT includes security-enhancement technology that can be applied to PQC. It is one of the last remaining candidates in the PQC standardization activity at the U.S. National Institute of Standards and Technology and is highly evaluated by cryptographers around the world [6]. We would like to combine this cryptography to construct a robust communication system.

7.8 Cradio® multi-radio proactive control technologies

I will now talk about the progress in the Cognitive Foundation® that enables rapid deployment and configuration optimization of ICT resources. Beyond 5G requires extreme coverage that can connect and stay connected across land, air, underwater, space, indoors, as well as outdoors. A promising method for achieving extreme coverage is the moving base station. Drones equipped with base-station functions could be flown to locations where there is a sudden increase in users. To meet this new need, NTT developed multi-radio proactive control technologies called Cradio®. This group of technologies estimates connection strength, derives station locational designs, and organizes wireless resources.

The logistics industry has been using automated robots at unmanned warehouses. For automated robots to operate accurately, it is necessary to create a network that remains connected and uninterrupted, even when the location of the robots or the environment in the warehouse changes. By applying Cradio®, we were able to combine information from the wireless environment with business information such as the increase in, decrease in, or arrangement of cargo, to enable the wireless network change

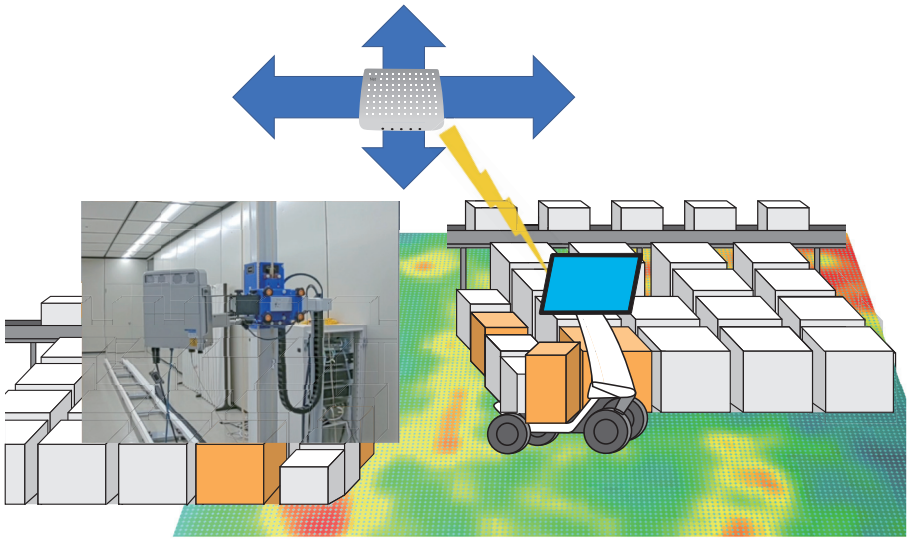


Fig. 8. Application example of Cradio®. The position of the moving base station in advance based on the amount of cargo.

autonomously in accordance with changes in the environment and stay connected (**Fig. 8**). By dynamically changing the position of the moving base station in advance on the basis of the amount of cargo, we can maintain an optimal wireless environment.

We aim to enable self-evolving lifecycle management of ICT resources in a multi-domain, multi-layer, and multi-service vendor environment with automatic design and autonomous operation of all types of ICT resources.

7.9 Large-scale three-dimensional spatial information processing technology

I would like to talk about the progress in the 4D digital platform™. This platform was designed to solve social issues and create new value by integrating various sensing data on a three-dimensional (3D) map database with high accuracy and rich semantic information, processing the data with high accuracy reflecting the time axis with for example real-time analysis, and providing the data to various industrial fields.

I will specifically talk about large-scale 3D-spatial-information processing technology, which is one of the technologies that make the 4D digital platform™ possible. Point-cloud data representing a space are usually acquired piecemeal by using, for example, measuring vehicles, but there are various challenges in integrating and using these data for an entire city.

Figure 9 shows point-cloud data for one corner of a city. The point clouds of different colors were collected on different dates, and only some of the data are overlapping. This makes it difficult to extract and use only some of the data due to the large quantity. In contrast, by applying new technology that compresses point-cloud data by dividing them into multiple blocks, it becomes possible to handle such data. It is also possible to handle blocks in a hierarchical manner, which makes it possible to efficiently handle data of large cities that are difficult to handle with conventional point-cloud-data processing.

There is also an ingenious means of comparing point clouds that have changed over time. The yellow area in Fig. 9 represents the point-cloud data collected in the past, and the pink area represents the point-cloud data currently being collected. Even if the two are displayed at the same time, it is difficult to notice the amount of change. Therefore, by visualizing the areas of change in small blocks instead of points, we can efficiently find only the areas of the city that have changed.

NTT is also developing a technology that uses deep neural networks to estimate structures from point-cloud data and automatically recognize 3D objects such as subway entrances and exits, manholes, and sidewalk edges.

Using these technologies as a foundation, we will further integrate environmental sensing data, GPS (Global Positioning System) positioning data, and existing map information to create an advanced

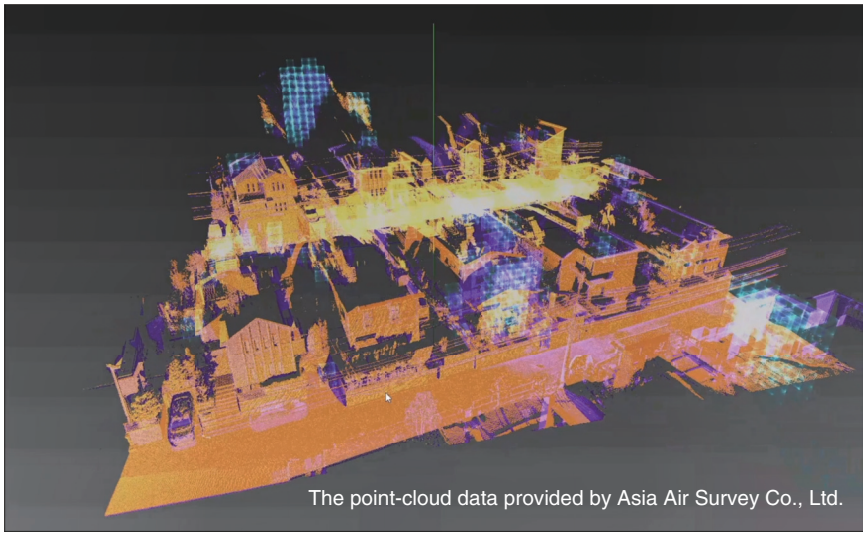


Fig. 9. Application example of 4D-point-cloud coding technology.

geospatial database. This database can be used as a digital twin of urban assets for the coordinated conservation of social infrastructure.

7.10 Infinite clustering technology

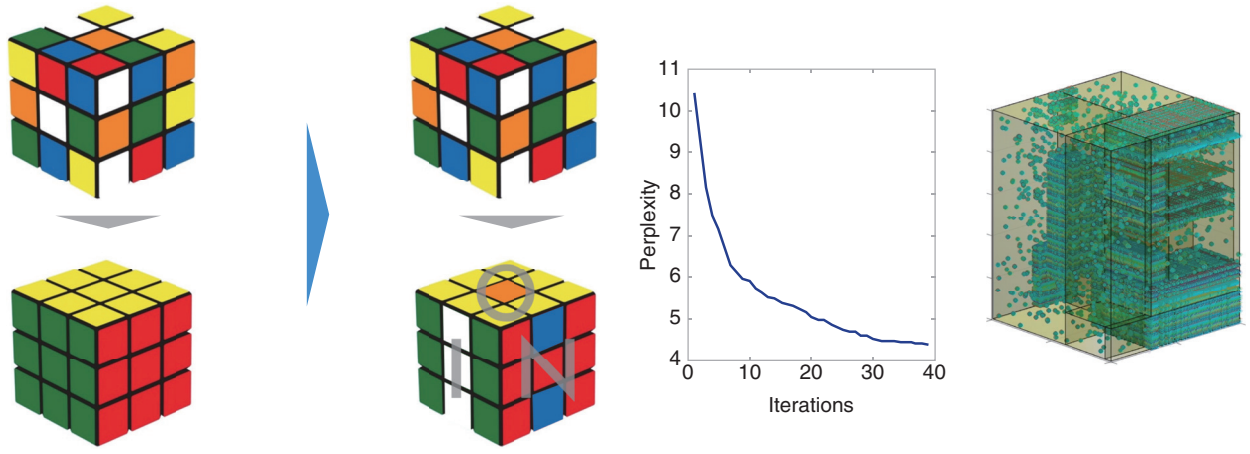
In the introduction, I talked about the world view that IOWN aims to achieve, and I would like to talk about an important technology that will help us understand the unknown world. Considering infinite possibilities and unknown events, we have devised the world's first infinite clustering technology that creates an infinite search space by flexibly grasping the concept of the analysis target [7]. This is a breakthrough in clustering technology, which reorders data to create clusters with common features. Clustering is easy to understand if you think of it as a technology for sorting and aligning data, such as a Rubik's Cube (**Fig. 10(a)**, left). By clustering, we can discover hidden patterns in seemingly disordered data.

With normal clustering techniques, it is necessary to know in advance what kind of clusters exist. In the case of a Rubik's Cube, six different colored clusters are given in advance. Imagine that you never heard of Rubik's Cube. You can imagine that it would be very difficult to know what to aim for when you are playing with the cube (Fig. 10(a), right). Our infinite clustering technology can generate an infinite number of combinations with an unknown number of chunks and features and create optimal clusters (**Fig. 10(b)**).

Since this technology allows us to explore infinite possibilities, we can add more factors than before and explore the relationships between the factors, which can be organized in clusters. For example, when a person visits a hospital because he or she is feeling unwell, but no lesion or disease is found that would lead to physical discomfort, in other words, an unidentified complaint, various factors can be added to find the cause. We search for infinite possibilities by adding various factors such as "at what time, at what temperature, in what climate, and how was the patient feeling." We may be able to find a cause we never thought of. We have already started this type of study. By having a variety of perspectives, this technology can get us out of the world of looking at the trees and not seeing the forest. We have also been able to guarantee that the technology will work without failure even when the input data becomes infinitely large.

This infinite search technology requires an enormous amount of processing time, but we believe this problem will be solved with the advancement in IOWN computers. We also believe that the coherent Ising machine LASOLV, which is being developed by NTT, can be used to speed up the processing. LASOLV has evolved since it was first announced and is now able to achieve 100,000 spins. It can find solutions to a 100,000-node combinatorial optimization problem 1000 times faster than simulated annealing used by CPUs and still with the same accuracy.

This technology has the potential to create AI



(a) Infinite clustering technology will help us understand the unknown world

(b) Example of complicated clustering with infinite clustering technology

Fig. 10. Infinite clustering technology.

unlike anything seen before, enabling us to pursue well-being from various perspectives. We hope to improve this technology to promote well-being with a global perspective.

7.11 Terminal user interfaces in the IOWN era

I would like to talk about how terminal user interfaces (UIs) will change in the IOWN era. Terminal UIs will connect to ultra-high-speed, low-power-consumption, low-latency network infrastructures that current IP networks cannot provide. They will be freed from various restrictions and what is now considered common knowledge. For example, it is common knowledge that content has to accept the intentions of the producer uniformly, and information such as video and audio is always compressed to reduce the load on networks and terminals. However, in the IOWN era, this sometimes changes depending on the purpose.

The point with the new UIs is that the information received will change depending on the values and environment of the recipients of the information, and that new discoveries will be made by the recipients. Even if the information is the same, you can understand it from the viewpoint of others who have different values from yours and become inspired or feel empathy. For example, you can discover problems by looking at a city from the perspective of a disabled person, or try to see and feel a creative work from the perspective of the opposite sex. Exposure to a variety of Umwelten can draw inspiration and create new value that we never thought possible.

To promote the research and development of new UIs for the IOWN era, we have started a collaboration with ACCESS Inc.

7.12 NTT Group's new environmental and energy vision

I have thus far talked about the progress in certain IOWN technologies. I will now talk about how IOWN can reduce environmental impact. The NTT Group's new environmental and energy vision was announced at the end of September 2021 [8] (**Fig. 11**). If the current situation continues, the amount of carbon dioxide (CO_2) emitted by the NTT Group per year will be approximately 8.6 million tons in 2040. By introducing energy conservation and renewable energy, we will be able to reduce CO_2 emissions by 55%, and by introducing IOWN, we will be able to reduce electricity consumption by 45% and achieve carbon neutrality by 2040. We assume that IOWN will be used worldwide by 2030. NTT will complete the development of IOWN devices by 2024, IOWN systems by 2025, and commercial launch in 2026.

7.13 IOWN space-computing concept

IOWN makes innovative new energy measures possible. I will now talk about the progress in the IOWN space-computing concept announced in 2020 to build a new space ICT infrastructure independent from planet Earth.

In May 2021, we began a partnership with SKY

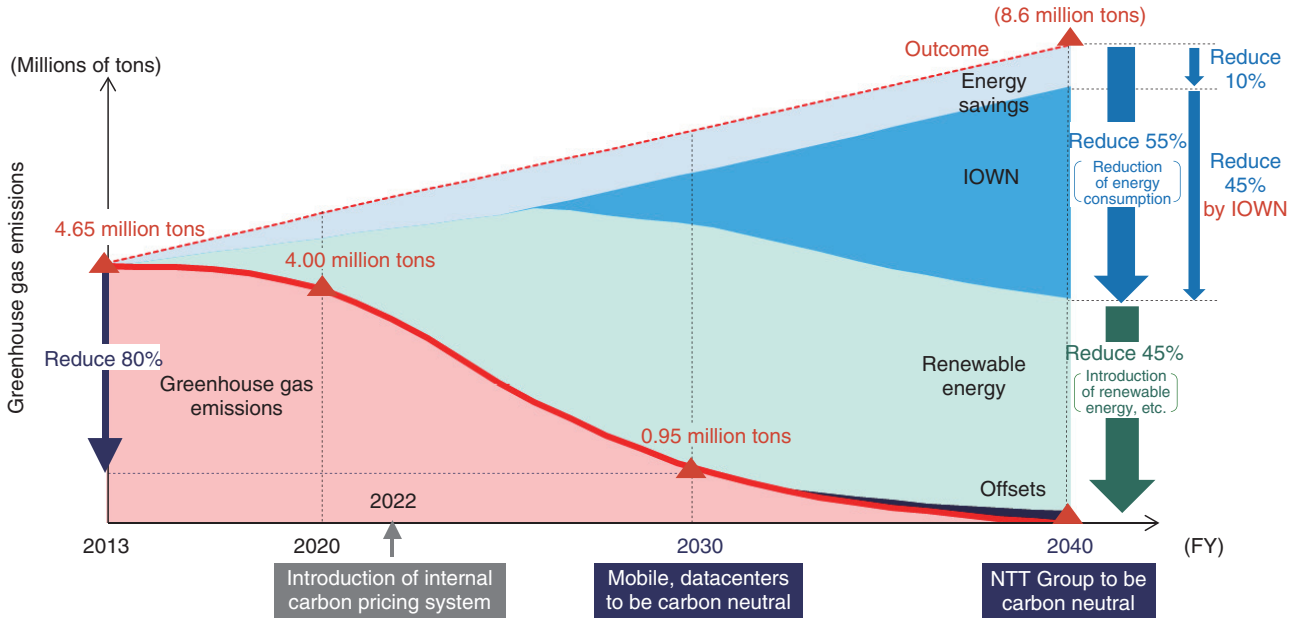


Fig. 11. NTT Group's new environmental and energy vision: NTT Green Innovation toward 2040.

Perfect JSAT to materialize this concept [9]. We are integrating the IOWN technology with SKY Perfect JSAT's space assets and business for commercialization and currently working together to solve a variety of issues. For example, with a single observation satellite, the timing of data transmission to ground stations is limited, and in some cases delays of several days occur. Therefore, high altitude platform stations flying in the stratosphere and satellites in low to geostationary orbits are integrated via optical radio communication, and the data acquired by the observation satellites are immediately transmitted to the integrated satellite system for distributed processing. Only the required processing information is transmitted from satellites that are close to the ground station, which greatly reduces delay time. This is the Space Integrated Computing Network presented by both companies. By creating this infrastructure, we will contribute to the dramatic improvement in real-time space-data utilization and user convenience and work to solve global-scale social issues.

We are developing this infrastructure with the aim of starting operations in 2025. As a part of this development, we are planning to conduct a demonstration experiment on one of the Japan Aerospace Exploration Agency's satellites in orbit in 2022. The Space Integrated Computing Network, which connects the vastness of space using light, will be the ultimate eco-friendly infrastructure and break away from terrestrial energy.

7.14 Space solar-power generation

The next environmental initiative I would like to talk about is space solar-power generation. This is a next-generation energy source that generates solar power in space and transmits that energy to Earth. NTT laboratories are conducting research and development on three technologies.

The first is a technology that collects sunlight in geostationary orbit 36,000 km above the ground and irradiates the collected light directly onto a special crystal we developed installed on a satellite to excite a laser with high efficiency.

The second is a technology to transmit lasers from space to the ground. When lasers pass through the atmosphere, atmospheric turbulence causes misalignment of the path and performance degradation. Therefore, we are researching technology to avoid such atmospheric effects and deliver lasers accurately over a long distance. When energy sent from the universe is visible light, because of the attenuation caused by atmospheric absorption and scattering and the fact that the human eye can detect it, an infrared laser is a good candidate.

The third technology is a photoelectric conversion system that can withstand the high intensity of

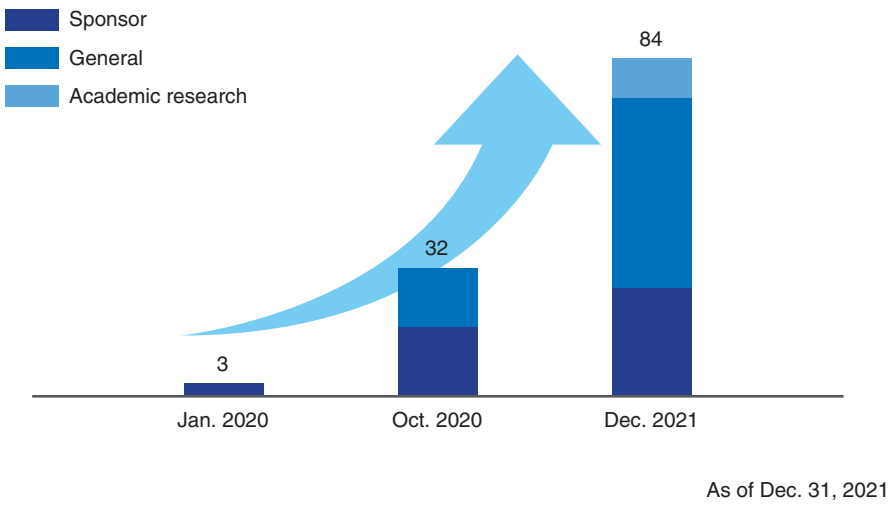


Fig. 12. Changes in the number of IOWN Global Forum members.

infrared lasers coming from space and generate electricity with high efficiency. We are also looking into technologies to convert electric power into storable forms, such as hydrogen and ammonium, using thermochemical reactions and catalysts. By linking this space solar-power generation system with the Space Integrated Computing Network I mentioned earlier, we aim to use energy obtained in this manner for local production and consumption.

7.15 Lightning-strike control technology

I would like to talk about the progress in the lightning-strike control technology that we announced in 2020. It prevents lightning strikes on important facilities and creates electricity from the lightning.

From the observation of thunderclouds from the Space Integrated Computing Network, drones can be brought close to clouds that are likely to cause lightning strikes to form a route to guide lightning and prevent it from striking the city. The current from lightning strikes can be sent to lightning-charging vehicles as electricity. We are developing the world's first drone that can withstand lightning. The drone is equipped with a metal shield called a Faraday Cage to protect it from lightning strikes. We tested the lightning resistance of the drone by striking it with artificial lightning. It flew without malfunction or failure even after being struck by lightning. We also verified that lightning can be induced through wires.

8. The IOWN Global Forum and new NTT organizations

I will now talk about the IOWN Global Forum, which is promoting IOWN and new NTT organizations.

8.1 IOWN Global Forum

The IOWN Global Forum, founded in January 2020 by NTT, Intel, and Sony, has grown to 80 members in less than two years, including the world's leading ICT companies that support IOWN's vision and innovation [10] (**Fig. 12**).

In addition to ICT companies such as Microsoft, Dell, Ericsson, and Nvidia, and companies such as Ajinomoto, Shin-Etsu Chemical, Yazaki Corporation, and AGC that possess device technologies, companies and organizations such as Mitsubishi Chemical, JGC, and NIED have joined as users of the IOWN technology. The forum aims to develop the technology and discuss use cases. Due to the pandemic, we have been conducting our activities online but are actively promoting global activities, including the release of three use-case documents and technical documents, starting with the white paper released in April 2020.

8.2 The IOWN Integrated Innovation Center

The IOWN Integrated Innovation Center was established on July 1, 2021 to strengthen research and development capabilities to develop IOWN and 6G. We will accelerate research and development toward

the implementation of IOWN by promoting flexible and integrated research and development that transcends the boundaries of technological fields and collaborating with many companies in Japan and overseas.

8.3 The NTT R&D Authority Team

I am pleased to announce the formation of the NTT R&D Authority Team. The purpose of this team is to lead our research and development on IOWN and beyond with renowned authorities in various fields. The team plays a leading role in each research area through implementation, guidance, and advice on research themes [11].

8.4 Basic mathematics research

To further strengthen research and development over the long-term, we established an organization to promote basic mathematics research [12]. In addition to working on the development of a basic theoretical system for modern mathematics, this organization will take an unprecedented approach to research and development using modern mathematical methods to address various research issues to promote IOWN, such as the identification of unknown diseases and discovery of new drugs. We will attempt to establish a theory of super quantum computation, *consciousness* for the post-quantum era, and construct a brain-type computational model. It is overseen by Research Professor and Fundamental Mathematics Research Principal Masato Wakayama, a leading expert in basic mathematics in Japan.

9. Conclusion

I talked about the progress in IOWN, an innovative technology that does not burden the Earth, by seeing the world as it is instead of a human-centered digitalization. IOWN contributes to "The Great Reset," the theme of the 2021 Davos Forum, for reviewing all aspects of society and the economy.

The NTT Group will make every effort to develop IOWN by launching IOWN devices in 2024, IOWN systems in 2025, and commercial deployment in 2026.

Through IOWN, we would like to contribute to society by collaborating with people in various industrial fields beyond the NTT Group and explore new possibilities together. We will continue to take on the challenge of breakthrough innovation to ensure the continued happiness of humans, animals, and the Earth. Thank you very much for your kind attention today.

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Women's Softball × Sports Brain Science

Masumi Yamaguchi, Daiki Nasu, Dan Mikami, Toshitaka Kimura, Takehiro Fukuda, and Makio Kashino

Abstract

In the world of sports, the key to success is often the ability to make snap decisions and act instinctively faster than making conscious decisions. The Kashino Diverse Brain Research Laboratory at NTT Communication Science Laboratories is researching the implicit brain functions that are exhibited by athletes under these special conditions. Together with the Japan women's national softball team, which won the gold medal at the 2021 international sporting event held in Tokyo, NTT has been working on practical initiatives in parallel with academic research to apply the findings of this research to improving the team's chances of winning.

Keywords: sports brain science, softball, pitching machine

1. Background of the initiative

The key to success in sports matches is the implicit brain functions that even the athlete himself or herself is unaware of, such as the instantaneous decisions that must be made when batting in a game of softball. The Sports Brain Science Project was launched at NTT Communication Science Laboratories in January 2017 (in July 2019 it changed its name to the Kashino Diverse Brain Research Laboratory). Its mission is to push forward with research that improves the performance of athletes on the basis of clarification of the superior implicit brain functions of top athletes and identification of the factors that help them win [1] (**Fig. 1**). We have received the cooperation of US and Japanese professional baseball teams, Japanese semi-professional baseball teams, university baseball teams, the Japan Softball Association (Japan women's national softball team), and corporate teams belonging to the Japan Women's Softball League. Therefore, we were able to clarify the special abilities and characteristics of athletes who compete at the topmost levels.

In October 2017, we signed a joint experimental agreement with the Japan Softball Association to carry out experimental and practical measurements of top and up-and-coming softball players. On August 3, 2016, before we entered into this agreement, the decision was made to reintroduce women's softball to the international sporting event to be held three years later in Tokyo. Alongside our academic research, we were engaged in practical initiatives with the Japanese national team to devise a strategy for turning brain training into success at softball with the aim of winning the gold medal at the event [2]. This article focuses on the efforts we made with the Japan women's national softball team to achieve this goal.

2. Working with the Japanese national softball team

In August 2016, Shinsuke Yabata, the then deputy training manager at the Japan Softball Association, paid his first visit to the Sports Brain Science Laboratory at the NTT Atsugi Research and Development (R&D) Center. The first time we met him, he told us that Japan's biggest challenge in winning the gold medal would be dealing with fast and changing balls thrown by US pitchers.

In September 2016, the Japan Cup was held in Takasaki City, Gunma Prefecture. This provided us with the opportunity to watch international matches

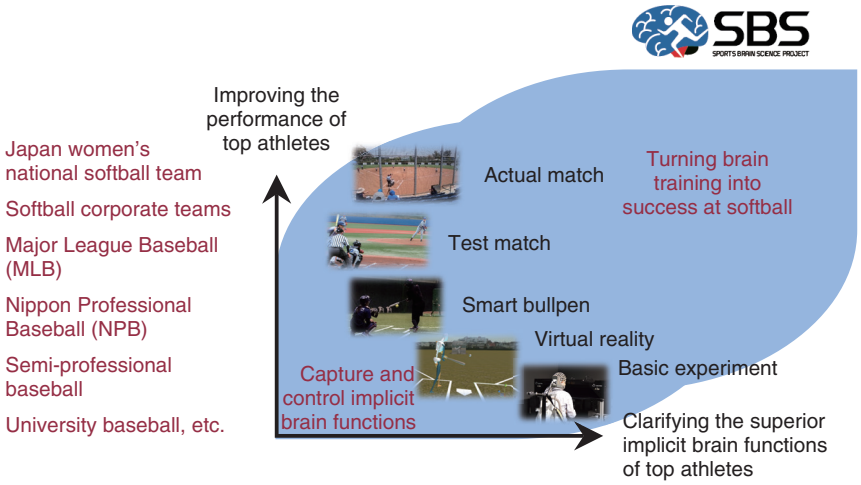

Fig. 1. Sports Brain Science Project.

Fig. 2. International matches and training camps.

among four national teams, including those of the US and Japan. We then attended most of Japan's international matches and obtained video footage of the teams as a member of the national team's information squad (**Fig. 2**). Our main purpose in obtaining this material was to understand the characteristics of the pitchers on opposing teams. We took videos of their pitching styles from various angles to analyze pitchers' habits. We also used a high-speed camera behind the back net to identify the characteristics of the balls thrown by pitchers and conducted ball-quality analysis to extract the ball's rotation axis and number of rotations.

While we were analyzing the other teams in this manner, we also attended the Japanese team's training camps to take videos and assess the players. To help the players improve their performance, we provided them with video feedback showing their

pitching and batting actions after a delay of a few seconds and analyzed the performance of the pitchers with the same high-speed camera technology that we used in the international matches. While providing this support, we also conducted measurements for research purposes with the help of the players. At the Okinawa training camp in December 2017, the top national team who would compete at the target international sporting event and the national teams in other age groups (under-19, under-16, and under-14) got together. We measured the hitting decisions of players of each team during actual gameplay by using virtual reality (VR). In June 2019, just before entering a long-term training camp, nineteen players from the top national team spent two days at the NTT Atsugi R&D Center, where we conducted various measurements including batting gaze, movement, and cognitive tasks. We analyzed the measured results as research data and provided feedback to the players.

3. Special abilities of top players

In women's softball, the pitcher delivers the ball to the batter from a distance of 13.11 m, which is about two thirds the pitching distance in baseball. US pitchers pitch the ball at speeds ranging from 72 to 118 km/h with various pitch types, such as riseball, dropball, curveball, and screwball, and the timing of the ball to reach the batter can also be adjusted using techniques such as change-up pitches. For some pitchers, the difference between a riseball and dropball can be as much as 80 cm. However, the time taken for a pitched ball to reach the batter is only about 0.4 seconds. This only gives the batter a short window of opportunity in which to respond by striking the ball. No matter how fast the batter can swing, there is a limit to the batter's ability to respond. It has been found that good batters can adapt to this particular environment [3, 4].

There are several measures that batters can take to deal with these fast and varied balls. The first is to read the pitch sequencing. Although it varies from person to person, batters are generally able to read pitch sequencing and narrow down the possible pitch types to some extent before the pitcher throws the ball. The second is to determine the pitcher's habits. For example, if a batter knows in advance that the pitcher sets the ball with the wrist in a different position when delivering a riseball, then she will be better able to focus the strike on the position of this ball. These pitching habits can be shared with the rest of the team through speaking and video.

However, not all pitchers are quite so easy to read. We heard an interesting story about Eri Yamada, the captain of the Japan women's national softball team. She is widely recognized as a batter with the ability to read a pitcher's pitch sequencing, and unlike other players, she seems to have the ability to identify different pitch types while sitting on the bench. However, it is not clear how she manages to do this. Apparently, there are many things that she somehow manages to understand. Even if she does not know where or what the difference is, she can somehow guess what type of pitch is coming and adjust her striking accordingly.

Even more interestingly, experiments with VR suggest that even if she does not aware of what type of pitch is coming, she can still sometimes react to it. The VR experiments incorporated motion captured from real pitches, and the batters were tasked with swinging a bat to strike randomly thrown change-up and fastball deliveries. A sensor was attached to the batter's waist to measure the timing of the swing. Using VR makes it possible to switch the correspondence between fastball and change-up of pitching styles and ball deliveries. As a result of carrying out switches in this manner, we found that the batters could swing their bats with the correct timing when the correspondence between the pitching style and ball delivery was correct, but could not with the correct timing more often when the correspondence was switched [5]. What is interesting is that the batters said they could not tell the difference between different pitching styles and did not know what type of pitch was coming from these pitching styles. Even after the experiment, they were completely unaware that the pitching styles had been switched. This means that even if a batter is not aware of what she is doing, she may be unknowingly using information from the pitcher's pitching style when striking a ball.

These types of predictions cannot be shared with the team because they cannot be explained to others, even when using video or data. However, if more players can acquire these abilities, the team's hitting ability will improve.

4. Honing skills

As a member of the Japanese team at the 2000 international sporting event in Sydney, Reika Utsugi, head coach of the current Japanese team, conducted image training by watching videos of opposing pitchers hundreds of times. Since visiting the NTT Atsugi

R&D Center in May 2017 and experiencing VR batting simulations, she became very interested in the use of this technology to defeat US pitchers.

At subsequent training camps, we brought in several times a VR system using footage and ball trajectories of pitchers from other countries that had been acquired thus far. However, there were issues with this system. At the level of a VR video game, it is possible to link the VR images with the swinging of a real bat, but there are still temporal and spatial discrepancies between the throwing of the ball in VR space and swinging of the real bat. It was therefore of limited value for player training because it was not possible to correctly assess whether the swings done by the players were actually appropriate. If we had pursued greater accuracy, we would have had to install many sensors and make the equipment much larger. This would have made it difficult to find a location to set up the equipment and placed more burden on the players; thus, making it difficult to use this approach for actual training. In 2017, most VR headsets had to be connected to a personal computer, but in 2019 stand-alone headsets became more widespread. With such equipment, it became possible for players to train individually in their hotel rooms. We began preparations to bring this system to the athletes' village during the international sporting event to be held in 2020. Although allowing players to access this system in their rooms removes constraints related to location, it reduces its interactivity to the point where the players can only watch footage and ball trajectories of pitchers. Being able to see ball trajectories in three dimensions is better than watching the video, but we were not sure how much this would benefit the players (**Fig. 3**).

Fig. 3. Our VR system.

5. The team's secret weapon: the "Nasu Machine"

In addition to the VR system, we also provided the players with a pitching machine for use in batting practice. We called this the "Nasu Machine," after Dr. Daiki Nasu, one of the authors of this article. Besides being able to deliver various types of breaking balls, this pitching machine also displays images of a pitcher, giving it the same appearance as a pitching machine at a batting cage that shows an image of a pitcher. At the Kashino Diverse Brain Research Laboratory, we are using this machine to experimentally investigate the perceptions of baseball batters under conditions that cannot be achieved with actual pitchers, such as switching them between left- and right-handedness [6]. To conduct similar experiments with softball batters, we had a pitching machine that could reproduce various pitching speeds and ball rotation speeds with softballs as well as baseballs. We decided to try combining this softball-pitching machine with the images of pitchers used in the VR system to create a practice machine with which players can actually hit balls. At the end of the 2019 Atsugi visits, we showed the players a prototype of this softball-pitching machine we had built in the laboratory and observed that it could be useful in practice (**Fig. 4**).

However, we had a few issues with this machine when it was used for actual training. Our biggest concern was that the equipment would be much larger than the VR-only equipment, so it could be difficult to find somewhere to install it. Since the pitcher's image is displayed using a projector, it had to be very bright for outdoor use. Furthermore, steps had to be taken to protect the machine from rain if used outdoors. Since the team's training involved other activities besides practicing with the pitching machine, it was important to ensure access from the ground where all the rest of training is conducted. If we set up the machine at our laboratory in Atsugi, it would be of no use because it is far from the training camp, and the players would not have time to visit us before the start of the target event.

In 2019, the Utsugi Stadium was built in Takasaki City as a dedicated softball venue, and it was decided that the Japanese team would hold a training camp

The Japanese team checking out the prototype

Survey of pitching machine installation location

Pre-event training camp

Fig. 4. Pitching machine.

there just before the target event. A covered practice area for use in rainy weather was set up in one corner of this facility. This was our preferred location for installing the pitching machine, but since the sides of this area are just covered by netting and semi-exposed to the outside, we were concerned that daylight coming in from the sides might make it hard to see the pitcher images. On a more practical note, we feared that this machine might not be allowed to occupy a part of the training area that plays an important role in wet weather. At the time, we had no idea how useful this machine would be.

Due to the novel coronavirus (COVID-19), the 2020 international sporting event was postponed for a year. As a result, we adjusted our schedule and moved the preview of our machine from April 2020 to November 2020 when we finally loaded the projector into a car and took it out for a field test. On this occasion, the machine was trialed by head coach Reika Utsugi and some players, Yutaka Miyake (president of the Japan Softball Association), Taeko Utsugi (vice president of the Japan Softball Association), Shinsuke Yabata (training manager), and Noriko Yamaji (coach), who were able to see how the video images looked, and were confident that the machine would work fine in this location.

For the pitcher images, we were able to use the same images that we had prepared for the VR system. Unlike the VR system, we were not able to perfectly reproduce the ball trajectories with the pitching machine. Specifically, the three-roller mechanism used in this pitching machine is physically unable to reproduce gyro spin components. It also varies the trajectory and rotation from one pitch to the next. Bearing in mind the performance limits of this pitching machine and how it would be used in actual training, we decided to label pitching styles with different pitch types and associate these labels with the ball trajectories set in accordance with each pitch type.

As mentioned above, the characteristics of the pitching machine made it impossible to impart gyro spin to the ball, so it was not possible to exactly reproduce the rotation of balls thrown by actual pitchers. Therefore, under the guidance of team analyst Minori Ota, we adjusted the pitching machine to produce the trajectories closer to those of deliveries made by a real pitcher by using the vertical and horizontal rotations that the pitching machine was capable of producing. Ms. Ota watches every game from behind the back net and is familiar with the data that have been gathered in relation to individual characteristics of pitchers. This enabled her to provide us with very detailed instructions on the variation of each pitcher.

We installed the pitching machine at the indoor training ground in Takasaki City on May 17, 2021, which was the first day of the team's first training camp just before the target event. When we did so, we found that the players (including head coach Reika Utsugi) were more interested in it than we had imagined. Our initial plan was to spend about a week

setting up the pitching trajectories, but on the following day, the players decided to start practicing with it straight away. The first training camp was followed by the second training camp after a one-week break, and the machine stayed in place until the end of this second camp on July 14. Throughout both camps, the players took turns on the machine on visits from the main training ground. During this period, we also added video footage of other pitchers, thus were able to prepare content for six pitchers from three different countries.

When the players came to the practice field where the machine was installed, they told the operators which pitchers and pitch types they were going to practice and practiced not only striking the ball but also bunts and hit and run. One team member (Yu Yamamoto) said that when facing an actual pitcher, she experiences various emotions such as a desire to strike the ball, but practicing on the machine was better because she could observe the pitcher's pitching styles and ball trajectory more calmly. The players also seemed to enjoy playing against virtual pitchers and were keen to try out new video images and pitch types as soon as we added them.

Since the team's policy was not to disclose any information about practicing with this machine until after the finals at the target event, it was described as the team's "secret weapon" in newspapers and television reports until after they had won the gold medal.

6. Japan brings home the gold medal

Throughout the tournament, the Japanese team batted well. We cannot tell how much they were helped in this achievement by being able to practice with their secret weapon. In addition to coaching each player in preparation for the event, the top pitchers from the Japanese men's softball team acted as batting pitchers to prepare the players for fastball deliveries from the US team. The team was also assisted by analysts, but since they were unable to work onsite due to the COVID-19 pandemic, they instead used the Internet and other sources to obtain information about opposing pitchers and analyzed their habits, pitch types, and pitch sequencing. The team also took part in other efforts, initiatives, and actions that cannot be described here, and the team won the gold medal through the combined effect of all these efforts.

Our pitching machine not only helped players learn about the combination of ball trajectories and pitching styles of opposing pitchers but helped them get used to the timing and the trajectories of balls thrown by opposing pitchers. It could also have positive psychological effects by making players better prepared. Although it is impossible to identify exactly how our machine benefited the players and to what extent, we are confident that it did have a positive effect. At the very least, it seemed that the players enjoyed using this machine and had a positive attitude toward using it as a practice tool. As mentioned by training manager Shinsuke Yabata in the October 2021 issue of Softball Magazine, a player called Saki Yamazaki, who had thrown no-hitters in previous games, hit a double in the final with a dropball thrown by Cat Osterman of the US team. He commented that the practice sessions with our machine may have contributed to this achievement.

It is not easy to pursue academic research and the improvement of sporting performance at the same time. In the initiatives introduced in this article, we were probably more focused on improving performance than on conducting research. However, the fact that our research tools played a role in this successful bid for the gold medal proves that our experimental environment is properly connected to actual matches. We will continue conducting research to elucidate and train the special abilities that athletes demonstrate in actual matches.

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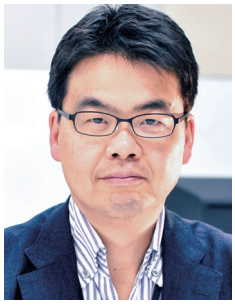

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Cycling × hitoe™: Dialogue with the Body via Surface Myoelectric Potentials

Kentaro Tanaka, Shingo Tsukada, and Masumi Yamaguchi

Abstract

For athletes, knowing the state of their muscle activity is key to improving their performance and maintaining peak performance. Using the surface myoelectric potential, which can be measured from the surface of the body, is an effective method for understanding muscle activity with little physical burden. Technology using hitoe™, a functional fabric for collecting biosignals (jointly developed by NTT and Toray Industries, Inc.), for measuring, visualizing, and analyzing surface myoelectric potentials of top cyclists is introduced in this article. This technology is expected to be used for not only top athletes but also for self-analysis by ordinary people participating in daily sporting activities.

Keywords: wearable devices, biometric signals, visualization of muscle activity

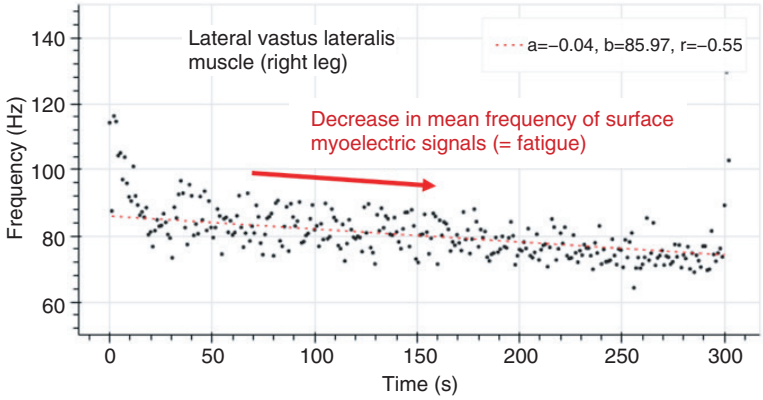
1. Introduction

Sensor information captured using power meters, heart-rate monitors, and other devices is actively used for training cyclists. Objective data showing physical information and training progress of top athletes are important clues for not only improving performance but also checking fatigue and injuries to maintain peak performance. Our goal is to evaluate the dexterity of movement and state of fatigue of an athlete from surface myoelectric potentials obtained from the skin covering the muscles and use the evaluation results for data-driven training concerning sports and rehabilitation. Surface myoelectric potentials, which can be measured from the surface of the body, provide athletes with data that are easy to acquire. We are researching and developing a usability-aware system that integrates wearable sensors and applications under the assumption that the system will be used for daily training and in daily life.

2. Measuring surface myoelectric potentials by using hitoe™

To measure the surface myoelectric potentials, hitoe™, a functional fabric for collecting biosignals (jointly developed by NTT and Toray Industries, Inc.), is used as a bioelectrode. One of the advantages of hitoe™ is the ease of movement and placement of the electrode. Conventional myoelectric sensors encounter problems such as detachment of electrodes due to sweat, long preparation time for affixing individual electrodes, and interference with the movement of the athlete in question. For myoelectric measurement using hitoe™, since hitoe™ is attached in advance to the lining of the training wear, the electrode simply contacts the skin when the clothing is put on and will not detach. In sports such as cycling, the cyclist usually wears training clothing that adheres to the skin, and the compression necessary for fixing the electrode to the skin can be secured. Therefore, hitoe™ does not interfere with the normal sensations and movements of the cyclist.

Photo 1. Eiya Hashimoto, a member of Team Bridgestone Cycling.



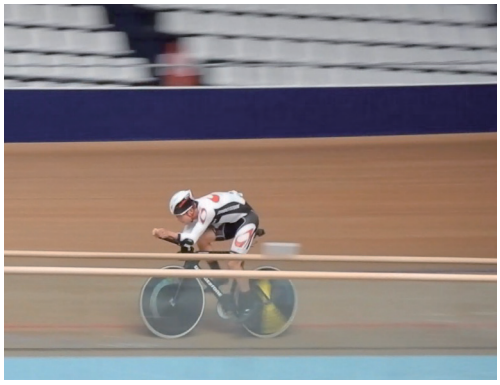
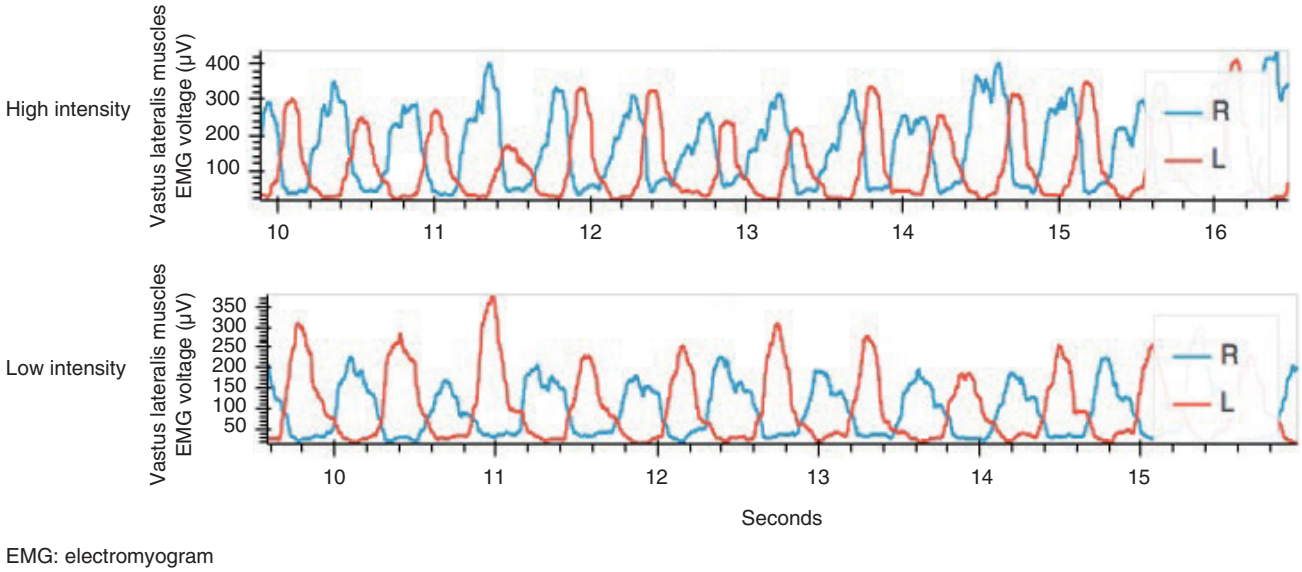


Fig. 1. Example of analysis of hitoe™ surface myoelectric potential data obtained during a time trial.

3. Evaluation of differences in pedaling styles on the basis of muscle fatigue and muscle activity of cyclists

To measure surface myoelectric potentials during cycling by using hitoe™, we evaluated the pedaling of cyclists on the basis of the muscle fatigue and muscle activity of top cyclists in Japan, including Eiya Hashimoto (**Photo 1**), a member of Team Bridgestone Cycling, during a joint experiment with NTT DATA. In the experiment, cyclists pedaled under various conditions, and from the collected pedaling data, we identified points to be enhanced in competition, provided feedback on the basis of differences in the way each cyclist pedaled, and held discussions that included the subjective feedback of the cyclists.

Surface-myoelectric-potential data obtained during a time trial at the Izu Velodrome, which was used as the venue for the international sporting event in 2021, is shown in **Fig. 1**. The temporal variation of the mean frequency component of the surface myoelectric signals is shown. The frequency component changes as muscle fatigue progresses. It is clear from the figure



EMG: electromyogram

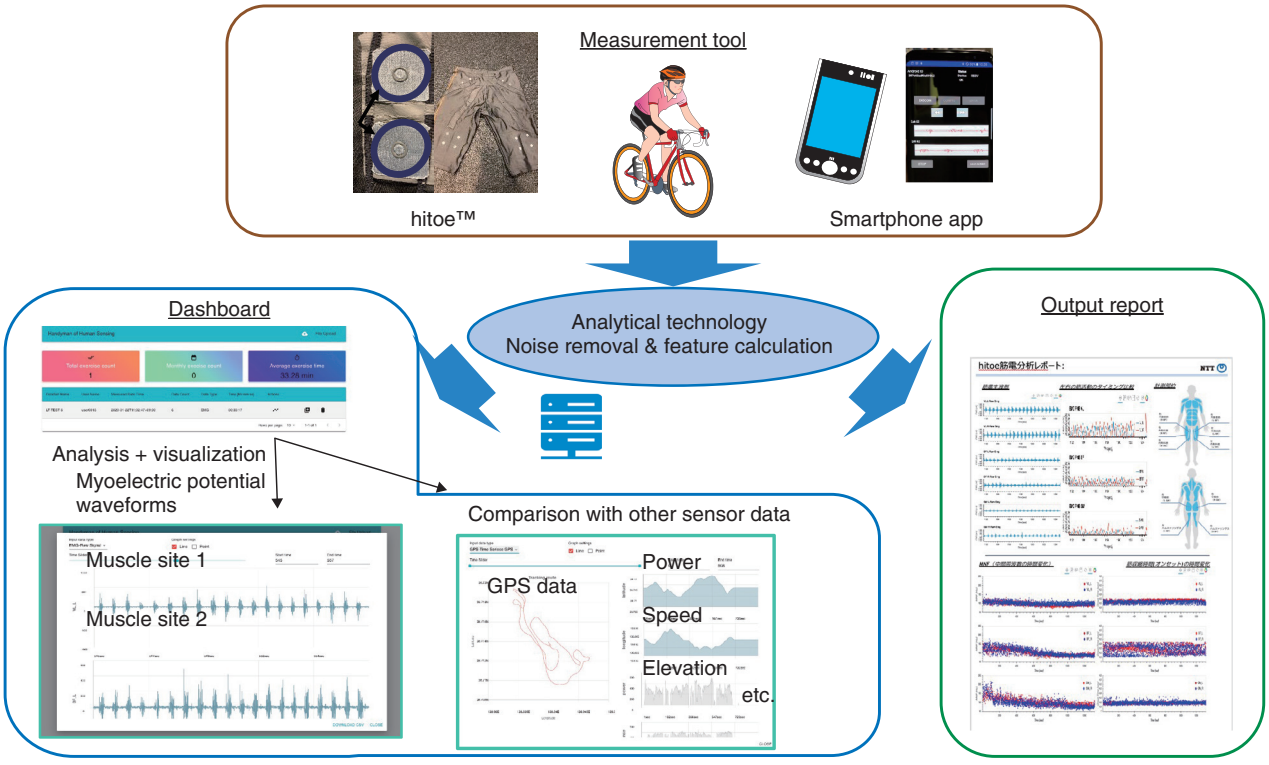
Fig. 2. Differences in timing of muscle activity of the right and left vastus lateralis muscles during high- and low-intensity pedaling.

that the mean frequency of the surface myoelectric potential of the vastus lateralis muscle (the muscle of the anterolateral thigh), which is a main muscle group, decreases over time. Since multiple muscles contribute to pedaling, the muscle areas that show this tendency and the degree of change vary according to race strategy, difference between the left and right legs of the cyclist, and difference in pedaling style. When the interpretation of the objective data matches the challenge facing the cyclist, such as identifying the muscles that tend to fatigue in the second half of the race, we can provide new insights for the cyclist.

A case study involving Eiya Hashimoto, who received feedback through insights, is described as follows. Inconsistency was observed in the timing and duration of muscle activity when pedaling under a higher load than normal. As shown in **Fig. 2**, the muscle-activity time of the vastus lateralis muscle of the right foot was longer than that of the left foot, and that time difference resulted in a delay in pedal strokes. When he was given feedback on this point, he felt that this muscle was prone to fatigue during races and was surprised that the difference in his muscle-activity pattern could be read from the objective data. This led to specific feedback such as being aware of the timing of the activity of the vastus lateralis muscle and the length of the pedal strokes during daily training.

We also analyzed how much muscle activity changed on the basis of the difference between indoor and outdoor environments, pedaling speed, and load, and verified the validity of the data through discussions with the cyclists. For meaningful discussion and self-feedback between coach and cyclist, it is important to visualize the data and provide the analysis results promptly after training. Accordingly, for this experiment, we developed a hitoe™-based system for measuring surface myoelectric potentials in stages and shortened the feedback cycle to the cyclist after the measurement (**Fig. 3**).

To establish this system in the field of sports, we must address the practical issues of finding more easy-to-understand indicators that allow the user to understand their issues and the effects of training as well as making it even easier to use than it is now. We are addressing these issues and will continue our research and development with the aim of creating a tool that can be used in everyday sports.



GPS: Global Positioning System

Fig. 3. System using hitoe™ for measuring surface myoelectric potential.

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Swimming × Online Coaching: Online Conditioning of Competitive Swimmers—Focusing on the Thorax—via Smartphones and Wearable Sensors

Shingo Tsukada and Yumiko Hamaguchi

Abstract

In response to the decline in motor function (centered on the thorax) caused by chronic muscle tension associated with strengthening exercises for competitive swimmers, we devised a training program that promotes awareness of the functional coordination of the thorax; spine, ribs, and core muscles, and restores natural and efficient body movement. This article presents the results of supporting athlete training during the novel coronavirus pandemic by providing regular coaching remotely using a web-conference system with smartphones, video recording, and a multi-sensor belt equipped with hitoe™ for measuring myoelectricity, respiration, and motion.

Keywords: online core training, wearable sensor, hitoe™

1. Background and target

For Japanese athletes to achieve success in international competitions, it is necessary to strengthen their overall physical fitness, including sufficient muscle strength and energy metabolism to compensate for the difference in body size compared with non-Japanese athletes. Satisfying this requirement requires long-term, high-intensity training.

Athletes who have undergone long-term strengthening exercises have suffered from joint pain, stiffening of developed muscle groups, and limited range of motion—all caused by accumulated fatigue and damage—that have resulted in poor performance and disappointing results.

Regardless of the athletic discipline, pain and limited range of motion are not limited to the major joints of the extremities and their regions; they can also be found in the thoracic spine, thoracolumbar junction, costovertebral joints, intercostal muscles, and around the shoulder girdle (**Fig. 1**). These parts are remote from the major muscles and joints, so they are easily overlooked. However, for swimmers, the effects of limited range of motion and pain due to chronic muscle tension in these parts can lead to increased water resistance in the streamline position due to poor posture, such as the compensatory lumber hyperextension. It has also been a concern that such pain and limited motion could affect overall performance because they could limit the expansion of the thorax (ribs), which is associated with breathing. To address this issue, we have been supporting competitive swimmers through regular conditioning to alleviate functional limitations and distortions of the joints and muscles around the thorax, evaluation using biometric sensors and video, and online coaching via a smartphone.

The target swimmers, whose training base is at the swimming club of Chukyo University (head coach: Yuichiro Sasaki), were Takeshi Kawamoto (Toyota

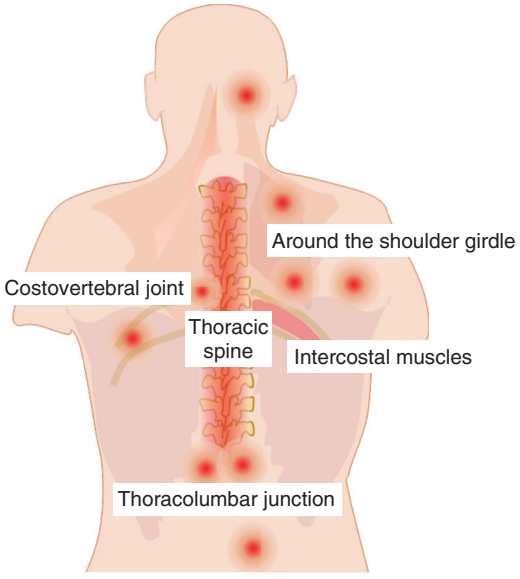


Fig. 1. Favorite sites of pain, muscle stiffness, and limitation of movement (the back in red).

Motor) and Ai Soma (MIKI HOUSE) who have both won top prizes in domestic competitions and participated in international competitions (butterfly sprint).

The pre-intervention subjective symptoms were chronic back muscle tension (**Fig. 2(a)**), middle back pain, and hardness of the thorax during breathing. The objective symptoms were restrictions in all directions throughout the thorax, excessive contraction of muscles around the scapula and erector spinae muscles, and a tendency of lumber hyperextension. In terms of whole-body coordination, the limited extension range of motion of the thoracic spine and hyperextension of the cervical spine and lumbar-sacral junction during whole spine extension in the prone position were observed (Fig. 2(a)). Limited range of motion of spine extension was also confirmed in the back line (side view) in the streamline position (**Figs. 2(c)** and **(d)**). Similar symptoms re-occurred due to intensive strengthening practice.

2. Concept of coaching

The thorax is a three-dimensional structure consisting of stacked vertebrates of the thoracic spine, each of which is connected to a pair of ribs on the left and right sides, which are joined by many joints and act like a suspension. The thorax is an important part of the body that fine-tunes the movements of the whole body. Accordingly, instead of focusing on simply gaining flexibility, we thus focused on how to enhance its function in coordinating the whole body. First, the whole body is prepared to work as one by co-contracting the components of the inner unit (i.e., diaphragm, multifidus, transversus abdominis muscles, and pelvic-floor muscles). The swimmers were trained to move their ribs and the linkage of the rib cage voluntarily when moving the whole body. By the swimmers self-checking the movement of their ribs by watching a video during the movement and repeating self-correction with attention (**Fig. 3**), it became possible to move involuntarily in the correct manner.

3. Actual coaching

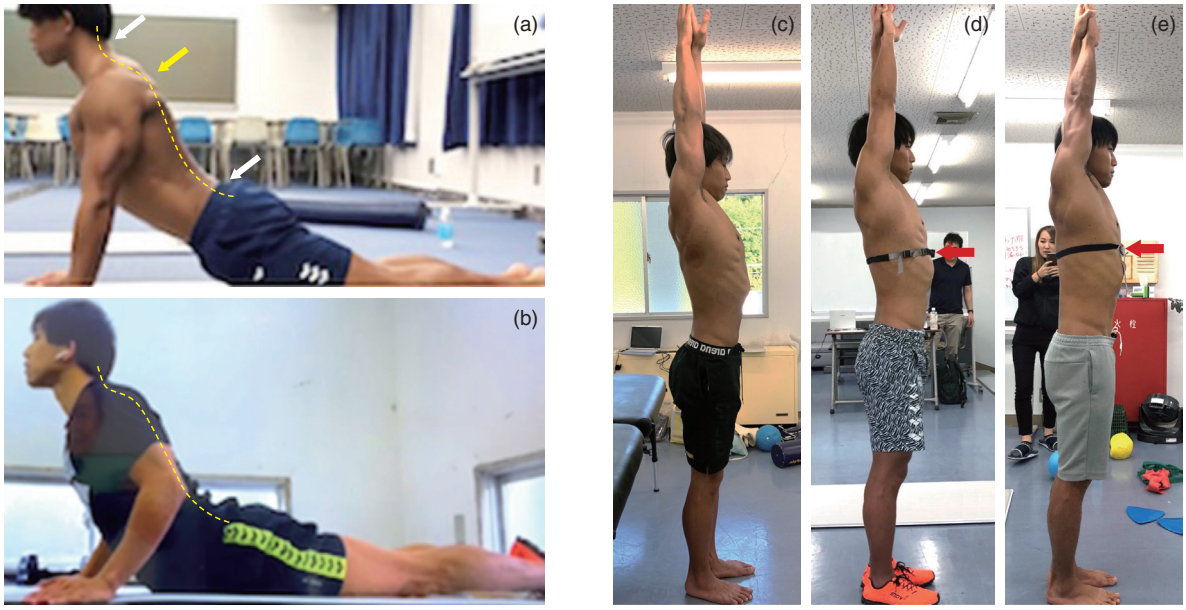
Following the step-by-step exercise plan listed below, individualized hands-on and online coaching, lasting approximately 45 minutes once every 1 to 2 weeks, was provided to the swimmers. The basic movements were first limited to those around one axis, and only one part of the body was moved to make it easier for the swimmers to become aware of it. After the movements that separate the stabilizing part (lumbar pelvis) from the ribs (thorax) were learnt, the number of moving parts was gradually increased to two or more. The number of planes and axes of movement were then increased. The swimmers increased their endurance by changing their posture while applying their body weight, performing the movements under unstable conditions, and changing the speed at which they moved.

(1) Awareness of inner unit (i.e., body axis)

The swimmers were coached to correctly understand their inner unit (i.e., pelvic-floor muscles, transversus abdominis muscles, multifidus muscles, and linked diaphragm). While maintaining the stability of the lumbar pelvis and checking their awareness of breathing and the contraction of the transversus abdominis muscles, the swimmers slowly repeated smooth movement of the hip joints. This procedure is done in supine, sitting, all-fours, and standing positions.

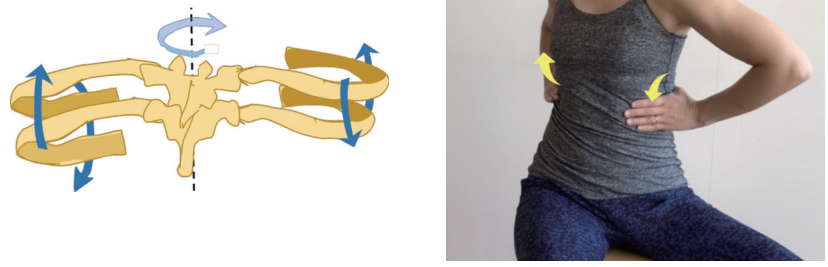
(2) Relationship between rib movement and inner unit

The swimmers were coached to understand the basic movements of their ribs (associated with thoracic-spine flexion, extension, lateral flexion, and rotation) by placing their hands on their ribs and performing self-tactile movements (i.e., self-correcting and guiding body movements). While keeping the lumbar pelvis stable, the swimmers moved their ribs



(a) Restriction of extension range of motion of the thoracic spine (yellow arrow, dotted line) and hyperextension of the cervical spine and lumbar-sacral junction (white arrow) in whole spine extension in prone (push up)
(b) Condition improved by regular conditioning
(c), (d) Limited range of motion of spine extension in streamline position
(e) Improved state
Red arrows in (d) and (e) indicate measurement of chest girth with the multi-sensor belt.

Fig. 2. Deterioration and improvement in functionality of the thorax.



(a) Linkage structure between thoracic spine and pair of ribs. Movement of the thoracic spine and rib rings during rotation of spinal column. Rib rings rotate in the opposite direction.

(b) In the sitting position, the swimmer fixes the pelvis and lumbar spine and places fingers on the ribs on both sides to feel the movement of the rib rings during rotation of the spinal column.

Fig. 3. Concept of coaching.

while maintaining awareness of their breathing and understanding the relationship of that movement to the area of the rib cage into which the thorax expands (**Fig. 4**).

(3) Consciously move the spine, shoulder joints, hip joints, and other parts of the body in a state of whole body connection

The swimmers were instructed to maintain a state

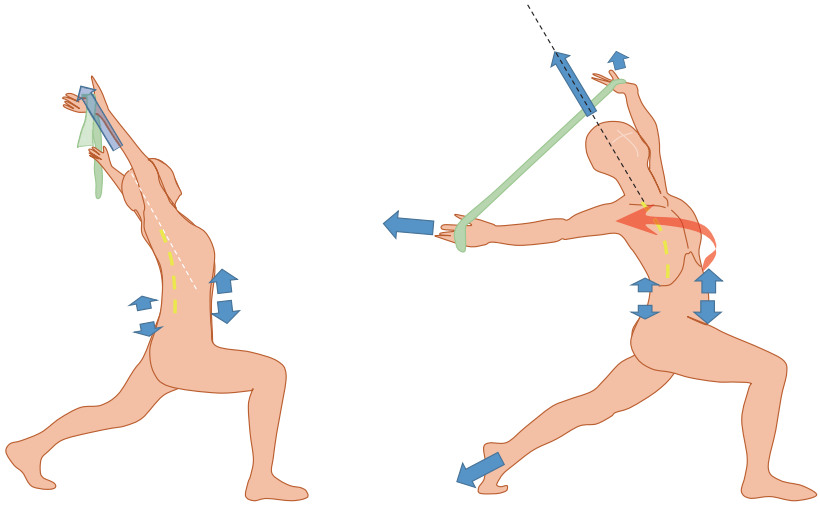
Fig. 4. In the supine position, the swimmer fixes the pelvis, places fingers on the ribs on both sides, and moves the thoracic spine to feel the movement of the ribs while consciously breathing.

Fig. 5. The swimmer moves the rib cage (ribs and thoracic spine) while maintaining a state of "whole body connection" on the mat.

of *whole body connection* (a state in which awareness of the inner unit, hip-joint stability, shoulder-blade stability, abdominal and back muscles, etc. are all connected and controlled) and to link the whole body while maintaining awareness of rib movement (**Figs. 5** and **6**).

4. Video evaluation of thorax function and biometric measurement using wearable sensors

We created a multi-sensor belt (for research) equipped with hitoe™ electrodes for myoelectric measurement, 9-axis motion sensors (i.e., 3-axis acceleration, 3-axis gyro, and 3-axis orientation measurements), and a stretch sensor for measuring expansion and contraction of the chest girth during



(a) Extension of thoracic spine
The pelvis is stabilized, centrifugal contraction of the psoas major muscle and rib movement are induced, and the swimmer is made aware of thoracic extension. Blue arrows indicate the directions of "eccentric contraction" of muscles.

(b) Application of extension + rotation
The lumbar spine is not extended, but the intervertebral space is widened. Blue arrows indicate the directions of "eccentric contraction" of longitudinal muscles. Red arrow represents the direction of thoracic rotation (upward twisting).

Fig. 6. Lunge with non-stretch straps.

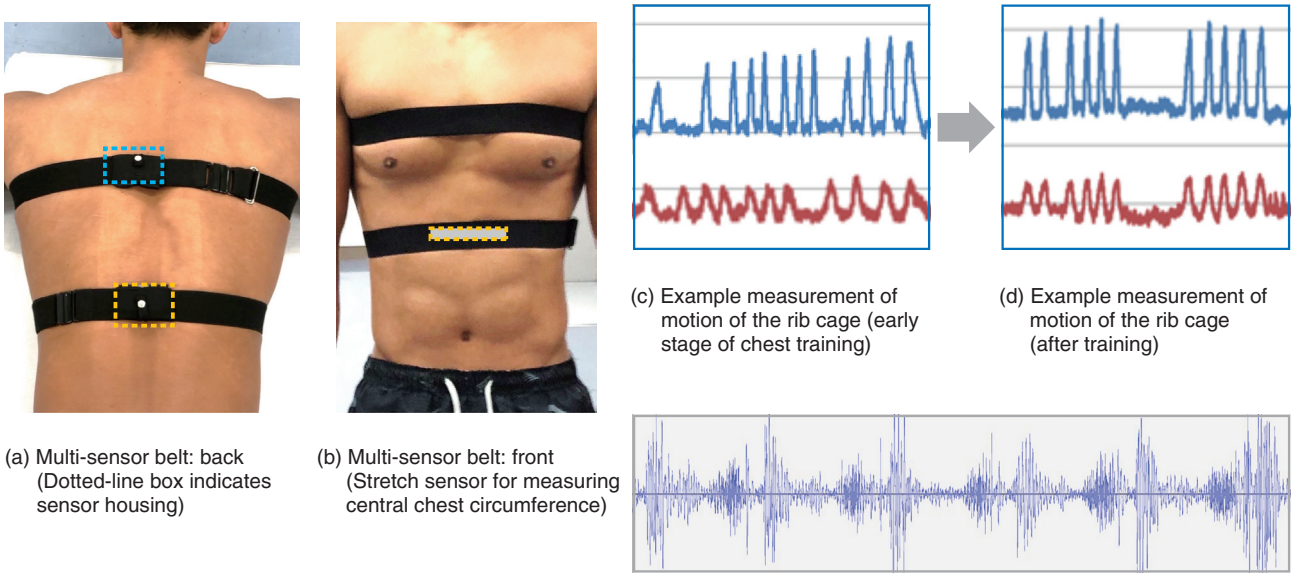
respiration for measuring the swimmers' bodies. The data were transferred to the smartphone via BLE (Bluetooth Low Energy) and stored in the internal memory of the smartphone (**Fig. 7**). A dedicated hitoe™ belt (waterproof and multi-sensor type; for research) was used for underwater measurement of electromyograms, heart rate, and motion (Fig. 7(e)).

5. Evaluation of thorax function with swimmers in streamline position

Ease of breathing and arm raising were evaluated on a five-point self-assessment scale before and after the above-stated exercise plan. The degree of thorax expansion during respiration in the streamline position was also measured (i.e., continuous measurement of chest girth) by using the stretch sensor of the multi-sensor belt. The changes in the streamline position before and after the exercise were photographed from three directions and evaluated. The results indicate that the ease of breathing and arm raising increased by one to two levels (on a five-point self-assessment scale) after the planned exercise. Over the course of the postural changes, we found that initially, the swimmers had a tendency toward lumber hyperextension and extension of the thoracolumbar junction; however, this tendency also gradually improved (**Figs. 2(b)** and **(e)**).

6. Online coaching using video conferencing via smartphones

Due to the novel coronavirus (COVID-19) pandemic, the international sporting event due to be held in 2020 was postponed for one year. Accordingly, to prevent the spread of COVID-19 infections, access to Chukyo University, the main training site, and swimming facilities where training camps were held was restricted. To continue regular conditioning of the swimmers, we switched from on-site hands-on instruction to online coaching via a smartphone video-conferencing system. Since the swimmers had already mastered the basic movements through hands-on coaching, we gradually upgraded the adjustments and techniques used in the online instruction by (i) determining the current state of the swimmers through dialogue and the above-mentioned evaluation indicators as well as their body movements from the video images and (ii) adjusting the coaching content accordingly. Conditioning through online coaching was helped by the motivation of the swimmers and continued until the main competition



(a) Multi-sensor belt: back (Dotted-line box indicates sensor housing)

(b) Multi-sensor belt: front (Stretch sensor for measuring central chest circumference)

(c) Example measurement of motion of the rib cage (early stage of chest training)

(d) Example measurement of motion of the rib cage (after training)

(e) Example of electromyogram of the quadriceps muscle acquired with the hitoe™ belt for underwater measurement

Fig. 7. Example measurements with a sensor for measuring multifunctional motion (for chest).

in 2021 over a period that included overseas expeditions and training camps.

7. Discussion

Swimmers must maintain a streamline position to ensure lower resistance while moving through the water. As well as achieving sufficient range of motion of the shoulder joint, they must satisfy two requirements: (i) coordination of many muscles involved in thoracic extension, especially control of the small muscle groups (local muscles) at the deep segmental level of the spinal column (such as multifidus and rotator muscles) and (ii) sufficient elongation of the peri-scapula muscles, erector spinae muscles, breathing-related muscles, latissimus-dorsi muscles, abdominal oblique muscles, etc. (collectively known as the global muscles).

It has been suggested that as a result of high-intensity training, stress concentrates on relatively fragile structures and tissues through fatigue or injury. This concentration of stress then triggers local inflammation and pain, which creates a vicious cycle through the neuromuscular and vascular control systems, resulting in chronic pain and impaired functions. Regular conditioning focused on the rib cage can effectively bring out the natural functions of this area while making the swimmer aware of the connection of the whole body and their overall condition.

Takeshi Kawamoto set a new personal best in the 50-m butterfly at the Japan Championships and competed as a member of the 100-m-butterfly team at the target international sporting event in 2021. Ai Soma won the 50-m and 100-m butterfly at the Japan Short Course Championships. Knowing that athletes need to strengthen their physical, technical, and mental strength while coping with fatigue and potential dysfunction associated with rigorous training, we will continue to support them by enhancing recovery and conditioning techniques.

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Yumiko Hamaguchi
Director of Springs Pilates Inc.

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Network Construction × Wearable Heat Countermeasures

Kazuhiko Takagahara, Hiroyoshi Togo, and Naomi Nagai

Abstract

One of NTT's key roles in the 2021 international sporting event held in Japan was the construction of a large-scale network during the hot and humid Tokyo summer to provide a stable and secure communication environment. We built and installed a health-management system that involves wearable biological/environmental sensors to prevent heat-related health issues and enable construction work to be carried out more safely.

Keywords: heat countermeasures, wearable sensors, health management

1. Background and objectives

The numbers of deaths and emergency room visits caused by heat stroke have been increasing due to climate change and other factors, and this has become a major issue for society in general. According to a survey by the Fire and Disaster Management Agency of the Ministry of Internal Affairs and Communications of Japan, 46,299 people required emergency hospital treatment for heat stroke between June 1 and October 3, 2021, and according to the Ministry of Health, Labour and Welfare of Japan, there were 829 cases of heat stroke at the workplace in 2020 resulting in an absence of four days or more, of which 22 cases resulted in fatalities. The Ministry of Health, Labour and Welfare and other organizations published guidelines and manuals on how to prevent heat stroke in the workplace.

At NTT, we developed a method for implementing heat-related health issue prevention measures for individual workers by estimating health risks on the basis of vital-sign data and issuing alerts when necessary. To verify the effectiveness of this method, we conducted a demonstration experiment with the cooperation of NTT EAST. We monitored 49 construction workers in the Tokyo, Kanagawa, and Hokkaido areas for a total of 834 person-days in August and September 2020. We asked the construction workers to fill out questionnaires about how hot or cool they felt while working, and we were able to confirm the relationship between their estimated internal-body-temperature fluctuations and whether they felt hot or cool.

2. Method for estimating health risks and issuing alerts

Our method estimates the risk of heat-related health issues by means of logic for estimating changes in internal body temperature,[*1] which was created in a new joint research project with Nagoya Institute of Technology (NIT). This logic is based on an original program developed by NIT that combines electromagnetic field analysis and thermal analysis by taking into account factors such as a person's internal-body-temperature regulation, clothing, and level of activity. In a joint experiment among NTT, Yokohama National University, Shigakkan University, and NIT, we conducted clinical experiments in the artificial weather room at Shigakkan University that confirmed the applicability of the logic for estimating internal-body-temperature fluctuations.[*2] On the basis of the theory of thermal and exercise physiology, we also

*1 Since the method described here is not a medical procedure, the expression "internal body temperature" is used instead of "core temperature."

*2 Shigakkan University Research Ethics Review Committee: Accession number 124.

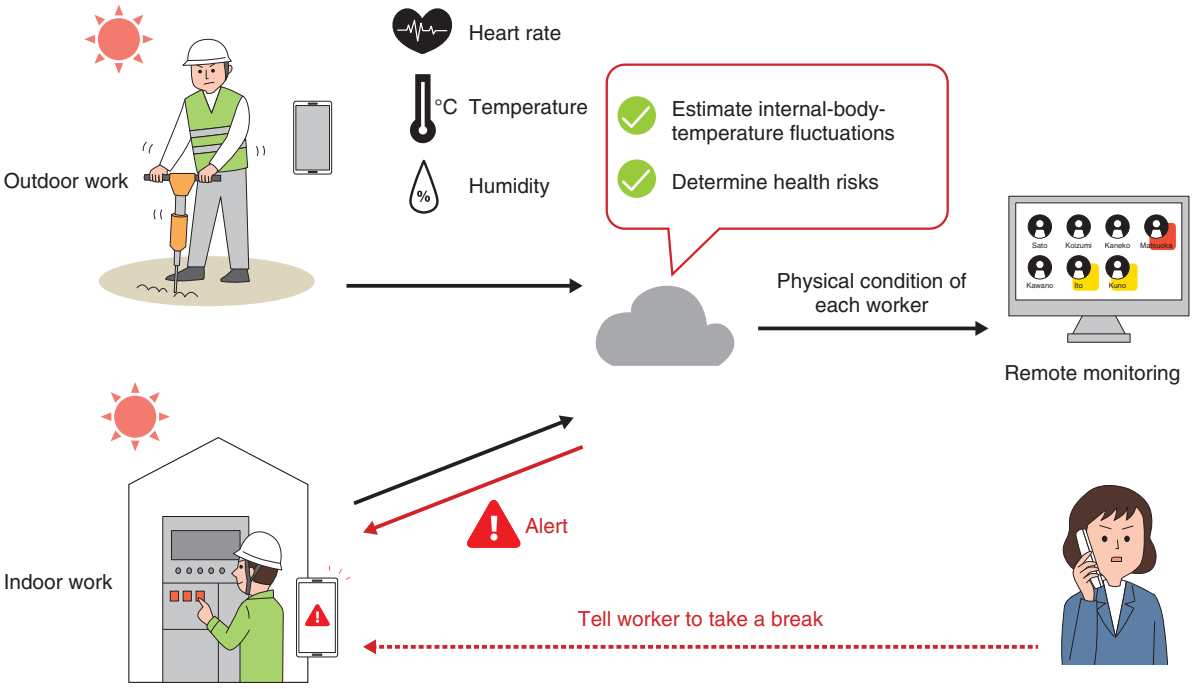

Fig. 1. Flow of our health-risk estimation method.

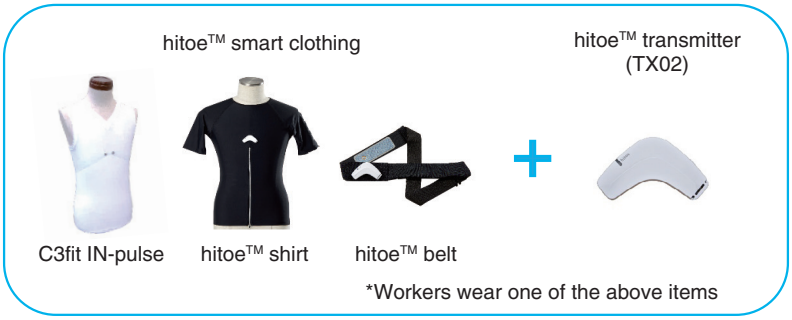

Fig. 2. Wearable biological/environmental sensors.

created criteria for using internal-body-temperature fluctuations and other factors to trigger alerts (**Fig. 1**). Together, the estimation logic and alert criteria constitute our method for estimating health risks.

3. Wearable biological/environmental sensors

Wearable biological/environmental sensors[*3] are used to acquire an individual's heart rate, temperature inside clothing, and humidity. In addition to a TX02 transmitter marketed by NTT TechnoCross based on wearable biological/environmental sensors developed by NTT Device Innovation Center, we use either a piece of C3fit IN-pulse clothing made by GOLDWIN Inc. or a hitoe™ shirt or belt developed by Toray Industries, Inc. [1] (**Fig. 2**) to monitor various parameters including the wearer's heart rate, R-R interval, step count, and upper-body tilt.

*3 This sensor is not a medical device. hitoe™ is a functional fabric developed by Toray Industries, Inc. and NTT to collect biomedical signals, which are weak electrical signals emitted from the body, with little burden on the wearer. The functional fabric hitoe™ is a trademark of both companies.

4. Operation support for the 2021 international sporting event

By applying this method to construction work at venues used for the international sporting event in 2021, we were able to prevent heat-related health issues among construction workers, enabling the event to be held safely and securely. From May 24 to September 30, 2021, the health-management system applying this method was used by a total of twelve construction workers at two sites [2]. In addition to remotely monitoring health risks, the system also issued appropriate alerts to the construction workers and their site managers based on the above-mentioned alert criteria. A total of ten alerts were issued during this period. In each case, the site manager was able to check the physical condition of the affected construction worker and take measures such as encouraging them to take a break if necessary. As a result, we were able to prevent the occurrence of health issues, such as heat stroke, among the construction workers.

5. Summary

At NTT, we will continue to deepen our knowledge by introducing this method to more sites with the aim of ensuring that large-scale events around the world can be held safely and securely.

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Venue-management Staff × CUzo

Takahiro Kusabuka, Yuichi Maki, Takuya Gouda, Akira Suzuki, Masaya Tamaru, and Takuya Indo

Abstract

For the 2021 international sporting event in Tokyo, NTT brought out a feature-distribution communication technology called CUzo and a mobile device with a transparent display called CUzo Card. This article describes our work on this project, which sought to enhance the hospitality afforded at venues by providing venue staff with information and communication technology tools to support the guidance they provide to visitors, and the technology used in this project.

Keywords: CUzo, transparent displays, AR

1. Overview

The purpose of this project was to improve the hospitality provided at venues by using information and communication technology (ICT) to support the efforts of venue-management staff who provide guidance to visitors including athletes and spectators. It is commonplace for people to use smartphones and tablets when dealing with inquiries, but they tend to do so while constantly looking at the screen of their device. This makes it difficult to properly engage in communication with other people while understanding their intentions based on non-verbal cues such as facial expressions and gestures. For this project, we used a system consisting of a feature-distribution communication technology called CUzo and handheld device called CUzo Card with a transparent display based on this technology (**Fig. 1**, **Table 1**) with which we implemented a communication style whereby venue-management staff could provide visitors with guidance while observing visitor expressions.

In 2021, this system was used at the international sporting event in Tokyo and was provided with applications to support face-to-face translation (**Fig. 2**) and facility guidance (**Fig. 3**). In face-to-face translation, the CUzo Card displays the translated content of a conversation in a manner similar to subtitles, allowing two people to have a conversation while watching the other person's facial expressions and gestures at the same time. When guiding visitors at a facility, this system can also be used to add visual annotations to

Front Back

Fig. 1. A CUzo Card.

Table 1. CUzo Card specifications.

Item	Specifications	Remarks
Size	82×157×20 mm	Thinnest part: 8 mm, thickest part 22 mm
Weight	198 g	Including battery

Fig. 2. Using the face-to-face translation app.

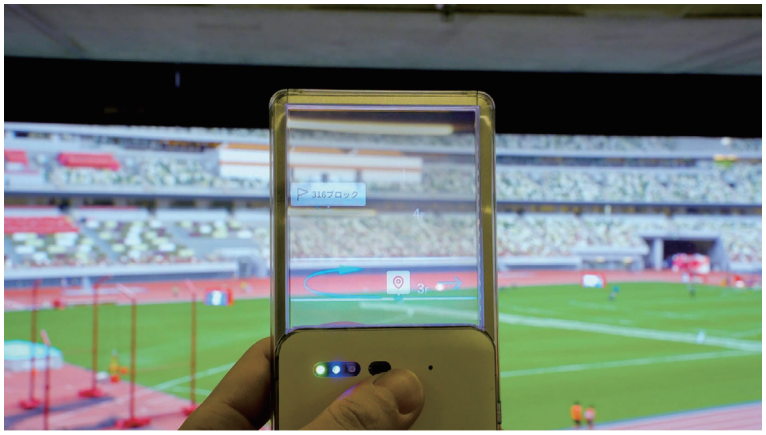


Fig. 3. Using the facility guidance app.

the user's actual surroundings. However, the event had to be held without spectators due to the COVID-19 pandemic, but the system was nevertheless used by approximately 250 venue-management staff to support attendees including event officials and athletes at three venues in Tokyo and the surrounding regions for a total of 28 days.

2. Applications

2.1 Facility guidance

When venue-management staff are showing visitors the way to their seats and on-site facilities, they can provide clear guidance by holding up the CUzo Card to provide annotations on the visitor's actual surroundings, including the location of the facility and the route to their destination.

(a) Face-to-face translation (b) Side-by-side translation

Fig. 4. Screenshot of the face-to-face translation app.

Previously, it would have been necessary to go through the complicated procedure of searching for the target facility on the basis of the information confirmed from a flat map while comparing this information with the actual scenery then rebuilding a mental picture of the route. Some venues do not have signs or facilities that can serve as landmarks, and even if explanations are attempted using descriptive words such as "the white sign," this can still lead to difficulties where smooth guidance is not possible when both parties understand these words as referring to different landmarks.

CUzo can solve this problem by superimposing annotations on the user's actual surroundings so that they can be seamlessly guided through the facility. In this project, we prepared guides to show people to their seats at sports events, and to other facilities such as restaurants, stores, toilets, multi-purpose (barrier-free) toilets, prayer rooms, lounges, medical offices, and automated external defibrillators.

2.2 Face-to-face translation

Although smartphone translation functions can be used to handle multiple languages, these functions are not geared toward face-to-face conversations, but it is assumed that both parties in a conversation are speaking while checking their smartphones for the translated results. As a result, they end up being glued their phones and more likely overlook the other person's facial expressions and gestures, which are regarded in conventional customer service as being important for understanding what someone is really trying to say. To address this issue, we designed an interactive system that allows users to view information while looking at the other person's facial expressions through a transparent display. This system is used by holding up the display between the two participants in a conversation. When one of them speaks, their words are translated into subtitles that are displayed where the other person can see the speaker's facial expressions and gestures together with the content of their speech (**Fig. 4(a)**). This system supported eight languages: Japanese, English, Spanish, French, Portuguese, Chinese (traditional and simplified), and Korean.

Due to the COVID-19 pandemic, it was felt that people might be unwilling to engage in face-to-face conversations, so we prepared the screen design shown in **Fig. 4(b)** to enable people to converse in a side-to-side manner without having to flip the screen around. Users can switch between the two screen designs at the press of a button, allowing the system to respond flexibly.

3. CUzo feature-distribution communication technology and the CUzo Card

The CUzo feature-distribution communication technology allows high-performance services to be accessed through simple devices by using communication to link up with distributed functions deployed on a network. By keeping the devices simple, we were able to address issues that can degrade the user experience, such as lack of responsivity when the device is subject to increased processing loads, and we were also able to improve the device's battery lifetime and reduce initial deployment cost. The CUzo Card is a compact and lightweight device

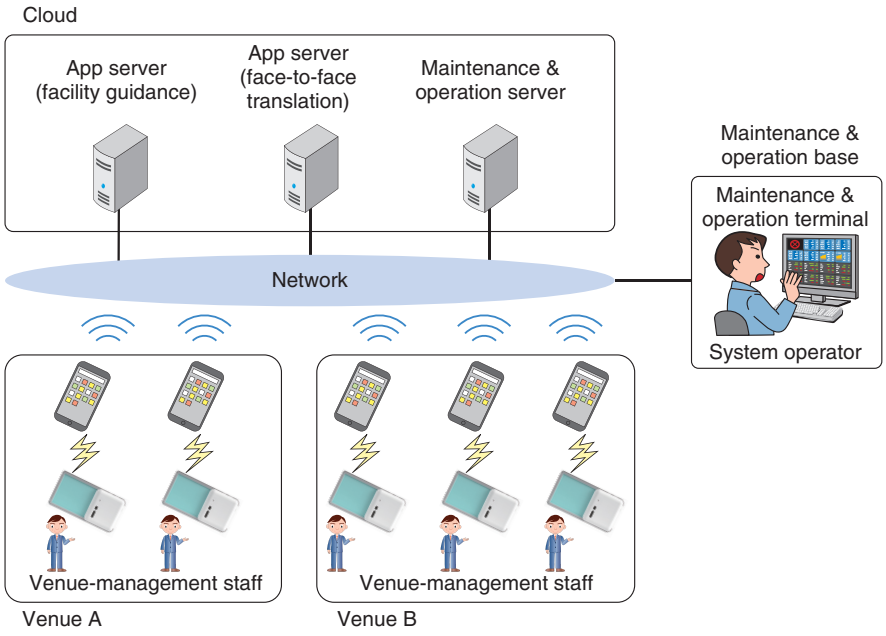


Fig. 5. System configuration.

based on CUzo, incorporating the latest transparent display technology. Since the CUzo Card has a transparent display, users can view information from both sides of the display while looking through it at their actual surroundings.

4. System

The system we provided for this project is shown in **Fig. 5**. Venue-management staff carry CUzo Cards on neck straps and can assist visitors by communicating with them via facility guidance and face-to-face translation apps. The app server runs on the cloud, and the CUzo Card connects to this server via a smartphone over a Bluetooth® connection.

5. Results

Since the international sporting event went ahead in 2021 without any spectators, only the face-to-face translation function was used. However, the CUzo Card was widely used for guiding foreign athletes and staff. Over a 28-day period, approximately 3500 translations were carried out by approximately 250 venue-management staff members at three venues. The system received favorable responses from users, who not only thought it looked cool but also appreciated being able to see who they were speaking to. This was due to the attractive and convenient design of the device based around a transparent display, providing users with a tool that allowed them to converse more naturally with other people while observing their expressions.

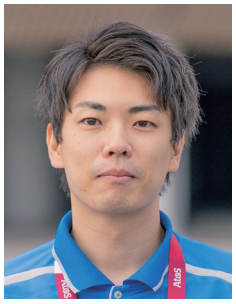
Users also found the device easy to operate and use, confirming the utility of our user-experience design of enabling people to use the system without disrupting actual work situations. However, some venue-management staff members who used the system in direct sunlight said that it was sometimes difficult to see the screen, so we will need to consider the characteristics of the display when used outdoors.

Regarding the translation function, some users said they were glad to be able to access other language pairs besides Japanese and English, and the system was welcomed by users who had few staff members capable of speaking languages such as French or Spanish. It was also pointed out that the speech-recognition results were sometimes inaccurate, and that the translated results sometimes took quite a while to appear, highlighting the need for improvements to the speech-recognition/translation engine performance and the bandwidth of the local network through which the devices were connected.

6. Summary

By applying our CUzo feature-distribution communication technology and our CUzo Card device with a transparent display for providing guidance for visitors to venues used during the 2021 international sporting event, we were able to provide a system that allows this sort of work to be performed more smoothly. This system is expected to be useful in a wide variety of customer-facing scenarios. Examples include public transport facilities such as train stations and airports, public amenities, and tourist facilities. Although in this case we asked the venue-management staff to use the system, the fact that they found it so easy to use suggests that CUzo Card could also be carried by visitors and tourists while travelling or when visiting places such as art galleries and museums.

In the future, we intend to continue with our ICT research and development to explore new experiences at places where people and information come into contact.



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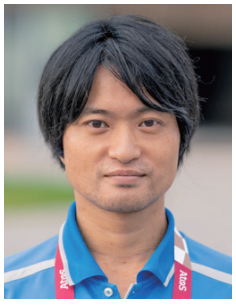

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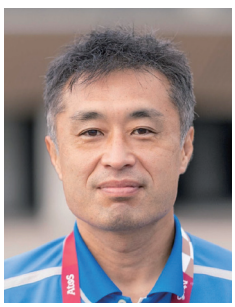

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Barrier-free Route Guidance × MaPiece®

Yusuke Ichikawa, Hirofumi Abe, Tatsuaki Ito, Shunsuke Konagai, Satoshi Sakuma, Satoshi Fukada, and Shingo Kinoshita

Abstract

NTT developed Japan Walk Guide, a barrier-free route-guidance application for wheelchair users and other people with limited mobility. Japan Walk Guide provides one-stop barrier-free route information, ranging from public transportation to walking routes, mainly based on barrier-free information collected by volunteers. This article discusses an evaluation by wheelchair users of Japan Walk Guide launched during the international sporting event held in Japan in 2021.

Keywords: barrier-free, mobility support, walking-space network

1. Overview

We want wheelchair users to be able to move around freely and enjoy watching sports. About 1900 volunteers gathered under the auspices of the All Japan Business Committee to collect barrier-free information with the aim of creating a society in which everyone can live comfortably without barriers. The information was collected over a wide area of Japan, from Sapporo, Hokkaido Prefecture in northern Japan, to Izu, Shizuoka Prefecture in central Japan, and covered 41 sports stadiums, including the Japan National Stadium (**Fig. 1**), and 98 stations nearest those venues. NTT has been supporting the collection of barrier-free information not only from volunteers but also from a technical standpoint by providing MaPiece®, a barrier-free information and communication technology developed by NTT laboratories.

The 2021 international sporting event held in Japan drew worldwide attention to barrier-free initiatives. Through this event, NTT aimed to further expand the culture of a cooperative society through citizen participation by promoting the efforts of volunteers to collect barrier-free information. To aid our efforts, we developed a barrier-free route-guidance service for wheelchair users, called Japan Walk Guide, covering the Japan National Stadium and other sports venues. Barrier-free information used in this service was collected by the All Japan Business Committee and Ministry of Land, Infrastructure, Transport and Tourism. Japan Walk Guide was released by the All Japan Business Committee for spectators and officials watching the event from July 13, 2021 until September 5, 2021, when the target event ended. A photograph of a wheelchair user using the app is shown in **Fig. 2**.

2. Japan Walk Guide

2.1 Service design of Japan Walk Guide

When we interviewed wheelchair users when we were designing Japan Walk Guide, we found that they all felt anxious about whether they could get to event sites by public transportation and had to looked up a great deal of information before going out.

Responding to concerns such as “Is there an elevator at the station I use?”, “Is the road from the station to the venue flat?”, and “Is there a wheelchair-accessible restroom at the station or along the walking route?”, wheelchair users must meticulously check various services, such as websites of event organizers

Fig. 1. Map of the venues where information about the surrounding area was collected.

Fig. 2. A wheelchair user using Japan Walk Guide.

and transportation companies, map apps, and street-photo provision sites, which has been a barrier to wheelchair users.

Accordingly, Japan Walk Guide was designed as a service providing necessary information—such as public transport-transfer information from the station closest to the departure point to the station closest to the venue, information on barrier-free walking routes from the station closest to the venue to the venue, and information on surrounding facilities that can be used by wheelchair users such as multi-functional toilets and rest areas, in a one-stop manner.

Considering the concept that we want people to enjoy going out without anxiety, we adopted a graphical design that creates a sense of enjoyment while being creative in the use of colors and illustrations in the design of the screen (see **Fig. 3** "(1) Start page" for a screenshot of the key design).

Following the postponement of the target sporting event due to the novel coronavirus (COVID-19) pandemic, we conducted more interviews with wheelchair users to investigate any change in their sense of values concerning their mobility as a result of the pandemic. We learned that wheelchair users have always tried to avoid congestion; however, during the pandemic, their need to avoid congestion has become even stronger. With that result in mind, we added a function to Japan Walk Guide that provides information on station congestion so that wheelchair users can move around with peace of mind by using stations when they are less crowded.

(1) Start page (2) Entire-route search (3) Walking-route guidance (4) Surrounding information (5) Station-congestion information

Fig. 3. Japan Walk Guide.

2.2 Details of Japan Walk Guide

Implemented as a web application, Japan Walk Guide can be used instantly by following a URL (uniform resource locator) link that is read via a QR code without the need to install a native application. It was implemented in this manner because attendees at sporting events would probably not use a dedicated app because of the high psychological barrier of installing it just for a short-lived event. As a responsive service, the app can be used to either gather information in advance on a personal computer at home or check information on a smartphone while on the move. The details of each function of the app, along with screen transitions when using the app, are described below.

(1) Entire-route search considering barrier-free walking routes

Clicking the *Start* button on the start screen takes the user to the search screen that includes public transportation for the entire route. The search for transfers on public transportation is linked with the "RakuRaku Odekake-net" (supported by the Nippon Foundation) provided by the Foundation for Promoting Personal Mobility and Ecological Transportation (Eco-Mo Foundation). The RakuRaku Odekake-net is a service that provides barrier-free information (such as barrier-free facilities in stations and transfer information) for the elderly and disabled in an integrated manner. It is operated by the Eco-Mo Foundation and uses information about barrier-free transportation collected from transportation operators and facility managers throughout Japan [1].

(2) Walking-route guidance

In addition to the public-transportation route search described in (1) above, the app also displays barrier-free route information covering the walking section from the station to the target stadium. This function allows the user to (i) specify the target stadium as the destination or departure point and (ii) search the entire route in consideration of barrier-free information for the walking route (Fig. 3(2)). The barrier-free route is based on the "Transportation Plan V2" [2] (published by the Bureau of Olympic and Paralympic Games Tokyo 2020 Preparation of the Tokyo Metropolitan Government) combined with barrier-free information collected by volunteers from the All Japan Business Committee. As well as showing the barrier-free route, it provides information about the route (such as slopes and steps) along with photos of the area collected by volunteers from the Committee. With this information, users can confirm in advance whether the route is passable in accordance with the degree of their disability (Fig. 3(3)).

(3) Information about the surroundings

Clicking the *Surroundings map* button on the walking-route guidance screen switches to the *surrounding information* screen. In addition to viewing information about the route between the venue and nearest station, the user can also refer to information about nearby wheelchair-friendly facilities such as multi-functional toilets, information centers, and rest areas. At the same time, the surrounding walkways are displayed in three different colors (green, yellow, and red) in ascending degree of barrier to mobility.

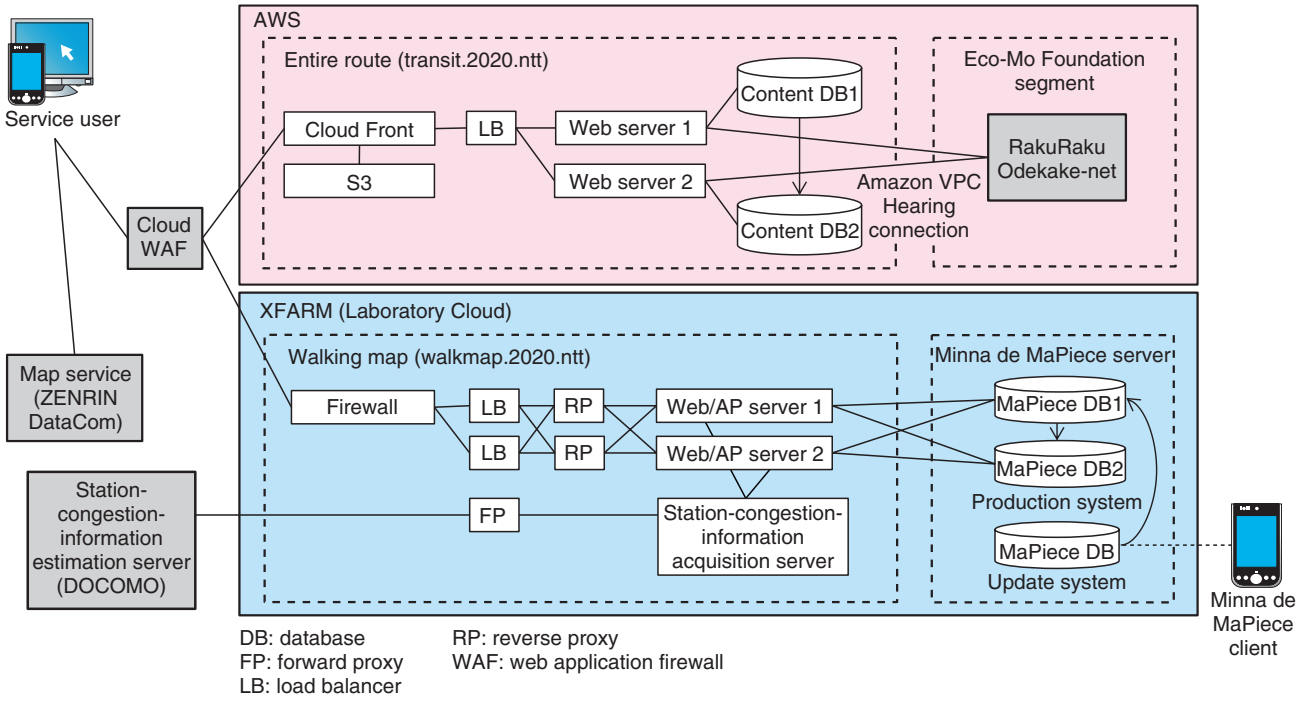

Fig. 4. Schematic of Japan Walk Guide system (omitting staging environment).

By clicking on a particular walkway, the user then can confirm its slope and width displayed in conjunction with photographs of the walkway. If the user wants to go to a facility that is in the vicinity but off the route between the venue and nearest station, they can check the best route that matches their particular disability characteristics. The app also has a function that allows users to correct errors in the barrier-free information. If the user finds an error in the barrier-free information, they can report it using the "○" or "×" button and request a volunteer to correct the information (Fig. 3(4)). Thanks to the cooperation of users and volunteers, it became possible to update the information during the service period, thereby creating a more-accurate barrier-free map.

(4) Information about congestion at stations

Wheelchair users find it difficult to move around a station and board a train when the station is crowded. As mentioned above, the COVID-19 pandemic has further strengthened the need to avoid congestion. For wheelchair users to be able to go out without anxiety, we added a function that displays information about expected congestion at the station nearest the venue so that wheelchair users can avoid congested areas (Fig. 3(5)).

The station-congestion information is provided through cooperation with railway companies (namely, Tokyo Metro, East Japan Railway, and Tokyo Waterfront Area Rapid Transit) by linking with station-congestion prediction technology (developed by NTT DOCOMO), which uses artificial intelligence and demographic information based on cell-phone base-station operation information. By modeling the relationship among the estimated number of passengers at a station during past events and the population-distribution data and weather data at that time, this technology can predict the number of passengers at a station at 10-minute intervals into the future (for up to 90 minutes) from the most-recent population distribution, weather, and event-schedule data. The population-distribution data are estimated using a service called Mobile Spatial Statistics® Domestic Population Distribution Statistics (real-time version) [3]. Since this service can obtain past (one hour ago at latest) population-distribution data, it is possible to reflect the latest congestion situation and predict congestion with high accuracy [4].

2.3 System configuration

The system configuration of Japan Walk Guide is shown in **Fig. 4**. The app is composed of two units: (i) an *entire route* unit that provides public-transportation

transfer information and (ii) a *walking map* unit that provides barrier-free information for walking routes. The transfer information is generated using the application programming interface (API) of RakuRaku Odekake-net [1]. Due to the security requirements of RakuRaku Odekake-net, it is necessary to use an Amazon Virtual Private Cloud (VPC) peering connection, so we built the entire-route unit on an Amazon Web Services (AWS) platform.

The walking routes were provided by combining the official accessible routes (official routes for people with limited mobility) to the venues described in the Transportation Plan V2 (published by the Bureau of Olympic and Paralympic Games Tokyo 2020 Preparation of the Tokyo Metropolitan Government) and barrier-free information collected by the All Japan Business Committee. The barrier-free information was created using Minna de MaPiece as a base/platform engine and superimposing it on the map service.

ZENRIN DataCom's "Itsumo NAVI API/SDK" [5] was used as the map service. The walking-map unit was built on XFARM, a cloud environment of NTT laboratories.

3. Barrier-free information and communication technology MaPiece®

To support people with limited mobility, such as the disabled and elderly, it is important to prepare barrier-free information for navigation that provides users with routes that can be taken without fail, in addition to the development of hardware such as barrier-free facilities.

In the past, municipalities commissioned experts with surveying skills to create barrier-free information on the basis of their standards. Due to the high cost of surveying, however, it was difficult to create and update the survey data frequently. Moreover, the standards differed from municipality to municipality, so it was difficult to use data across the board.

To address these issues, MaPiece® was developed to enable volunteers who do not have map-making expertise to collect barrier-free information for highly accurate navigation in accordance with the Specification for Spatial Network Model for Pedestrians formulated by the Ministry of Land, Infrastructure, Transport and Tourism [6].

To enable sustainable collection and update of barrier-free information, MaPiece® is configured as three sub-technologies: (i) Hakatte MaPiece, a field-survey tool for collecting initial information; (ii) Minna de MaPiece, which collects corrected and updated information from users when they use the service and updates the information in a social-networking manner; and (iii) Aruite MaPiece, which automatically collects road-surface information from pedestrians' smartphone sensor data by using cloud-sensing technology (**Fig. 5**).

The barrier-free information collected by volunteers using Hakatte MaPiece and Aruite MaPiece is imported for Minna de MaPiece, and through the API of Minna de MaPiece, the information from users is retrieved and reflected in the latest posted information. The updated data are compliant with the Specification for Spatial Network Model for Pedestrians and can be used for other barrier-free information services even after the Japan Walk Guide service ends.

4. Results

Table 1 lists the number of users of Japan Walk Guide from July 13, 2021 to September 5, 2021. In 2021, the international sporting event was held in Japan without spectators, and Japan Walk Guide was used by volunteer staff with impaired mobility.

Through a questionnaire and interviews, we also evaluated the experiences of five wheelchair users during the event. All five respondents answered that they would use Japan Walk Guide for finding out how to get to event sites compared with current guiding current services. Each user gave a different reason. Comments such as "road conditions to the venue are displayed accurately," "the train-information function is convenient," "various barrier information such as the slope of the walkway is posted," and "information on wheelchair-accessible toilets is useful" demonstrated the usefulness of providing information via Japan Walk Guide in conjunction with the above-mentioned information on slopes and steps based on standards provided by the Ministry of Land, Infrastructure, Transport and Tourism in a one-stop manner.

The majority of the respondents felt that the congestion information was necessary; in particular, four out of five answered that it was "necessary" or "better to have than not," indicating that the information was generally useful. Regarding a comparison of the usage rates by function, the usage rate of station-congestion information was the highest among the users who referred to the walking-route guidance screen (Table 1). However, because the target event was held without spectators, cases of congestion at

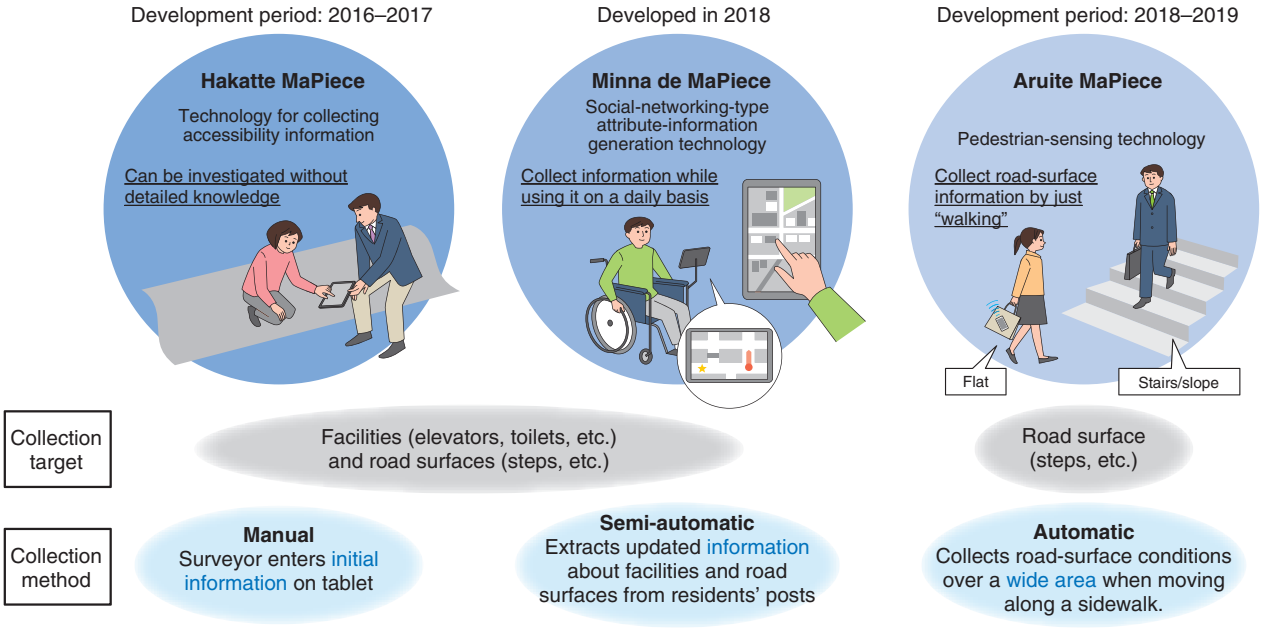

Fig. 5. Overview of three technologies comprising MaPiece®.

Table 1. Total number of users during the service-provision period.

(xx%) indicates usage ratio in relation to total number of users

Total number of users	Number of users referring to walking-route guidance	Number of users by function on the walking-route-guidance screen			
		Number of users referring to surrounding information	Number of photo-reference users	Number of users referring to road information	Number of users referring to station-congestion information
1895	982 (51.8%)	128 (6.8%)	94 (5.0%)	71 (3.7%)	210 (11.1%)

stations did not occur, so we were unable to evaluate the actual effect of the station-congestion information.

5. Concluding remarks

Due to the fact that many of the venues were not open to the public, only those involved in the event were able to use our service, and the general public was not able to experience it. Even so, the release of Japan Walk Guide at a sporting event that drew worldwide attention to barrier-free initiatives in the domestic and international press. For example, it was featured in Taiwanese web media as one of ten friendly actions that supported athletes in the "spirit of inclusion." We believe that our efforts were significant from two aspects: (i) raising awareness of the fact that ordinary people can collect barrier-free information and create barrier-free maps themselves and (ii) fostering a culture of continuously updating barrier-free maps.

The barrier-free information collected by the All Japan Business Committee will be released as open data by the Geospatial Information Center (operated by the Association for Promotion of Infrastructure Geospatial Information Distribution). We hope that the above-described recognition will be an opportunity for the barrier-free information created by the volunteers to be used in various applications and services. In the future, we will use our efforts for the event as a first step to promote research and development of new inclusive services on the basis of the evaluation results through the provision of applications. We will also contribute to the creation of an inclusive society where people with disabilities can live independently with peace of mind.

Acknowledgments

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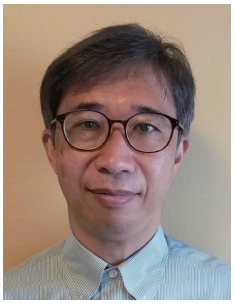

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He has been in his current position since 2021, where he manages R&D on information and communication processing of humans based on human-centered principles.

Goalball × Ultra-realistic Communication Technology Kirari!

Kazu Miyakawa, Takuya Gouda, Yuki Yoshida, Kimitaka Tsutsumi, Kentaro Shimizu, and Takuya Indo

Abstract

NTT is promoting research and development to enable people with various physical conditions, including disabilities, to enjoy watching sports. Focusing on goalball, which is a type of parasport, this article introduces a new experience of sports watching that provides a sense of realism as if the spectators were watching the game at the competition venue. This experience is possible by using ultra-realistic communication technology called Kirari! (particularly, highly realistic sound-image localization technology) for producing stereophonic sound.

Keywords: sports viewing, ultra-realistic communication, sound-image localization

1. Overview

To create a symbiotic society through sports, we at NTT laboratories have been researching viewing methods that allow the visually impaired to enjoy sports events. The main method for the visually impaired to watch sports has been through live radio and television broadcasts. However, verbal explanations cannot effectively convey the details of an action (for example, the rhythm of a rally or impact of hitting the ball) or feeling the intensity of play [1]. The visually impaired use sensory information other than sight to watch sports. One such example is using sound. In the system described in this article (called "goalball experienced through sound"), we reproduced the acoustic space of a game of goalball, in which sound plays a leading role, through 100 speakers (**Fig. 1**) by using our ultra-realistic communication technology called Kirari!. This system enables the visually impaired to enjoy watching goalball by following the movement of the ball via sound only. This provides them with a realistic experience as if they were on the playing court.

2. Spectating experience

With "goalball experienced through sound," we created a spectator area that simulates a full-scale tournament court and enables visually impaired spectators to experience the acoustics where the players are located in front of the goal (team area) (**Fig. 2**). Two rows of 50 speakers (speaker arrays), one placed in front of and one placed behind the spectator seats, sequentially synthesize the sound of the ball bouncing and the sound of the players' movements in a manner that reflects the position of the ball on the

Fig. 1. Reproduction of an acoustic space with 100 speakers.

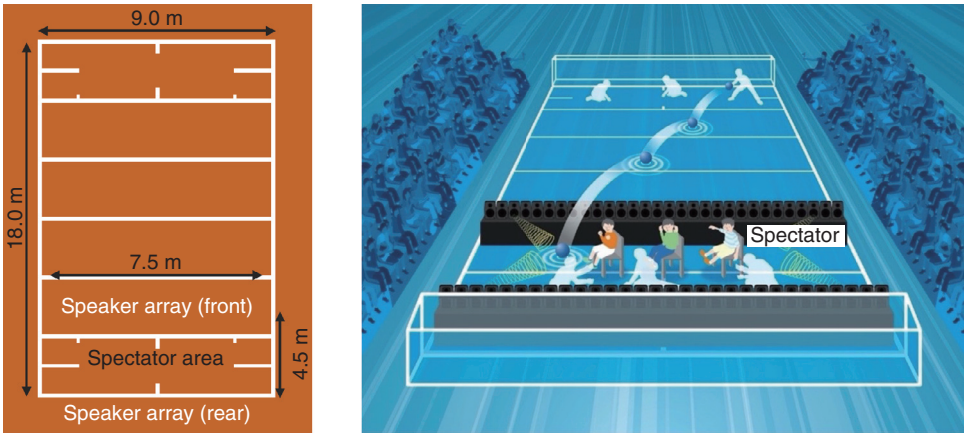

Fig. 2. Spectator area that simulates a tournament court.

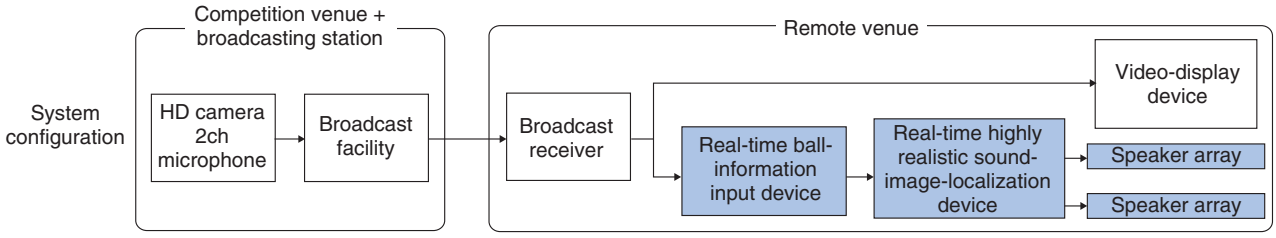

Fig. 3. Configuration of the entire system.

playing court. This setup allows the spectators to follow the movements of the players and ball by sound alone in such a way that they can experience the powerful sound of the ball as if the ball were flying towards them.

3. Technology

3.1 Highly realistic sound-image localization technology: Kirari!

Kirari! is a communication technology that enables spectators to experience watching a game as if they were in the competition venue, even if they are far from the venue [2]. With "goalball experienced through sound," we created an acoustic experience by using highly realistic sound-image localization technology, one of the technical elements of Kirari!. This technology reproduces the spatial and physical wavefronts of sound on the basis of a physical model [3]. It separates the sound collected with a single microphone at the tournament venue and reproduces it as if a specific sound were generated at an arbitrary position. A key point of this technology is a group of speakers (speaker array) closely arranged in a straight line. By adjusting the playback timing and power of the sound radiated from each speaker to focus the sound at an arbitrary position, a sound field is reproduced as if a sound source existed there.

The configuration of "goalball experienced through sound" is shown in **Fig. 3**. Due to operational constraints, we could not set up our own cameras to transmit the event, so we decided to use broadcast video. Video images of the game shot at the venue of a goalball tournament are transmitted to a remote site as broadcast waves via the broadcasting equipment of the broadcasting station. At the remote site, the position of the ball and players as well as the information about the type of ball thrown (acquired from the received broadcast-wave images) are input in real time, and an acoustic space is created on the basis of that spatio-temporal information (**Fig. 4**).

We aimed to extract the locations of the ball and players, as well as information about the type of ball thrown, from the broadcast video. However, the

Fig. 4. Real-time acoustic-space reproduction.

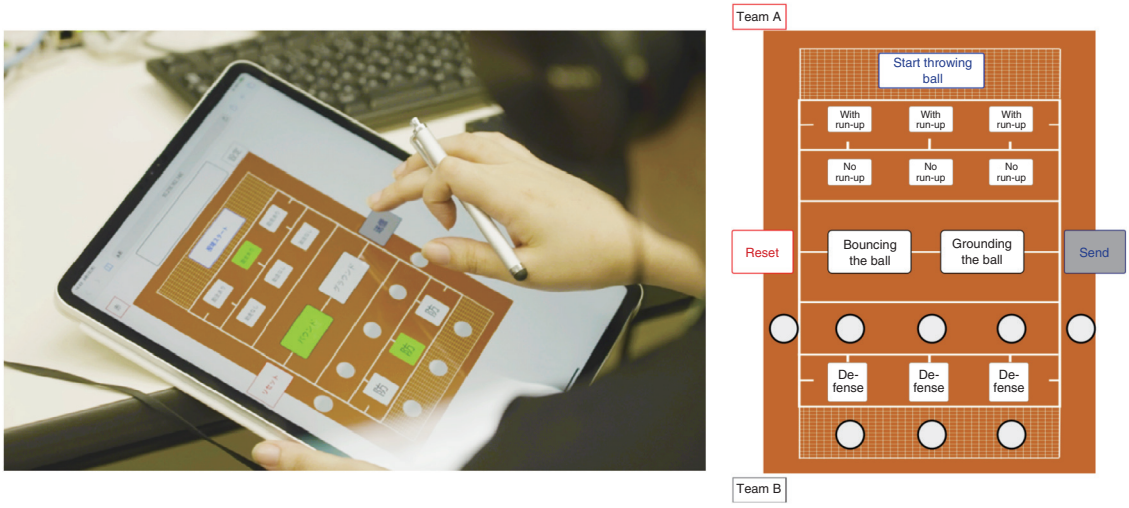

Fig. 5. Real-time input UI for ball-throwing information.

cameras and angle of view change frequently during broadcast video, so we adopted a user interface (UI) through which the ball position is input manually (**Fig. 5**). Two people, one in charge of team A and one in charge of B, each used a tablet with the UI installed to watch the broadcast video and enter the starting position and time of each team's attack, type of throw (*bouncing ball* or *ball along the ground*), and result of the throw (*blocked*, *goal*, or *out of bounds*) with the push of a button. From the input result, sound information is generated from a sound-source file of the throwing sound prepared in advance. That information is then processed using Kirari! via the network to reproduce the ball-throwing situation in real time.

3.2 Acoustic production with inclusive design

(1) Selecting sounds to localize as the sound image

To reproduce the acoustic space that the players hear on the court and allow non-players to fully experience the players' excellent sense of hearing, we used an inclusive design method, which involved goalball players and the visually impaired in the upstream design process. Specifically, we defined and created the requirements for the sound through a process of interviews, observation of ball-throwing situations, and acoustic evaluation (**Fig. 6**). This process enabled us to understand the various sounds heard on the goalball court, but distracting sounds made by the opposing team (such as the sounds made to obscure the throwing position by hitting the floor) were included but are ignored by the players. In other words, the players always search for the ball by following a series of *throwing sounds* such as the run-up sound of the player holding the ball and that of the ball hitting the floor in the manner of *a single stroke*. Accordingly, we decided to focus on the *throwing sounds* (run-up sound, ball sound, and result sound of ball throwing such as blocked shot or goal) and reproduce those sounds. That is to say, instead of trying to reproduce the acoustic space of the physical tournament venue as is, we attempted to reproduce the sounds that the players selectively perceive from the

Fig. 6. Players experiencing "goalball experienced through sound".

various sounds that they hear. By doing so, we aimed to allow non-players to experience the simulated *exceptional auditory sense of the players*.

(2) Simplification of sound-image localization

For the path of the thrown ball, the players distinguish the distance from one end of the goal to the other (9 m) in nine segments (each with width of 1 m). However, the spatial resolution of sound of non-players is not as good as that of players, so it is difficult for non-players to determine the route of the thrown ball when the sound image is localized as is. By reducing the spatial resolution in the goal direction from nine segments to three (*left*, *center*, and *right*), we improved the non-players' recognition rate of the ball position by sound.

We also created an introductory content to give a lecture on sound localization to the non-playing spectators so they could get used to sound localization. In preparation for experiencing a game, the sound of throwing the ball along various paths was localized. Non-players commented that they could gradually determine the path of the thrown ball just by listening to the sound. This suggests that listening the introductory content before the game was useful to understand the game. Therefore, by simplifying the path of the thrown ball and creating the introductory content, we were able to create a system that allows non-players to experience the sounds that the players hear during a game.

4. Results

Initially, "goalball experienced through sound" was supposed to be a spectator event at the international sporting event in 2021 for people with disabilities, but the event was cancelled to prevent the spread of COVID-19 infections. However, during a hands-on evaluation of the experience to prepare the actual event, we received high evaluations from non-players with visual impairments.

The evaluation was based on three questions: "Can you understand the state of the play," "Can you feel the texture of the goalball-like sound," and "Can you feel the power of a ball and realism." In response to these questions, the evaluators commented, "The sound texture is realistic. Reproduction of the sound of the ball going back and forth is excellent. It's like a real game!", "Unlike listening to television, I could see where the ball was coming from and going to," and "In a stadium, you hear the sound from outside the court, but this system gave me a more realistic feeling as if I was inside the court."

We also received comments such as, "It would be easier to follow the path of the ball if we could also hear the sound of the players moving with the ball" and "It would be better if we could hear the players talking so we could understand their strategies." In general, by focusing on the goalball-like sound players hear through the inclusive design method mentioned above, we were able to create an acoustic system that enables non-players to understand the state of play of a goalball game.

5. Concluding remarks

We developed a system called "goalball experienced through sound," which allows people to enjoy goalball through only sound and evaluated it in a hands-on manner with real spectators (including those with visual impairments). Initially, we planned to reproduce the sound of the ball moving on the court by using Kirari!; however, from the results of the evaluation, we realized that not only the sound of the ball moving but also the sound of the players' movements and the connection of a series of sounds are important in creating the spectator experience.

Although the spectator event at which we were planning to provide this technology was cancelled due to the COVID-19 pandemic, we plan to enable many people to experience the results of "goalball experienced through sound" in conjunction with goalball tournaments and efforts to promote parasports. We will also continue our research and development from an inclusive perspective that allows people with various physical conditions to learn the value of information and communication technology.

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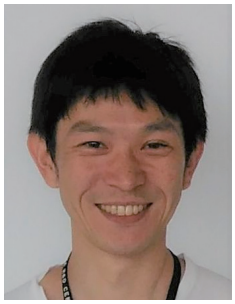

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Recent Activities of ITU-R Study Group 5 on Terrestrial Radiocommunication Systems

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Abstract

Radiocommunication systems, such as mobile communication systems, which are represented by smartphones, wireless local area network systems, which are commonly used at home and office, and fixed wireless systems, which provide flexible and resilient communication in times of disasters, play important roles in telecommunication networks. The International Telecommunication Union - Radiocommunication Sector (ITU-R), an international standardization organization, is responsible for standardization of radiocommunication systems and the frequencies they use. Recent activities of the ITU-R's Study Group 5 and its Working Parties, which deal with terrestrial radiocommunication systems, and the contributions of NTT laboratories and NTT DOCOMO to those activities, are outlined in this article.

Keywords: ITU-R, wireless LAN, IMT

1. Structure of ITU-R and jurisdiction of Study Group 5

The International Telecommunication Union - Radiocommunication Sector (ITU-R) is a sector of the ITU responsible for establishing regulations and standards for radiocommunication systems. The structure of ITU-R is illustrated in **Fig. 1**. The Study Groups (SGs) work on developing technical, operational, and procedural bases for efficient use of the radio spectrum and the geostationary-satellite orbit and develop ITU-R Recommendations and Reports. One of the missions of SGs is to conduct research necessary for discussions at the World Radiocommunication Conference (WRC), which revises the Radio Regulations (RR) providing international rules and regulations for spectrum allocation to radio services, use of satellite orbits, and administrative and operational procedures for radio stations, all of which are needed for the use of radio waves. Six SGs have been established at the ITU-R, and their compositions are shown in **Table 1** [1].

As shown in the table, SG 5 is in charge of systems and networks for fixed, mobile, radiodetermination, amateur, and amateur-satellite services, and Dr. Hiroyuki Atarashi (NTT DOCOMO) from Japan was appointed as the vice chair for the current study cycle (2019–2023) as well as the previous study cycle (2015–2019). Under SG 5, there are four Working Parties (WPs), as shown in **Table 2**, and these WPs conduct discussions on ITU-R Recommendations. As delegations of part of Japan led by an official of the Ministry of Internal Affairs and Communications, NTT laboratories have been participating in WP 5A, which is in charge of land mobile services excluding International Mobile Telecommunications (IMT)[*1], and WP 5C, which is in charge of fixed services. NTT DOCOMO has been participating in WP 5D, which is in charge of IMT.

*1 IMT: Includes 3rd-generation mobile communication systems and beyond, such as IMT-2000, IMT-Advanced, and IMT-2020 systems. IMT-2000 includes W-CDMA (Wideband Code Division Multiple Access), HSPA (High-Speed Packet Access), and LTE (Long Term Evolution) as radio interfaces. IMT-Advanced includes LTE-Advanced as a radio interface.

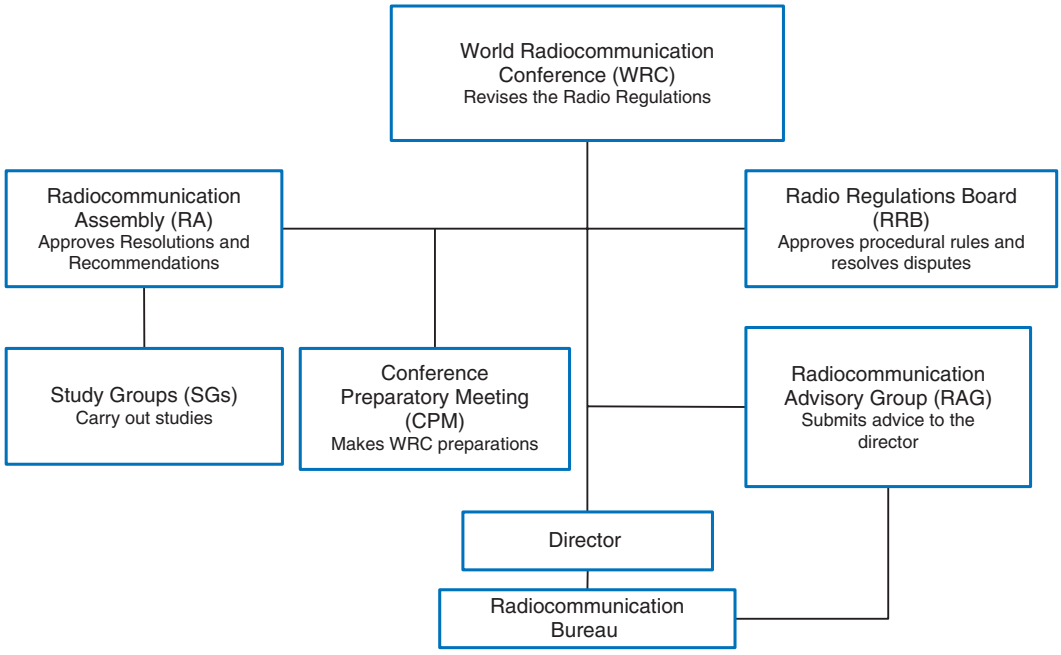

Fig. 1. Structure of ITU-R.

Table 1. Structure of ITU-R SGs.

	Scope of work
SG 1: Spectrum management	Spectrum management principles and techniques, general principles of sharing, and spectrum monitoring
SG 3: Radiowave propagation	Propagation of radio waves in ionized and non-ionized media, and the characteristics of radio noise
SG 4: Satellite services	Systems and networks for fixed-satellite, mobile-satellite, broadcasting-satellite, and radiodetermination-satellite services
SG 5: Terrestrial services	Systems and networks for fixed, mobile, radiodetermination, amateur, and amateur-satellite services
SG 6: Broadcasting service	Radiocommunication broadcasting, including vision, sound, multimedia, and data services principally intended for delivery to the general public
SG 7: Science services	Systems for space operation, space research, earth exploration and meteorology; systems for remote sensing, including passive and active sensing systems; radio astronomy; and standard frequency and time signals

2. Recent status of SG 5-related meetings

2.1 WP 5A

WP 5A is mainly responsible for land mobile services (excluding IMT). Wireless access systems including wireless local area networks (LANs), public protection and disaster relief wireless systems, railway wireless systems, intelligent transport systems (ITS), amateur radio, and new technologies for land mobile services in general are being discussed as the main target systems, and Recommendations and Reports are being developed. In this section, the status of discussions at WP 5A, focusing on the topic of

Table 2. Structure of WPs in SG 5.

	Scope of work
WP 5A	Land mobile service above 30 MHz (excluding IMT); wireless access in fixed services; amateur and amateur-satellite services
WP 5B	Maritime mobile service including Global Maritime Distress and Safety System (GMDSS); aeronautical mobile service; and radiodetermination service
WP 5C	Fixed wireless systems; HF and other systems below 30 MHz in fixed and land mobile services
WP 5D	IMT Systems

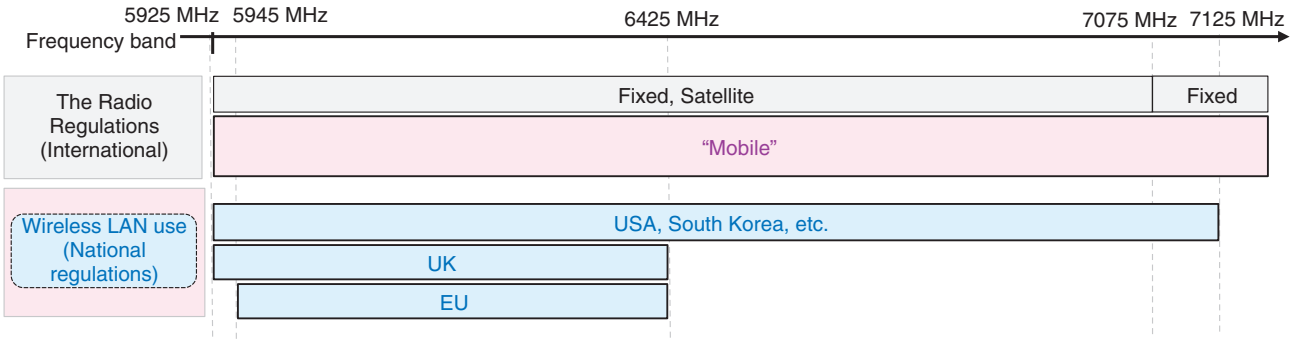

Fig. 2. International regulations regarding the use of the 6-GHz band of wireless LANs and domestic services of several countries.

wireless LANs, which is strongly related to the NTT Group's business, is explained.

2.1.1 Discussions on wireless LANs

At the 2019 World Radiocommunication Conference (WRC-19), the revision of the RR [2] was agreed to ease the restrictions on 5-GHz-band wireless LANs that allows outdoor use and higher transmission power in the 5.2-GHz band. Since WRC-19, discussions on wireless LANs have continued, and the revision of ITU-R Recommendations M.1450 and M.1801, which contain technical guidelines for wireless LANs, are being discussed. Two points for the revision are under discussion. The first is that Recommendation M.1450 includes the conditions of wireless LANs described in the RR and the national regulations of major countries; however, it does not reflect the latest modification of them, and its current version is being discussed for revision. Japan proposed to revise the texts on the basis of the recent revisions of the RR that include relaxed conditions for the 5.2-GHz band decided at WRC-19 and relevant national regulations in Japan, which were reflected in the working document for the revision of the Recommendation. It is expected that the Recommendation will be discussed further for revision. The second point of discussion is revision of the Recommendations on the basis of the recent status of wireless LANs including updates to the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standard. IEEE is proposing to update the summary section of the wireless LAN standards in Recommendations M.1450 and M.1801 to reflect the extension of the frequency band specified in IEEE 802.11ax that uses the 6-GHz band. Although this proposal is supported by the US, the UK, and other countries, China and Russia do not support it because they are concerned about interference with fixed satellites that may be caused by increased use of wireless LANs in the 6-GHz band. With regard to the frequency allocation in the RR, as shown in **Fig. 2**, the 6-GHz band is allocated to multiple services (such as fixed satellite services and other fixed services) in addition to mobile services such as wireless LANs and IMT. In several countries, wireless LANs are used in the 6-GHz band. The use of the 6-GHz band for wireless LANs is also being discussed in Japan.

2.1.2 Discussions on other systems

With regard to railway wireless systems, developing a new ITU-R Recommendation for global or regional harmonization of radio frequency between trains and trackside is being discussed. In regard to ITS, the preparation of an ITU-R Report that clarifies the requirements for wireless communications for connected automated vehicles, which are expected to be put into practical use in the future, is being discussed. Regarding the terahertz band (275 to 450 GHz), which is expected to be used for future sixth-generation mobile communication systems (6G), technologies for the coexistence of multiple different systems are being discussed.

2.2 WP 5B

The scope of WP 5B is the maritime mobile service, aeronautical mobile service, and radiodetermination service (e.g., radar), and this WP deals with many topics discussed at WRCs such as unmanned aircraft systems and sub-orbital vehicle communication systems. Although telecom operators have made few contributions to this WP, the NTT Group addresses these topics via liaison statements from other WPs that reflect the Group's opinions.

Table 3. WRC-23 Agenda Item 1.2: Candidate frequency bands for additional identification for IMT.

Frequency band	Region 1 (Europe, Russia, Arab countries, Africa)	Region 2 (North and South America)	Region 3 (Asia-Pacific region)
3300–3400 MHz	Subject of study	Subject of study	–
3600–3800 MHz	–	Subject of study	–
6425–7025 MHz	Subject of study	–	–
7025–7125 MHz	Subject of study	Subject of study	Subject of study
10,000–10,500 MHz	–	Subject of study	–

2.3 WP 5C

The scope of WP 5C is mainly fixed wireless systems (FWSs). This WP is developing ITU-R Recommendations and Reports on transport/trunking wireless network systems, fixed wireless access systems, mobile backhaul for land mobile radiocommunication, electronic news-gathering systems in the fixed service, and systems for temporary use in disaster relief.

One of the discussions in WP 5C is on the use of the high-frequency band above 92 GHz, which is expected to be used for communication systems in accordance with recent technical developments. Radio-frequency channel arrangements for FWSs (between 92 and 174.8 GHz) and the technical conditions to protect the Earth-exploration satellite service (EESS) are being studied. As a result of WRC-19, the 275-to-450-GHz band discussed at WRC-19 is now available for FWSs, and technologies for protecting EESS that are required for some of these frequency bands are being evaluated and studied. The completion of these studies is expected to facilitate high-capacity FWSs for the mobile backhaul and fronthaul in mobile networks. In addition, WP 5C has completed a revision work on Recommendations relating to parameters for FWSs for ultra-high-definition-television signal transmission used for broadcast auxiliary services.

2.4 WP 5D

At the ITU, cell-phone systems are collectively referred to as IMT, and WP 5D is responsible for this. WP 5D is responsible for developing Recommendations and Reports on the IMT radio interface, future technologies and concepts (vision) of IMT, usage of frequency bands identified for IMT (radio frequency arrangement), and frequency-sharing studies between IMT and other services. The standards for fifth-generation mobile communication systems (5G) are called IMT-2020[*2] in ITU-R, and the first version of Recommendation ITU-R M.2150, "Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-2020 (IMT-2020)" was published in February 2021. After publication of this Recommendation, development of an ITU-R Report on the trends regarding future technologies of IMT has started and aiming for completion in 2022. This ITU-R Report contains a compilation of technologies that can be applied to IMT in the future. Development of an ITU-R Recommendation on the future IMT vision for 2030 and beyond has also started and is scheduled for completion in 2023. This Recommendation is aimed to serve as a guide for the further development of IMT and will include use-case scenarios, required capabilities, and a specific development schedule for IMT in the 2030s.

In preparation for WRC-23, studies on utilization of frequencies for IMT are proceeding at full speed. In WRC-23 Agenda Item 1.2, which covers identification of additional frequencies for IMT, the frequencies listed in **Table 3** are considered for each region. In Region 3 (Asia-Pacific region), including Japan, 100-MHz bandwidth from 7025 to 7125 MHz is under consideration. At WRC-19, it was decided to identify additional frequencies above the millimeter-wave band for IMT [3], and at WRC-23, the frequencies to be considered are being selected in the expectation that the demand for IMT frequencies below the millimeter-wave band will increase in the future.

WRC-23 Agenda Item 1.4 discusses issues concerning the use of frequencies for high-altitude platform stations (HAPS) as IMT base stations (HIBS). As of 2021, as shown in **Fig. 3(a)**, 1885 to 1980 MHz, 2010 to 2025 MHz, and 2110 to 2170 MHz are available as HIBS frequencies in Region 3, including Japan. In addition to considering those frequencies, WRC-23 Agenda Item 1.4 considers further identifications of the frequencies used by HIBS in terms of several

*2 IMT-2020: The 3rd Generation Partnership Project (3GPP) 5G-SRIT and 3GPP 5G-RIT are included as radio interfaces.

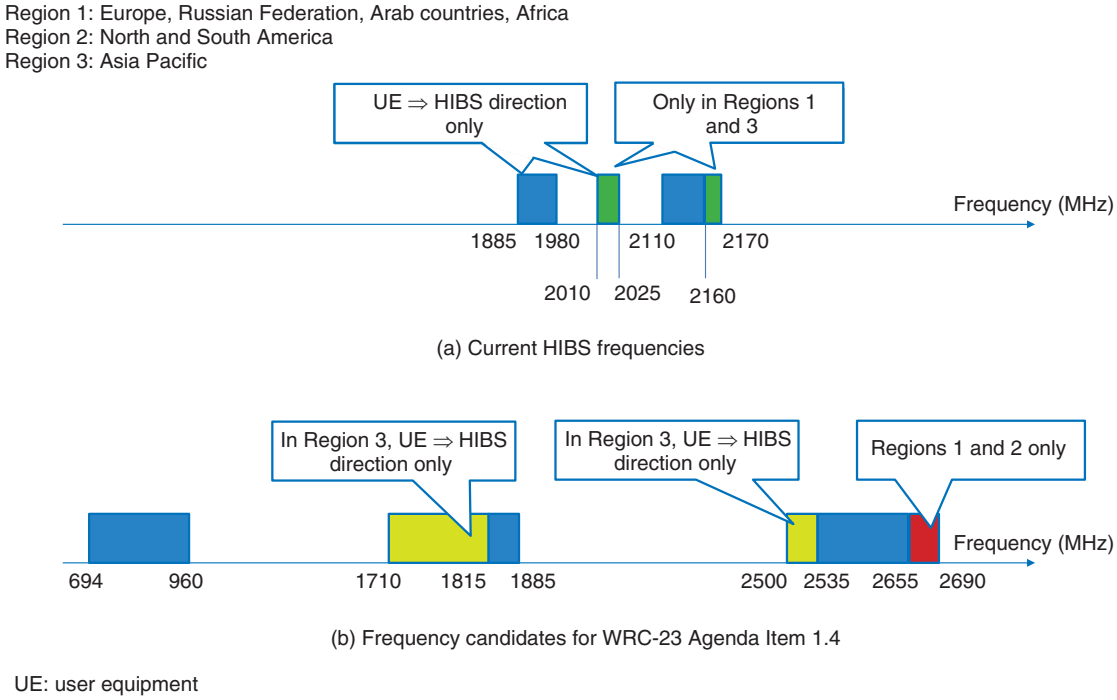

Fig. 3. Frequencies for HIBS.

candidate frequencies below 2.7 GHz, as shown in **Fig. 3(b)**.

WP 5D is conducting preliminary technical studies to determine (i) whether these candidate frequencies will harmfully interfere with other wireless systems if they are used for IMT or HIBS and (ii) what conditions are necessary to avoid such interference. Experts on other wireless systems, such as satellite systems, are also participating in detailed discussions as well as experts on IMT. On the basis of the results of these studies, WRC-23 will make the final decisions on whether to identify additional frequencies for IMT (Agenda Item 1.2), and whether to identify additional frequencies for HIBS (Agenda Item 1.4).

3. Future prospects

The year 2022 is important in regard to studies for the 2023 Radiocommunication Assembly (RA-23) and WRC-23 to be held in 2023. The draft texts for discussions at the Second Session of the 2023 Conference Preparatory Meeting (CPM*3 23-2), which is the preparatory meeting for WRC-23, will be completed in 2022.

Among the agenda items at WRC-23, such as additional identification for IMT, some discussions on the future deployment of 5G and Beyond 5G, such as 5G Evolution and 6G [4], are important from the viewpoint of Japan as a whole. Regarding discussions other than the WRC-23 agenda, for example, discussions on a wireless LAN, which is an important access method along with 5G, will have a significant impact on future wireless access. As the demand for the wireless spectrum is increasing yearly, in addition to the above discussions, various discussions on a wider range of frequency bands are expected. We would therefore like to continue to promote ITU-R activities with an awareness of international coexistence.

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*3 CPM: Preparatory meeting for the WRC. The 1st session of the CPM is usually held immediately after the previous WRC, and the 2nd session of the CPM is usually held about six months before the WRC. At the 2nd session of the CPM, the CPM Report will be prepared. The CPM Report is submitted to the WRC and contains technical studies, solutions based on the studies, and examples of RR revisions.

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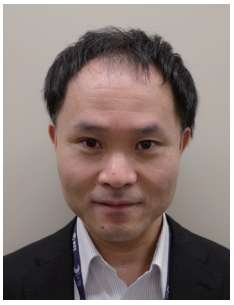

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Impact of Wildlife on Access Network Facilities—Problems Caused by Monkeys and Countermeasures against Them

Technical Assistance and Support Center, NTT EAST

Abstract

Telecommunication network facilities are exposed to a variety of indoor and outdoor environments in which they can be affected by the activities of wildlife. This article introduces problems caused by monkeys on access network facilities and countermeasures against these problems. This is the sixty-eighth article in a series on telecommunication technologies.

Keywords: aerial cable, cosine curve hanger (CCH), monkey

1. Introduction

Telecommunication network facilities are exposed to a variety of indoor and outdoor environments in which they can be affected by the activities of wildlife. Various problems caused by wildlife on access network facilities (such as telecommunication cables) have been reported (**Fig. 1**). Technical Assistance and Support Center (TASC) has investigated the problems caused by wildlife on telecommunication network facilities and has taken countermeasures against these problems [1]. In this article, we focus on the problems caused by monkeys and our countermeasures against these problems.

2. Problems caused by monkeys regarding telecommunication network facilities and countermeasures against them

Cases of monkeys entering residential areas have become more common due to factors such as the depopulation of villages [2]. Consequently, monkeys have directly affected telecommunication network facilities, and through behavior such as crossing aerial cables, they have also affected the lives of residents in the neighborhood. Two such cases and the countermeasures taken are introduced in the following sections.

2.1 Direct impact on NTT's telecommunication network facilities

2.1.1 Background

Along an aerial cable route crossing a national highway, a sagging optical fiber cable was broken by a passing vehicle snagging it (**Fig. 2**). At the initial deployment, this aerial optical-fiber cable was bundled together with other cables by using a cosine curve hanger (CCH). However, from the footage captured from the dashcam of the vehicle involved in the incident, it was clear that the cable in question was unbundled from the CCH even though other cables remained bundled at the time of contact with the vehicle.

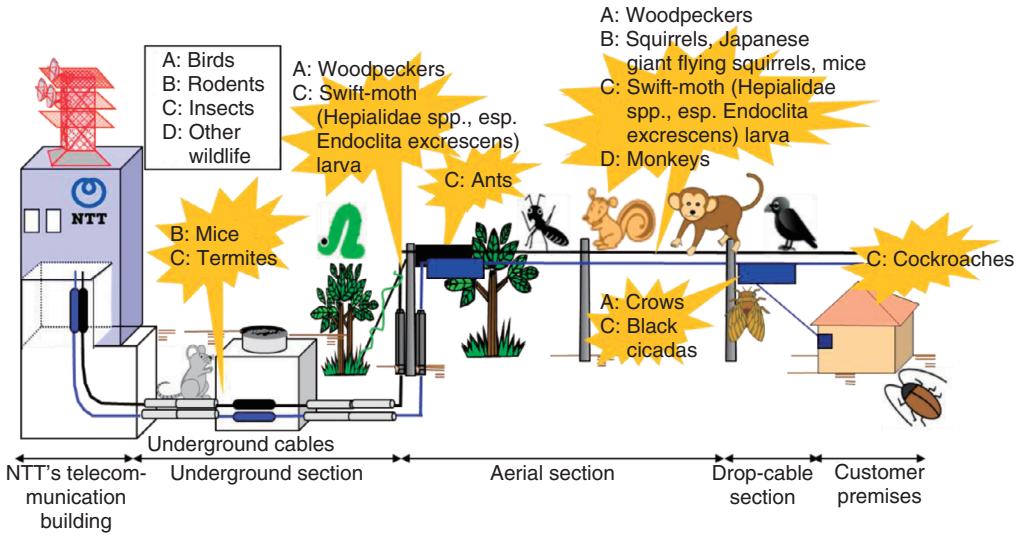


Fig. 1. Impact of wildlife on telecommunication network facilities.

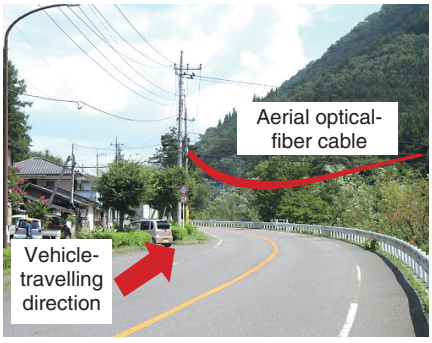


Fig. 2. Sagging cable.

Fig. 3. Monkeys crossing cables.

2.1.2 Investigation and analysis of the cause

To investigate the cause of the problem, we set up a fixed-point camera at the site to monitor the cable status for approximately a month. From the captured video, we observed more than a dozen monkeys per day crossing the cable in the incident section. Although the monkeys did not deliberately unbundle the cable, they strongly grabbed the cable for running and sometimes pulled the cable when losing their balance (**Fig. 3**).

After observing the monkeys' actions, we conducted an experiment to verify the possibility that the behavior of the monkeys caused the sagging of the cable. At an experimental site, we deployed optical cables bundled using a CCH, as shown in (1) in **Fig. 4**, and locally applied a pulling force to a part of the cable (Fig. 4(2)) to simulate a monkey applying a pulling (down) force on a cable at that part. When the locally applied pulling force was gradually increased and reached about 3 kg, the cable was unbundled from the CCH (Fig. 4(3)) and sagged (Fig. 4(4)). The monkeys captured on video were Japanese macaques, which were estimated to weigh about 7 to 15 kg. We therefore considered that they were capable of applying a force exceeding 3 kg when they pulled the cable. There was also no occurrence of severe weather conditions or natural disasters, such as typhoons or heavy rainfall, that could have caused the cable to sag before the incident; therefore, we determined that the sagging of the cable was due to the behavior of monkeys crossing the cable.

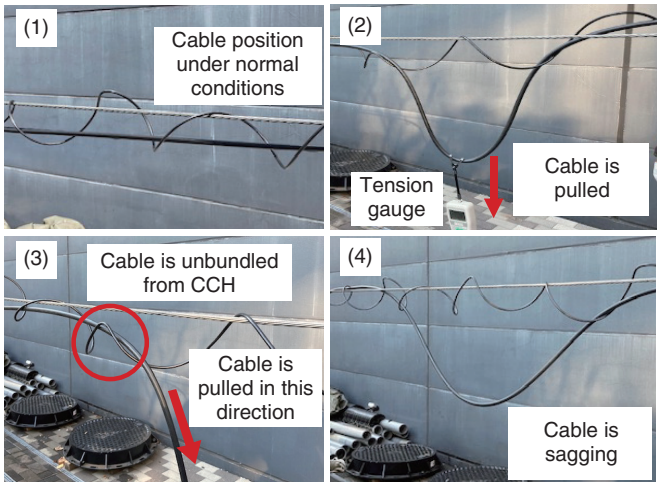


Fig. 4. How a cable sags.

(a) Securing a cable (b) Reinforcing SH

Fig. 5. Countermeasures against cables sagging.

2.1.3 Countermeasures

We took the following countermeasures to prevent the cable from sagging due to the above-described behavior of monkeys.

(1) The CCH was replaced with a spiral hanger (SH), which is mainly used in high-wind areas, and the cable was secured to the suspension wire with tying bands (**Fig. 5(a)**).

(2) To prevent the SH from falling, "quick holders," which are fixtures that prevent damage to the connectors of the SH and stop them from dislodging, were installed (**Fig. 5(b)**).

After these countermeasures were implemented, cable sagging did not recur. We thus believe that similar countermeasures will be effective at other locations in similar environments.

2.2 Example of impact on the neighboring community

2.2.1 Background

In an area, a large number of monkeys were seen crossing telecommunication cables and became a hot topic of conversation on social networking services. Neighboring residents requested that the monkeys be prevented from crossing NTT's telecommunication cables because they were invading nearby fields and destroying crops. From the results of interviews with a person monitoring monkeys commissioned by local governments, we learned that the monkeys formed groups of about 40 and traversed the cables daily in search of food.

2.2.2 Countermeasures

Since the above problem was already affecting the

Fig. 6. Bird-damage-prevention device

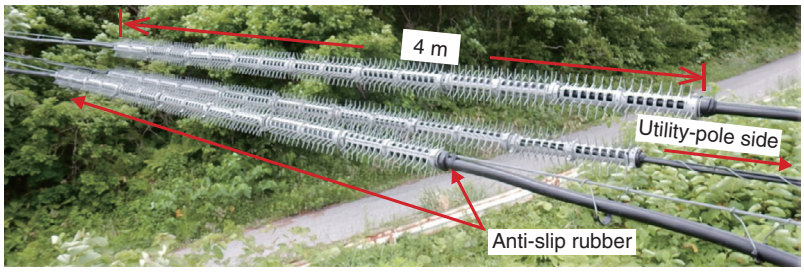


Fig. 7. Appearance of countermeasure device.

lives of nearby residents and immediate countermeasures were needed, we examined countermeasures using currently available products. From the perspective of biodiversity protection, we focused on devising a countermeasure that would not significantly affect the behavior of the monkeys but would prevent them invading the living areas of nearby residents by traversing the cables.

We devised a countermeasure using a commercially available bird-damage-prevention device to make it harder for monkeys to cross the cable (**Fig. 6**). This device has a spiked surface for preventing birds from perching on cables, and when attached to the cable, it rotates and makes it difficult for a monkey to grab the cable.

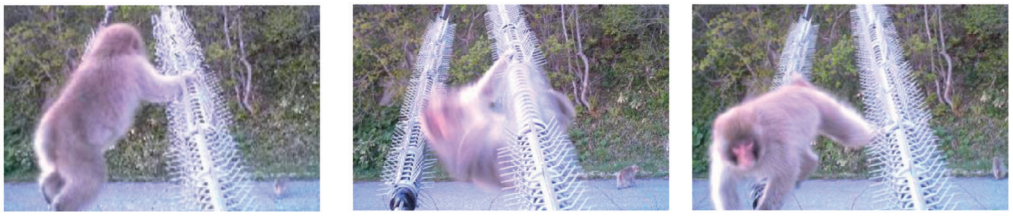
We installed the device on an optical fiber cable deployed in high monkey traffic area. Initially, the device was effective in preventing monkeys from crossing the cable. However, we found that monkeys have very high motor skills, i.e., can leap two to three meters horizontally and have an excellent sense of balance, so they can easily avoid the device and cross the cable, even from a precarious position. After repeated trials while studying the structure and installation method of the device, we determined that the following installation method to be effective (**Fig. 7**).

(1) To make the countermeasure device rotate more easily (i.e., more unstable), cut the device into two pieces of 250 mm in length (half the original length) and install the pieces.
(2) To stop the monkeys jumping over the device, attach multiple pieces (16 in total) with a total length of 4 m to the cable.

After adopting this installation method, we confirmed that any monkeys that tried crossing the section of the cable in question gave up and turned back (**Fig. 8**).

3. Concluding remarks

Examples of problems with telecommunication network facilities caused by monkeys and countermeasures against them were introduced. The surrounding environments of telecommunication network facilities vary considerably, and even if the problem is the same at each site (in this example,



(a) Monkey places its hand on the countermeasure device

(b) The device spins

(c) The monkey turns back and runs away

Fig. 8. A monkey trying to cross the countermeasure device, failing, and turning back.

monkeys crossing telecommunication cables), it is necessary to consider countermeasures that are appropriate for each site.

TASC, including its predecessor, the Technical Cooperation Department, has been supporting the field through technical cooperation activities for more than 50 years. Using the knowledge and experience accumulated to date, as well as new technologies, we will continue our efforts to improve the reliability of telecommunication network facilities and reduce failures.

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Report on NTT R&D Forum—Road to IOWN 2021

NTT R&D Forum Office

Abstract

NTT R&D Forum—Road to IOWN 2021 was held online over a four-day period from November 16th to 19th, 2021. This article is an introductory overview of the Forum.

Keywords: R&D forum, IOWN, technical seminar

1. Forum overview

The NTT R&D Forum introduces the latest efforts by NTT laboratories every year. This year, 97 exhibits were held in six categories based on the concept of "Road to IOWN 2021," and 10 lectures/seminars were streamed as an accessible introduction to the present status of the Innovative Optical and Wireless Network (IOWN) initiative in which the NTT Group as a whole is engaged.

2. Keynote speeches/special sessions

2.1 Keynote Speech 1

Jun Sawada, President and CEO of NTT, spoke on the theme "What is IOWN?" (**Photo 1**). First, President Sawada presented the importance of "Umwelt" (environment or surroundings) in the midst of natural disasters and a pandemic unexpected in traditional naturalism, and the significance of IOWN as a "media connecting different Umwelten." President Sawada introduced three demonstration experiments as IOWN use cases, including the "Avatar Robot Café DAWN," which provides a place for people with disabilities to work via the Internet and technology. In addition, the roadmap for IOWN introduction and research and development (R&D) through 2030 for photonics-electronics converged devices was presented, with the aim of implementing optical materials between chips by 2025, and both between chips and within chips by 2030. The new NTT Group Environment and Energy Vision of "NTT Green Innovation toward 2040" was also introduced, simultaneously working to achieve the contradictory aims of "solving environmental problems" and "economic growth" through reducing environmental impact and creating innovation that breaks limits through business activities. Under the NTT Group philosophy of "Self as We," which aims for altruistic coexistence, the company has declared that it will continue to work on three themes: "Ensuring the coexistence of nature and humanity," "Improving prosperity for all people and cultures" and "Maximizing well-being for all," aiming for the realization of a sustainable society.

Photo 1. Keynote Speech 1: President Sawada.

Photo 2. Keynote Speech 2: Executive Vice President Kawazoe.

Photo 3. Special Session 1: (from left) Vice President Kawashima, Senior Vice President Tsukano, and Senior Vice President Oono.

For more information, see the article entitled "What is IOWN?" in this issue.

2.2 Keynote Speech 2

Katsuhiko Kawazoe, Executive Vice President, Head of Research and Development Planning, NTT, gave a lecture on the theme of "Road to IOWN 2021" (**Photo 2**). The IOWN concept, which began with the invention of optical transistors at one NTT research laboratory, now extends beyond the entire NTT Group to operations worldwide. In his speech, Executive Vice President Kawazoe reported on the progress of the technological developments that make up the IOWN concept, which was announced in May 2019 and is now in its third year, and introduced 15 leading innovative technologies. In addition, he reported that the number of members of the IOWN Global Forum has increased to approximately 80 in less than two years. He also noted the establishment of the NTT IOWN Integrated Innovation Center on July 1, 2021 to accelerate R&D toward realizing IOWN, and the NTT R&D Authority Team, which includes prominent executives and researchers in each field. For more information, see the article entitled "Road to IOWN 2021" in this issue.

2.3 Special Session 1

Masahisa Kawashima, Vice President, Head of IOWN Development Office, moderated a discussion between the new leaders of the organization, titled "New R&D leaders talk about steps toward the realization of IOWN" (**Photo 3**). Hidehiro Tsukano, Senior Vice President, Head of IOWN Integrated Innovation Center, which was established in July 2021 in order to realize the core technologies of IOWN, is from Fujitsu, the supplier side. In addition, Tomoyoshi Oono, Senior Vice President, Head of Service Innovation Laboratory Group, which aims to create a society in which all people can live in a state of well-being by utilizing Digital Twin Computing (DTC), was involved with service creation in the R&D department of NTT DOCOMO. In this session, opinions were exchanged on issues such as how IOWN will be used to create markets and what activities to proceed with in the future. In response to the question, "What is necessary for global vendors to participate in IOWN?" Senior Vice President Tsukano pointed out the importance of standardization through the IOWN Global Forum, and Senior Vice President Oono pointed out the importance of partners who create services together.

2.4 Special Session 2

This IOWN Global Forum members' session was held on the theme of "IOWN Global Forum and its Initiatives Toward 2030" (**Photo 4**). The four participants were Gonzalo Camarillo, Vice Chair of the Marketing Steering Committee, who served as the moderator; Clara Li, member of the IOWN Global Forum and chair of the Technology Steering Committee; Philippe Chanclou, contributor to IOWN Global Forum activities related to the All-Photonics Network; Katsutoshi Itoh, Chair of the Use Case Working Group; and Masahisa Kawashima, Vice President, Head of IOWN Development Office and Chair of the Technology Working Group. Each panelist spoke about the current situation and challenges in their own field of expertise, on themes such as "the relationship between the IOWN Global Forum and other standards organizations" and "the social benefits of IOWN." Regarding the social benefits of

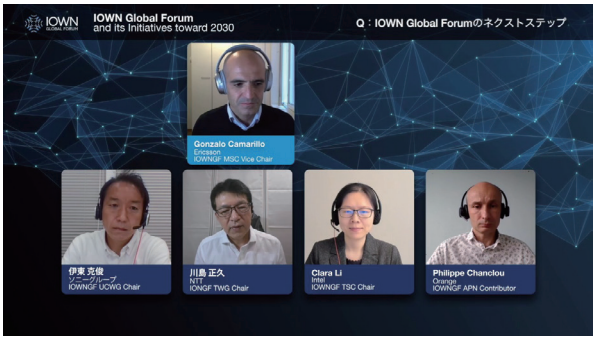

Photo 4. Special Session 2.

Photo 5. Technical Seminar 1: (from left) Mr. Sugiyama, Dr. Yamamoto, and Ms. Kawana.

IOWN, Vice President Kawashima pointed out the contribution to energy efficiency, Dr. Itoh spoke on improved operational efficiency through modeling, and Dr. Li noted the contribution of building a Data Centric Infrastructure (DCI) to energy efficiency and sustainability.

3. Technical seminars

The streaming technical seminars provided an introduction to the latest results from research that NTT is currently engaged in, as well as a discussion with guests. This year, seminars were streamed on six themes: "Application of ICT technology to agriculture and prospects for the future," "Trusted dataspace: To overcome the barrier of cross-domain data sharing," "New era in AI: Think and grow like humans - Next generation media processing AI 'MediaGnosis™'," "New user experiences through the interplay of the real and cyber space," "New relationship between humans and the earth pioneered by blue carbon technology" and "The future pioneered by networking optical lattice clocks." Here we present an overview of each seminar.

3.1 Technical Seminar 1

The seminar was held by Hiroshi Yamamoto, Senior Research Engineer, Supervisor at NTT Network Service Systems Laboratories, under the title "Application of ICT technology to agriculture and prospects for the future." Television personality Harry Sugiyama served as MC and Kei Kawana, founder of Neighbor's Farm, was invited as a guest (**Photo 5**). "Smart Agri," one of the six priority areas for NTT Group efforts to resolve social issues, was discussed in this session under the theme of "Networks and the Agricultural Environment." The seminar introduced level 3 robotic agricultural machinery currently being jointly researched with Hokkaido University, and topics concerning improving availability, multi-layered safety measures and general-purpose platform development. Ms. Kawana, who runs a farm founded in Tokyo in 2018 as the first new farmer under the Act on Urban Farmland Lease Facilitation, expressed her hope that "significant levels of automation will be implemented while I am still working in this field, and that agriculture will grow into an attractive industry for the following generations."

3.2 Technical Seminar 2

The seminar, titled "Trusted dataspace: To overcome the barrier of cross-domain data sharing," was held by Daigoro Yokozeki, Executive Research Engineer at NTT Social Informatics Laboratories. Television personality Harry Sugiyama served as MC and Noboru Koshizuka, Professor, Interfaculty Initiative in Information Studies, The University of Tokyo, was invited as a guest (**Photo 6**). Prof. Koshizuka established the Data Society Alliance (DSA), and is working with governments, industry associations, and NTT with the aim of "creating an environment for the free distribution of data." The seminar introduced the concept of a "trusted data space for cross-domain information distribution" that can be used to provide and share the minimum amount of information to the minimum number of parties while remaining encrypted. In addition, the three elemental technologies of "high-performance encryption," "secure computation AI" and "next-generation data hubs" were explained by engineers having expert knowledge in each field.

Photo 6. Technical Seminar 2: (from left) Mr. Sugiyama, Executive Research Engineer Yokozeki, and Prof. Koshizuka.

Photo 7. Technical Seminar 3: Ms. Nakamura experiencing "MOTESSENSE™".

3.3 Technical Seminar 3

The seminar, on the topic of "New era in AI: Think and grow like humans - Next generation media processing AI 'MediaGnosis™'," was held by Senior Research Engineer and Supervisor Yoshinori Kusachi and Distinguished Researcher Ryou Masumura, both from NTT Computer and Data Science Laboratories. Television personality Harry Sugiyama served as MC, and the actress Shizuka Nakamura was invited as a guest. At the seminar, Ms. Nakamura experienced "MOTESSENSE™," which helps everyone discover their own charming individuality, as an example of an artificial intelligence (AI) that thinks and is capable of growth like a human. It pointed out that her "charm factor" or personal appeal was "emotion," and she was surprised at the detailed diagnosis (**Photo 7**). Afterward, there was an introductory overview of "MediaGnosis™," which is used in MOTESSENSE™. This aims to integrate all media information into "Gnosis" in the style of human knowledge, and then to make a "Diagnosis" based on it.

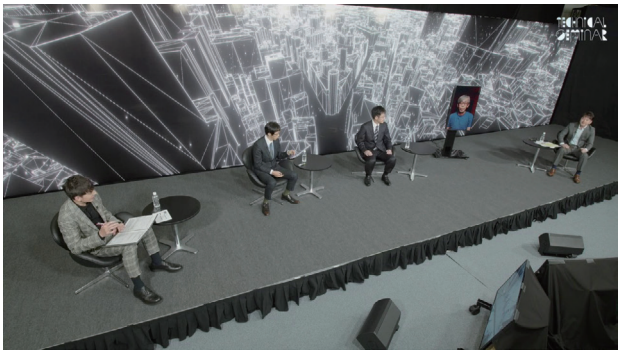

Photo 8. Technical Seminar 4: (from left) Mr. Sugiyama, Senior Research Engineer Fukatsu, Director Yagi, CEO Fujii, and Senior Executive Officer Uematsu.

3.4 Technical Seminar 4

This seminar featured television personality Harry Sugiyama as MC, with Naotaka Fujii, CEO of Hacosco Inc., and Michimasa Uematsu, Senior Executive Officer, CTO, ACCESS Co., LTD. as guests. The seminar was conducted under the title of "New user experiences through the interplay of the real and cyber space," by Takeshi Yagi, Director, Research and Development Planning Department, NTT, and Shinji Fukatsu, Senior Research Engineer and Supervisor at NTT Human Informatics Laboratories (**Photo 8**). When low power consumption, broadband bandwidth, and low latency are realized, users can receive all information and choose from it freely depending on their intentions. During the seminar, user interface (UI) and user experience (UX) experts discussed what UI and UX should be like in the IOWN era, and what the UX should be if real and cyber space are intertwined through the 4D digital platform™.

3.5 Technical Seminar 5

Television personality Harry Sugiyama served as MC at this seminar, with guests Kouji Kinjyo, CEO of Sea Seed Co., Ltd., a company working on coral cultivation and transplantation, and Karibu Suzuki, CEO of Karibu Collaboration Co., Ltd. and collector and researcher of juvenile fish. The seminar was conducted on the theme of "New relationship between humans and the earth pioneered by blue carbon technology" by Katsuhiko Okazaki, Senior Research Engineer and Supervisor at NTT Space Environment

Photo 9. Technical Seminar 5: (from left) Mr. Sugiyama and Senior Research Engineer Okazaki.

Photo 10. Technical Seminar 6: (from left) Mr. Sugiyama, Dr. Akatsuka, and Research Engineer Arai.

and Energy Laboratories (**Photo 9**). The focus of this year was NTT Space Environment and Energy Laboratories, which tackles environmental and energy issues from a space perspective. This time, the focus was on carbon dioxide (CO_2) issues with the keyword "blue carbon." Among the carbon absorbed by the global ecosystem, the carbon absorbed into the marine ecosystem is known as blue carbon, and carbon absorbed by shallow seas accounts for 35% of CO_2 absorbed on the Earth. At the seminar, a lively discussion was held, with the introduction of joint research between Regional Fish Institute, Ltd., a venture company originating from Kyoto University, and NTT.

3.6 Technical Seminar 6

Television personality Harry Sugiyama served as MC for this seminar, with guests Hidetoshi Katori, Professor, Department of Applied Physics, Graduate School of Engineering, The University of Tokyo, and Tetsuya Ido, Director, Space-Time Standards Laboratory, Radio Research Institute, National Institute of Information and Communications Technology. The seminar was held by Tomoya Akatsuka, Senior Research Scientist, NTT Basic Research Laboratories, and Kaoru Arai, Research Engineer, NTT Network Service Systems Laboratories, under the title "The future pioneered by networking optical lattice clocks" (**Photo 10**). NTT is currently working on miniaturization of the optical lattice clock invented by guest Prof. Katori in 2001 through using a chip called a planar lightwave circuit for the path the cooling laser follows to an atom. The concept of an "Optical Lattice Clock Network," a time-space information infrastructure in which optical lattice clocks are placed throughout Japan and connected with NTT's fiber optic network, was also introduced. The seminar explained the principle of optical lattice clocks and pointed out the range of applications such as time synchronization and altitude difference measurement based on the theory of relativity.

4. Exhibits of research results

NTT's latest technology and research results were divided into six categories and presented in a virtual exhibit booth. Of these, particularly noteworthy research is reported below.

4.1 Networks

In the "Networks" category, IOWN's optical and wireless network technologies and their advanced control and operational technologies were introduced. At the exhibit "Extreme NaaS for comfortable quality of end-end communication," technologies that optimize performance by using method-independent radio technologies depending on the changing radio environment, such as analog radio over fiber (RoF) and reconfigurable intelligent surface (RIS), and also to optimize performance across non-wireless systems such as optical networks and application layers were presented (**Fig. 1**). In addition, the "All-photonics network transport technology with a variety of optical paths" exhibit featured technologies such as direct on-demand access between any two points, including customer sites, and low-latency service linking terminals across domains with end-to-end optical paths.

4.2 UX/UI Devices

In the "UX/UI Devices" category, technologies that seamlessly connect the real world with the cyber

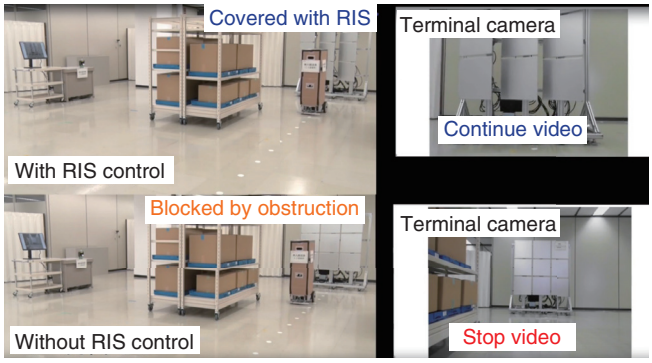

Fig. 1. Control technology for terminal tracking using RIS.

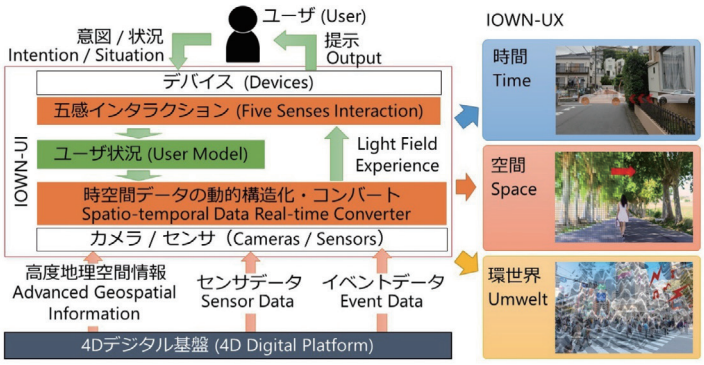

Fig. 2. New UI/UX created by IOWN.

world and maximize human ability through physical, psychological and social interactions were introduced. In the "Personalized Sound Zone" exhibit, research on creating sound spaces suitable for users through advanced control of the surrounding sound space was exhibited, including noise control technology to block out ambient sounds, and event detection and localization technology to allow listening to required sounds. In addition, the exhibit "New UI/UX created by IOWN" introduced technology for realizing experiences that meet the needs of diverse recipients (able-bodied individuals, people with disabilities, living things and machines) through a fusion of the real world and cyber space (**Fig. 2**). Use cases were demonstrated, such as constructing and experiencing past times and spaces, and visualizing the sounds of daily life to make life easier for people who are hard of hearing.

4.3 Security

In the "Security" category, various technologies were introduced that enable new security by taking advantage of the unique features of IOWN in order to realize a Smart World and create varied social values. In the "Secure optical transport network for quantum computer era" exhibit, cryptographic techniques that support the security of IOWN, which prevent information from being decrypted even with quantum computers, were introduced (**Fig. 3**). In the exhibit, it was demonstrated that uncompressed 8K images can be transmitted after encryption and displayed with virtually no delay using actual hardware. In addition, the exhibit "Security transparency assurance technology to make trusted networks" presented technology for providing accurate, leak-free security management through visualization of the configuration and risks to equipment throughout the supply chain. It was announced that the goal is to create a world that everyone can use information and communication

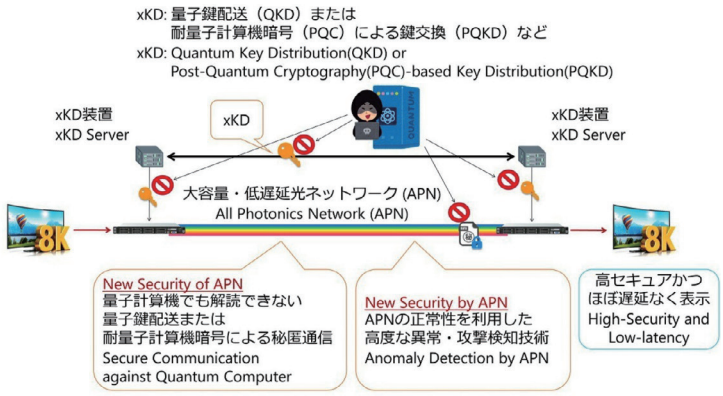

Fig. 3. Secure optical transport network for quantum computer era.

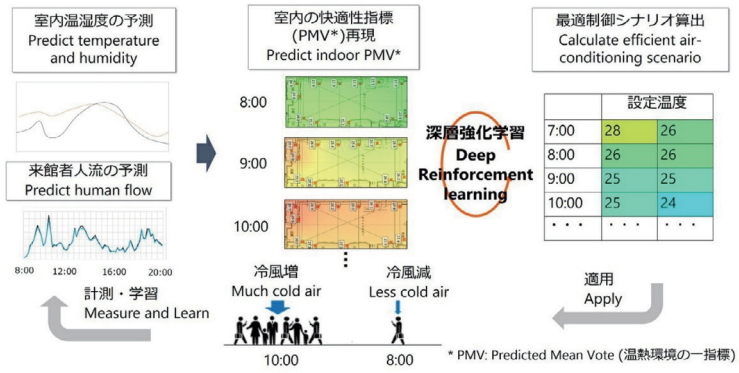

Fig. 4. Calculating efficient scenario of air-conditioning system.

technology with peace of mind in the IOWN era.

4.4 Computing

In the "Computing" category, the computing technologies and DTC that underpin IOWN, as well as the latest AI and digital transformation-related technologies and initiatives, were introduced. In the exhibit "Calculating efficient scenario of air-conditioning system," technology was introduced that recreates the interior comfort indicator (predicted mean vote (PMV)) for temperature, humidity and momentum, and optimizes energy consumption and comfort simultaneously, all using climate control scenarios calculated with deep reinforcement learning (**Fig. 4**). In the "Initiatives to implement the 4D digital platform™" exhibit, the 4D digital platform™, a technology providing high-precision, real-time integration of diverse sensor data into the Advanced Geospatial Information Database with rich semantic information was introduced as a foundation supporting DTC, resolving social issues and creating new value.

4.5 Zero Environmental Impact (Environment and Energy)

In the category "Zero Environmental Impact (Environment and Energy)," environment and energy technologies were introduced that innovate for the future of the global environment from a space perspective, based on the concept of "the Earth, from space." The exhibit "Environmental regeneration and adaptation technologies," provided an introduction to biological conversion technology for oceanic CO_2 using genome editing, and ultra-wide air/ocean observation technology utilizing satellite Internet of Things (IoT) sensors (**Fig. 5**). Based on these technologies, we aim to reduce environmental impact in the future and to realize an ultra-resilient society that can adapt to global environmental changes. In the "Space photovoltaic

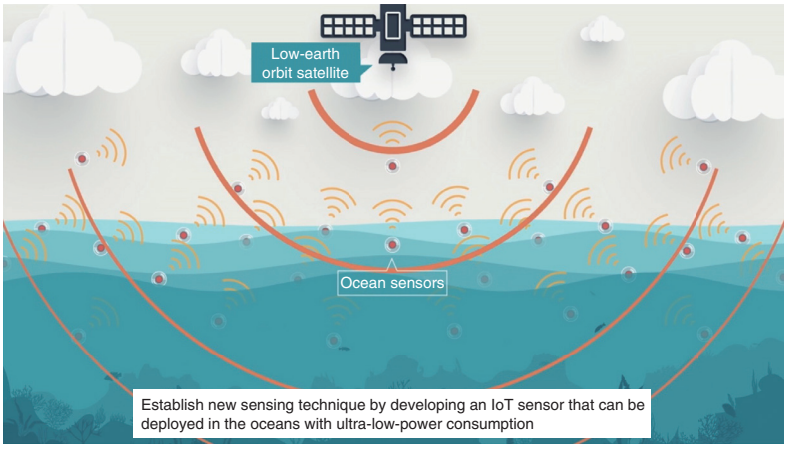

Fig. 5. Ultra-wide air and ocean observation technology utilizing satellite IoT sensors.

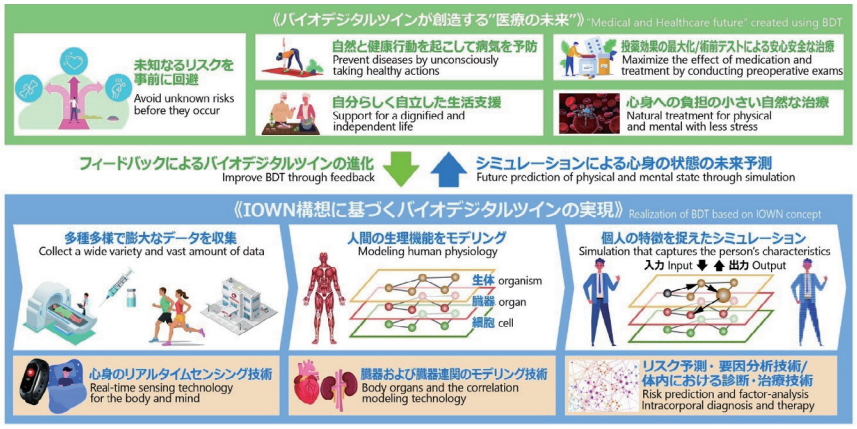

Fig. 6. Realization of a bio digital twin based on the IOWN concept.

power generation technology" exhibit, technology was introduced to use solar energy by installing an immense light collector in a geostationary satellite orbit at an altitude 36,000 km, convert it into lasers and microwaves, transmit it, receive it in a receiver installed on the ground and convert it into energy, such as electricity.

4.6 Basic Research

In the "Basic Research" category, basic research in various fields that contribute to the IOWN concept was exhibited, including R&D on information technology, advanced device and photonics technology, and medical and bio-technology. In the exhibit "Optical lattice clock (OLC) network technology," the technology of the Optical Lattice Clock Network was introduced. Using a network of optical lattice clocks that can achieve an accuracy more than 100,000 times higher than that of conventional frequency standards for communication, we aim to achieve long-term, stable time synchronization for the fifth-generation mobile communication system (5G) and 6G, and achieve accurate altitude differential measurements for disaster prevention. In addition, the exhibit "Medical and healthcare vision: Realization of Bio Digital Twin" exhibited the efforts to create a bio digital twin (BDT), a detailed picture of the individual's body and mind (**Fig. 6**). The realization of BDTs is expected to contribute to a brighter future for medical care, in the form of predictions on the mental and physical condition, and hopes for a healthy future.

5. After the Forum

This year marks the third year of the IOWN initiative. The device is expected to be completed in 2024, the completion of development of the system in 2025, and the commercial introduction of IOWN in 2026. We hope you can feel through this forum that steady progress has been made toward the full-scale deployment of IOWN, which is scheduled for 2030. NTT will continue to make further efforts in R&D in order to meet your expectations.

Keynote speeches (videos), exhibits, etc. are posted on our special website "Report on NTT R&D Forum—Road to IOWN 2021" (https://www.rd.ntt/e/forum/2021/).

Members of NTT R&D Forum Office: (from left) Takafumi Mukochi, NTT Service Innovation Laboratory Group; Taeko Tamada, Research and Development Planning Department, NTT; Takayuki Onzuka, Research and Development Planning Department, NTT; Tomohisa Hosoda, Research and Development Planning Department, NTT; Takayoshi Mochizuki, Research and Development Planning Department, NTT; Keita Takahashi, NTT Information Network Laboratory Group/NTT IOWN Integrated Innovation Center; Kenichi Hitachi, NTT Science and Core Technology Laboratory Group; and Shunsuke Mori, Research and Development Planning Department, NTT.

External Awards

Medal with Purple Ribbon
Winner: Yutaka Miyamoto, NTT Network Innovation Laboratories
Date: April 29, 2021
Organization: Japan

For development of high-capacity optical transmission scheme using coherent-multicarrier multilevel modulation.

Optica Fellow
Winner: Shinji Matsuo, NTT Device Technology Laboratories
Date: November 3, 2021
Organization: Optica (formerly OSA)

For pioneering contributions to ultra-high-speed and low-power-consumption membrane lasers.

Visual Movie Award
Winner: Riku Takahashi, NTT Basic Research Laboratories
Date: November 11, 2021
Organization: The Society for Chemistry and Micro-Nano Systems (CHEMINAS)

For "Construction of Vessel-like Tissue Using Fluidic Device Based on Hydrogel Film."
Published as: R. Takahashi, A. Tanaka, and M. Yamaguchi, "Construction of Vessel-like Tissue Using Fluidic Device Based on Hydrogel Film," CHEMINAS 44, IR-01, Nov. 2021.

Highly Commended Paper Award
Winners: Kei Fujimoto, Ko Natori, Masashi Kaneko, Akinori Shiraga, NTT Network Innovation Center
Date: November 25, 2021
Organization: The 31st International Telecommunication Networks and Applications Conference 2021 (IEEE ITNAC 2021)

For "NIDP: Low-latency Networking without Application Customization in Virtual Machine."
Published as: K. Fujimoto, K. Natori, M. Kaneko, and A. Shiraga, "NIDP: Low-latency Networking without Application Customization in Virtual Machine," IEEE ITNAC 2021, Nov. 2021.

APSEC 2021 Best ERA Paper
Winners: Hiroto Watanabe, Shinsuke Matsumoto, Yoshiki Higo, Shinji Kusumoto, Osaka University; Toshiyuki Kurabayashi, Hiroyuki Kirinuki, Haruto Tanno, NTT Software Innovation Center
Date: December 8, 2021
Organization: The 28th Asia-Pacific Software Engineering Conference (APSEC 2021)

For "Applying Multi-objective Genetic Algorithm for Efficient Selection on Program Generation."
Published as: H. Watanabe, S. Matsumoto, Y. Higo, S. Kusumoto, T. Kurabayashi, H. Kirinuki, and H. Tanno, "Applying Multi-objective Genetic Algorithm for Efficient Selection on Program Generation," APSEC 2021, Dec. 2021.

2021 IEICE Communications Society OCS Young Researchers Award
Winner: Takeo Sasai, NTT Network Innovation Laboratories
Date: December 14, 2021
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE) Technical Committee on Optical Communication Systems (OCS)

For "Digital Backpropagation for Optical Path Monitoring—Loss and Dispersion Profile Estimation—."
Published as: T. Sasai, M. Nakamura, S. Yamamoto, E. Yamazaki, H. Nishizawa, and Y. Kisaka, "Digital Backpropagation for Optical Path Monitoring—Loss and Dispersion Profile Estimation—," IEICE Tech. Rep., Vol. 120, No. 309, OCS2020-39, pp. 61–64, Jan. 2021.

Papers Published in Technical Journals and Conference Proceedings

Quantum Remote Sensing under the Effect of Dephasing
H. Okane, H. Hakoshima, Y. Takeuchi, Y. Seki, and Y. Matsuzaki
Physical Review A, Vol. 104, No. 6, 062610, December 2021.

The quantum remote sensing (QRS) is a scheme to add security about the measurement results of a qubit-based sensor. A client delegates a measurement task to a remote server that has a quantum sensor, and eavesdropper (Eve) steals every classical information stored in the server side. By using quantum properties, the QRS provides an asymmetricity about the information gain where the client gets more information about the sensing results than Eve. However, quantum states are fragile against decoherence, and so it is not clear whether such a QRS is practically useful under the effect of realistic noise. Here, we investigate the performance of the QRS with dephasing during the interaction with the target fields. In the QRS, the client

and server need to share a Bell pair, and an imperfection of the Bell pair leads to a state preparation error in a systematic way on the server side for the sensing. We consider the effect of both dephasing and state preparation error. The uncertainty of the client side decreases with the square root of the repetition number M for small M, which is the same scaling as the standard quantum metrology. On the other hand, for large M, the state preparation error becomes as relevant as the dephasing, and the uncertainty decreases logarithmically with M. We compare the information gain between the client and Eve. This leads us to obtain the conditions for the asymmetric gain to be maintained even under the effect of dephasing. Then, we can quantify how much information the client can gain while preserving the information asymmetricity.

Suppression of Intensity Noises in Forward-pumped Raman Amplifier Utilizing Depolarizer for Multiple Pump Laser Sources

H. Kawakami, S. Kuwahara, and Y. Kisaka

Journal of Lightwave Technology, Vol. 39, No. 23, pp. 7417–7426, December 2021.

We investigate the random intensity noises that occur in forward-pumped distributed Raman amplifier systems. First, we show pump-to-signal intensity noise transfer characteristics, which strongly depend on the group velocities of pump light and signal light in optical fiber used as a gain medium. When signal light is in the C-band, dispersion shifted fiber (DSF) transfers much larger noise compared with standard single mode fiber. Next, we discuss the origin of the noise induced in pump light. We define the concept of "synthesized polarization" and show that fluctuation in the state of synthesized polarization (SOSP) can induce a large gain instability even if the relative intensity noise (RIN) of each pump laser source is negligible experimentally. Next, we propose a novel optical depolarizer for pump light. It can simultaneously depolarize pump light generated by multiple laser sources. Moreover, it can manage optical phases precisely to suppress the gain instability induced by the fluctuation in SOSP. Finally, we present a measurement of the Q factor of a 16-QAM signal (32 Gbaud) after 35-km transmission, with and without a forward-pumped Raman amplifier. Two pump laser sources with RINs of –134 to –126 dB/Hz were depolarized by the proposed depolarizer, and the generated on-off gain was 7 dB. Though amplified signal light was in the C-band and the gain medium was DSF, 16-QAM transmission specifications were successfully improved, and acceptable noise was observed for 5 hours operation.
