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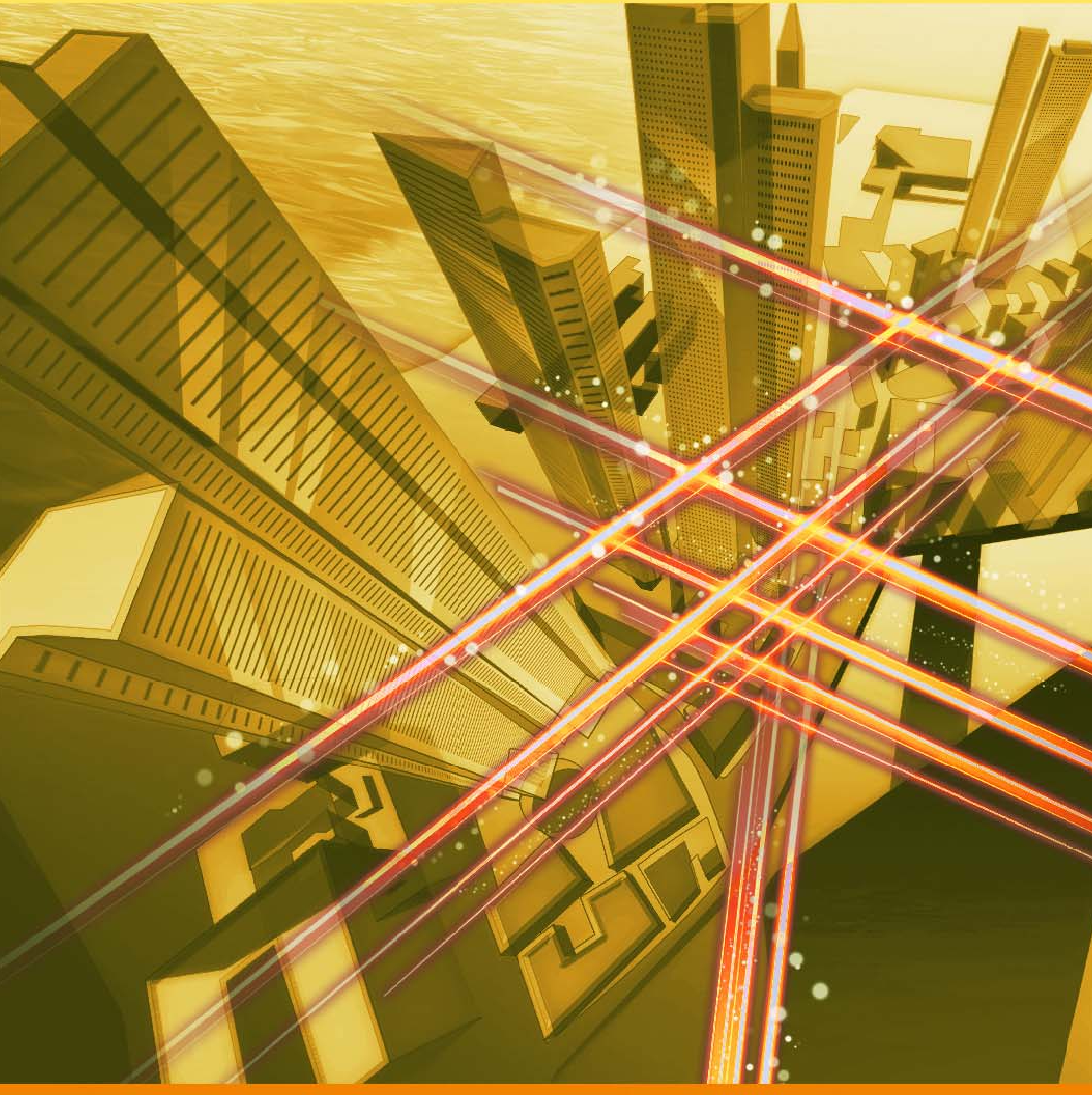

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Information-presentation Technology That Gives an Illusory Texture of Objects without Needing to Touch Them

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Abstract

Head-mounted displays for cross reality (XR) have been released by various companies and are gradually gaining popularity. Such XR displays present three-dimensional stereoscopic images that take advantage of the characteristics of the human visual system and give users a greater sense of reality. However, illusions are not just created by sight; they are the result of a combination of sight with other senses, such as hearing and touch. Takahiro Kawabe, a senior distinguished researcher at NTT Communication Science Laboratories, is engaged in research on illusions related to the texture of objects created by the combination of multiple senses. We interviewed him about his research on presenting the texture of objects for touchless user interfaces, the fusion of psychology and engineering, and his attitude as a researcher.

Keywords: illusion, texture impression, touchless user interface

Using illusions to manipulate the texture of objects without needing to touch them

—What research are you currently conducting?

I'm investigating information-presentation technology that uses illusions. I believe that by using illusions, we can perceptually present information that is physically difficult to present. In the previous interview (November 2020 issue) [1], I introduced our information-presentation technologies that use projection mapping, namely, "Hengento," which gives an illusion as if a stationary object is moving and "Ukuzo," which gives an illusion as if a stationary object is floating in the air. I'm currently working on two themes: "technology for manipulating the texture impression of virtual objects for touchless user interfaces" and "tangible interfaces and virtual interfaces."

Regarding the first theme, I'm investigating methods for more directly manipulating the texture perception of objects that I briefly touched upon in the previous interview. Together with my research colleagues Takumi Yokosaka and Yusuke Ujitoko, I studied the problem of how to convey the weight of an object on a screen, which cannot be touched directly, to a user when they make a lifting motion. In an experiment, we moved the stripes displayed on a screen in synchronization with the user's lifting motion. When the speed at which the stripes moved was decreased, the user felt that the stripes were heavier, even though no force was actually applied to the user's hand. We also found that the direction of movement of the stripes does not necessarily have to coincide with the direction of the lifting motion; for example, the user feels that the stripes are heavier even if the speed of the stripes moving horizontally is decreased to match the upward lifting motion (**Fig. 1**). I expect that by applying these research results, we will be able to give a sense of weight to virtual objects that a user manipulates without needing to touch them in a manner that creates a highly realistic impression of the manipulation.

As shown in **Fig. 2**, when the user holds their hand in front of the laptop and moves it left or right, the textured virtual object in the upper left corner of the screen appears to stretch. The amount by which the virtual object is stretched changes in accordance with the amount by which the user's hand moves, and more stretching makes the object feels soft and less stretching makes it feel hard. If the hand goes out of the range detected by the camera and the hand movement is not reflected in the virtual object midway through the movement (the state of being stretched stops midway through the movement), something felt strange to the user, but we did not understand the reason for that strange feeling in details. Therefore, Yusuke Ujitoko and I set an effective range (i.e., detection range of the camera) in which the sensing function works for hand movements that stretch the virtual object and investigated how the impression of the virtual object changes in accordance with the effective range. We found that when the stretching of the object is stopped midway, the object feels hard, heavy, and has friction. This result indicates that engineers who create touchless devices must understand the effect that the effective range of hand movement for manipulating a virtual object has on the impression of the texture of the object. Conversely, it also indicates that by using the effect of the effective range, they may be able to provide people with additional texture impressions of an object.

We submitted many papers to academic journals on technology for manipulating the texture impression of virtual objects for touchless user interfaces, and our latest research has been accepted for publication in a high-impact-factor journal, the IEEE (Institute of Electrical and Electronics Engineers) Transactions on Visualization and Computer Graphics [2]. Under the theme of moving robots in a touchless manner, I also started researching causal perception and texture perception when moving objects by moving a cube-shaped robot through hand movements.

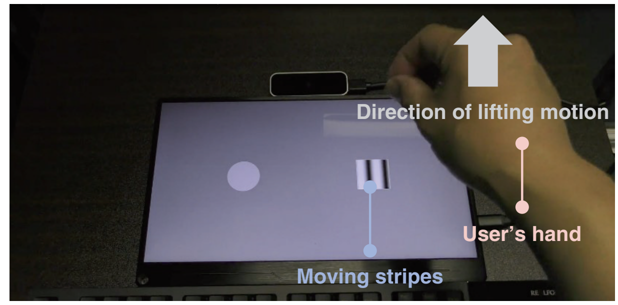

Fig. 1. Illusion of weight.

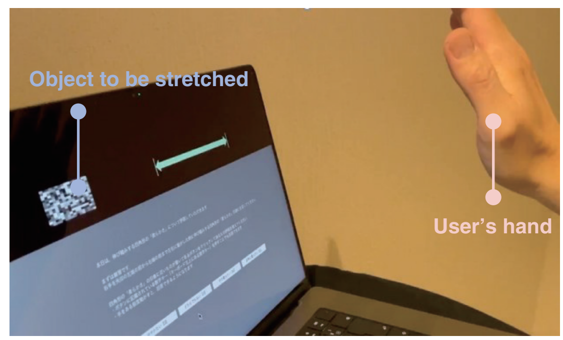

Fig. 2. Changes in the impression of stretching.

Regarding the second theme "tangible interfaces and virtual interfaces," using scientific understanding of human characteristics and physical properties, I aim to develop a next-generation user interface that supports interaction between people and information. I started this theme in October 2022 as research on a new form of user interface that fuses tangible interfaces and virtual interfaces. Tangible interfaces enable users to access information while touching real objects and intuitively interact with information as an extension of their daily lives. They, however, use real objects, so they are subject to time and physical constraints. On the contrary, virtual interfaces enable users to access information virtually, so time and physical constraints are fewer; however, it is more difficult for users to interact with information as an extension of their daily lives because they have to wear a head-mounted display or use unfamiliar devices. Accordingly, I imagine a new user interface that merges tangible and virtual interfaces by, for example, adding a tangible interface to the cross reality (XR) approach. I am considering tangible interfaces as one solution to the question of how to provide natural XR experiences for people.

—So, letting users feel the texture of objects in a touchless manner makes it possible to provide them with a more convenient and enriching experience, right?

We have shown the possibility of presenting textures, such as weight and hardness, of objects by combining hand movements and video. We are now entering a research phase of increasing the reality of the presentation. I believe that in the future, our research results could be applied to present information in online-shopping and other applications. For example, you may have heard stories of how the firmness of a pillow or the feel of clothes bought online differed from what you imagined. Although the use of video can express a feel of a material to some extent, it has yet to accurately convey the texture to the potential buyer. Further development of information-presentation technology that conveys the texture of objects will make it possible to correctly convey information, including texture, to buyers so that they can buy items that match the ones they imagine. Conveying textures, such as the warmth of skin and feel of palms with family members living in remote locations makes deeper communication possible. By linking texture-manipulation technology using touchless interfaces with appropriate visual-expression technology, information presentation using illusions can be made richer and more elaborate.

Deepening research through the integration of psychology and engineering

—You originally majored in psychology, right?

In Japan, illusions and perception are studied in the field of psychology. We are currently using a psychological approach to explain the phenomena concerning illusions and perception and applying the phenomena to everyday life through integration with engineering technology. Since psychology is the study of people, psychological experiments take time, and unlike mechanical systems, people do not always respond in exactly the same way to the same stimuli, interactions, etc. It is therefore difficult to reproduce and collect data, and it also takes time to build theories using the collected data. Research on engineering is evolving at a dizzying pace, so how to close the gap in speeds of these two research fields will be the key factor in research on illusions and perception. Artificial intelligence (AI) has developed remarkably, and I believe that by using AI, we can close this gap.

If it were possible to create a complete human model and analyze it using Digital Twin Computing, which uses AI, I believe the above problem could be solved. However, people interact with each other and react differently according to the environment; therefore, it would not be straightforward to create a human model by taking all the data and training the model using them.

In psychology, we analyze elements of human perception separately, for example, visual perception, auditory perception, and interpersonal perception. I believe it is possible to use AI to model each element, and, in fact, such efforts have been made. By fusing these models, we will be able to explain the full picture of the human mind.

Scientifically understanding the psychological characteristics of the recipients of information is also important in the field of user interfaces. I believe that scientific research concerning user interfaces can only be completed by fully understanding how the nature of an object to be conveyed can be expressed via an interface and why it is conveyed to users.

Break the mold and create new values by integrating the values of others with your own values

—What do you keep in mind as a researcher and what do you aim to achieve in the future?

I think that researchers tend to get caught up in their own logic and think that their values are correct when they immerse themselves in their research. If you continue to conduct your research while being confined to your own values, you may begin to struggle as you are not really sure if you are doing the right thing or hit a wall. I became a group leader three years ago and have had many opportunities to learn about the values of others in various ways. Of course, sometimes I feel that the values others hold do not match those of mine; regardless, I have recently come to strongly believe that it is important to understand and recognize the values of others then create new values by integrating their values with my own and that by doing so, I can grow as a person.

For example, the speed of recent academic research on AI is remarkable, and it is not uncommon for a problem that could not be solved yesterday to suddenly be solved today. The researcher working on that problem must look for their next research target. In that case, some researchers may lose sight of their goals because their research field suddenly becomes obsolete or others may shortsightedly set easy targets in an attempt to stay just slightly ahead of new technologies. Therefore, it is crucial to acquire knowledge in multiple fields, connect a variety of knowledge, and expand your own research area. To that end, it is important to create new values by merging the values of others with your own. Even if there is one answer to a problem, there is often more than one way to solve that problem. The speed and effectiveness of each solution will differ, and in some cases, combining several solutions may create synergy. By combining several solutions, you may also discover new problems. I believe that learning and combining knowledge from multiple disciplines to solve problems will naturally expand your research area and your capability as a researcher will broaden.

I hope to continue to be a researcher, but I want to be a researcher who can accommodate and combine diverse values and continue to create and provide new values. As I create new values, I may look at other areas or themes. I think that even in such a case, I always have something to rely on as a starting point, and by using that point as a foundation, I can make great progress. My foundation and starting point is psychology, and I intend to absorb various new knowledge on the basis of psychology. I want to continue my research so that I can successfully integrate psychology and engineering and contribute to society.

—Do you have a message for younger researchers?

I know that your superiors and peers expect a lot from you. It is, of course, important to meet those expectations, but also exceed those expectations and break the mold. Since meeting expectations means staying within the range imposed by your superiors and peers, you will inevitably have less scope and fewer opportunities for growth. I believe that the moment you exceed those expectations, you will have more discussions with your superiors and peers. By having discussions, you can involve the people around you and move the whole process forward. To do so, it is necessary to have a foundation, or something to rely on, which may be knowledge including your own experience, knowledge of others, or accumulation of such knowledge. Let us exceed the expectations of those around us, go beyond our imagination, and move forward together.

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■ Interviewee profile

Takahiro Kawabe received a Doctor of Psychology from Kyushu University, Fukuoka, in 2005. In 2011, he joined NTT Communication Science Laboratories, where he studies human material recognition and cross-modal perception. He received the 2013 JPA Award for International Contributions to Psychology: Award for Distinguished Early and Middle Career Contributions from the Japanese Psychological Association. He is a member of the Vision Sciences Society and the Vision Society of Japan.

Analysis of Complex Data Based on C*-algebra and Operator Theory to Explain Unknown Phenomena in Data Analysis Using Mathematical Theories

Yuka Hashimoto
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Abstract

Current neural networks achieve a high level of accuracy when constructing learning models using large amounts of data, but learning accuracy drops significantly when only a small amount of data can be obtained for learning. Additionally, in the field of automating the operation of current information and communication technology (ICT) systems that detect anomalies beforehand, data analysis is performed under a variety of conditions, so there is a need for analyzing data that behaves in complex ways such as "data with noise" or "mutual interaction between multiple items of data and continuous change." This time, we talked with NTT Distinguished Researcher Yuka Hashimoto to learn about her research in applying advanced mathematical theories such as C*-algebra and operator theory to diverse social problems including improving the accuracy of data analysis even with a small amount of data and automating the operation of ICT systems.

Keywords: C-algebra, operator theory, data analysis*

Applying advanced mathematical theories to data analysis to solve social problems in diverse fields including communications

—Dr. Hashimoto, what type of technology is "analysis of complex data based on C-algebra and operator theory"?*

Analysis of complex data based on C*-algebra and operator theory is technology for expressing and analyzing complex data using the concept of an "operator" as a generalized matrix. To give some background on the need for this technology, automating the operation of current information and communication technology (ICT) systems requires the analysis of data that behaves in complex ways such as "data with noise" or "mutual interaction between multiple items of data and continuous change." For example, in network communication traffic, the mutual interaction of communication traffic at various locations must be simultaneously considered such as "when traffic increases at point A, the traffic at point B also increases." In addition, when investigating the state of equipment and devices, different types of data must be simultaneously considered such as CPU (central processing unit) usage and memory usage. Moreover, when constructing a learning model using a current neural network, a large amount of data is needed, but in actuality, there are cases in which a highly accurate learning model cannot be constructed due to an insufficient amount of data, so there is a growing demand for technology that can perform analysis with high accuracy even with a small amount of data.

In response to this problem, a mathematical theory that has been commonly used up to now involves the observing of a single value (scalar value) such as a real number or complex number. In contrast, analysis of complex data based on C^*-algebra and operator theory proposes a new framework for data analysis that uses advanced mathematical theories such as C^*-algebra and operator theory to integrate (make continuous), abstract, and simplify models or data. If we apply to data analysis the property in which an object can be considered to have multiple values simultaneously as an extension of conventional theories, multiple values can be extracted from one type of data when analyzing data, thereby enabling high-efficiency, high-accuracy data analysis.

My research into this technology of analysis of complex data based on C^*-algebra and operator theory came about when I had been toying with the idea that matrices or mathematical concepts extending matrices could be used to good effect for analyzing the relationships among multiple data items. Then, on being taught about C^*-algebra from my co-researchers, I began to apply it in earnest. Mathematical theories used in analysis of complex data based on C^*-algebra and operator theory are not limited to specific application fields. Rather, as a framework, they are very general in nature, which means that they can be deployed in a variety of fields beyond communications and ICT systems. I am also studying whether problems can be solved by using a continuous framework to represent time-series-like changes as in the propagation of light. For example, in studies that I am now conducting, I'm using this research to analyze biological data such as the brain waves and body temperature of animals in the natural world. In addition, using data that has been analyzed with high accuracy should make it possible to detect anomalies such as disasters or faults beforehand or to mount responses to unknown anomalies based on communication traffic and signals. In this way, I am conducting interdisciplinary research in machine learning, mathematics, physics, biology, and quantum mechanics and other fields regardless of the framework of communications. My target here is a comprehensive approach beyond traditional field boundaries to enhance industry and explain natural and social phenomena (**Fig. 1**).

—Please explain the specific technique behind analysis of complex data based on C^*-algebra and operator theory.

In analysis of complex data based on C^*-algebra and operator theory, data that continuously changes over time is treated as a mathematical object for analysis. When analyzing time-series data by conventional means, data at different times are treated as a collection of separate "points." In contrast, treating that data as a mathematical object called a function, that is, as a "line," enables data analysis on a more advanced level.

In addition, high-accuracy analysis even with a small amount of data becomes possible by finding values such as eigenvalues or singular values that characterize that data. In existing research, such values have been found by abstracting the data to convert it to mathematical information and to then return it to discrete values to extract approximate features. This technique, however, has a drawback in that the properties of the data are lost and the accuracy of the analysis drops. In analysis of complex data based on C^*-algebra and operator theory, I have been working on a technique for analyzing data continuously while preventing a loss of information as much as possible. A technical issue here is that the property of being continuous (infinite dimensional) is completely different from the property of being discrete (finite dimensional) and that unimaginable concepts from each dimension frequently arise. This makes it difficult to analyze data simply by attempting to extend discrete data to continuous data, so I am studying the application of advanced mathematical knowledge to determine how best to extend present concepts. Handling data in continuous form requires advanced mathematical knowledge, so at present, I myself can proceed with my research with the help of many experts.

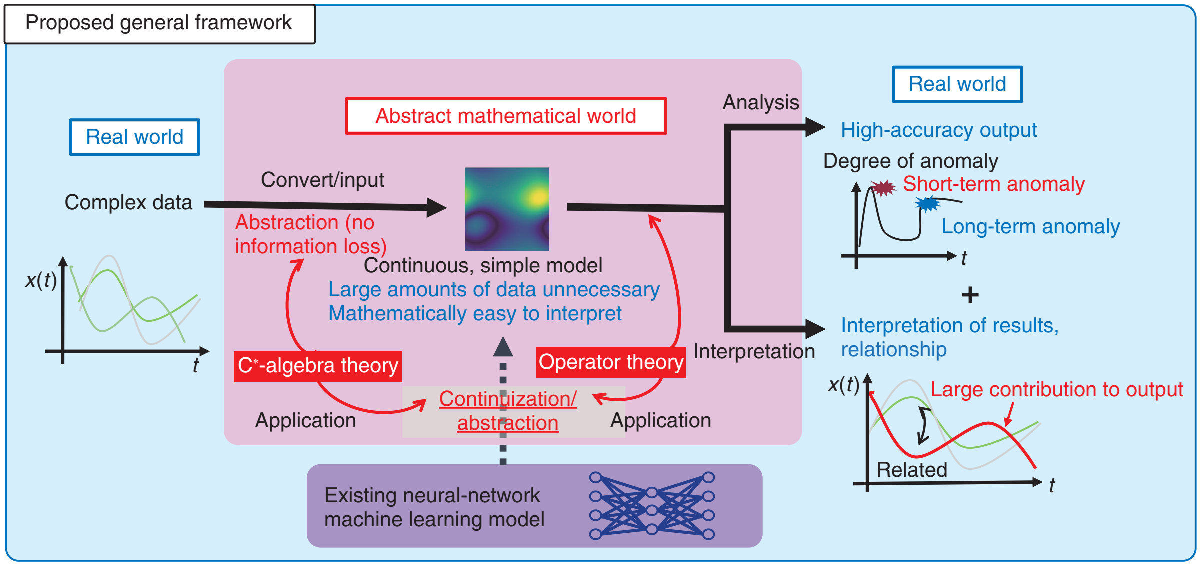


Fig. 1. Overview of analysis of complex data based on C*-algebra and operator theory.

—Are there any difficult points to deal with in your research of analysis of complex data based on C-algebra and operator theory?*

A major problem is how to link data in the real world with the theoretical world of mathematics. For example, in neural-network analysis, neural networks are studied as a simple structure having a form that is easy to mathematically describe in theory. However, to completely reproduce an actual and complex neural network, a variety of operations are needed such as data processing or the cutting of values during the information-processing step, which at present is not fully reflected in neural networks. Improving accuracy by performing such detailed operations has actually been demonstrated by experimental results. My current aim therefore is to construct a high-accuracy neural network by newly conducting as many studies as possible on two key points. These are "what kind of mechanism does a neural network use to operate," and once that is explained, "how can accuracy be further improved." In this regard, given that there are many cases in data analysis that can be thought of as simple in theory, I would like to make every effort in the construction of a technique using theoretical analysis and mathematical theories to enable data analysis while incorporating many realistic settings.

In addition, I pay particular attention to guaranteeing theoretical accuracy in my research. In the case of neural networks, for example, a data model used in training may fit a certain type of data thereby raising the accuracy of data analysis, but there are cases in which the same model does not fit other types of data resulting in a drop in accuracy. Of course, in actual research, this can happen even for results described in a paper. Even if a paper states that "XX% accuracy was achieved using this data," it cannot necessarily be guaranteed that a similar improvement in accuracy can be expected when actually attempting to use that technology with one's own settings. It often happens that changing the data changes the results, so to prevent such a problem from occurring, it is necessary to place importance on theoretically investigating beforehand whether high-accuracy data analysis can be performed for all sorts of data. In this way, it is easy to make this technology attractive even to people accustomed to using technology—I feel that it's an important undertaking to get people to understand that this technology can be used without worry.

Toward research that places importance on collaboration with other fields while having a broad perspective

—Going forward, what is your research vision for analysis of complex data based on C-algebra and operator theory?*

My research vision for the future is to apply this technology to a variety of fields requiring the analysis

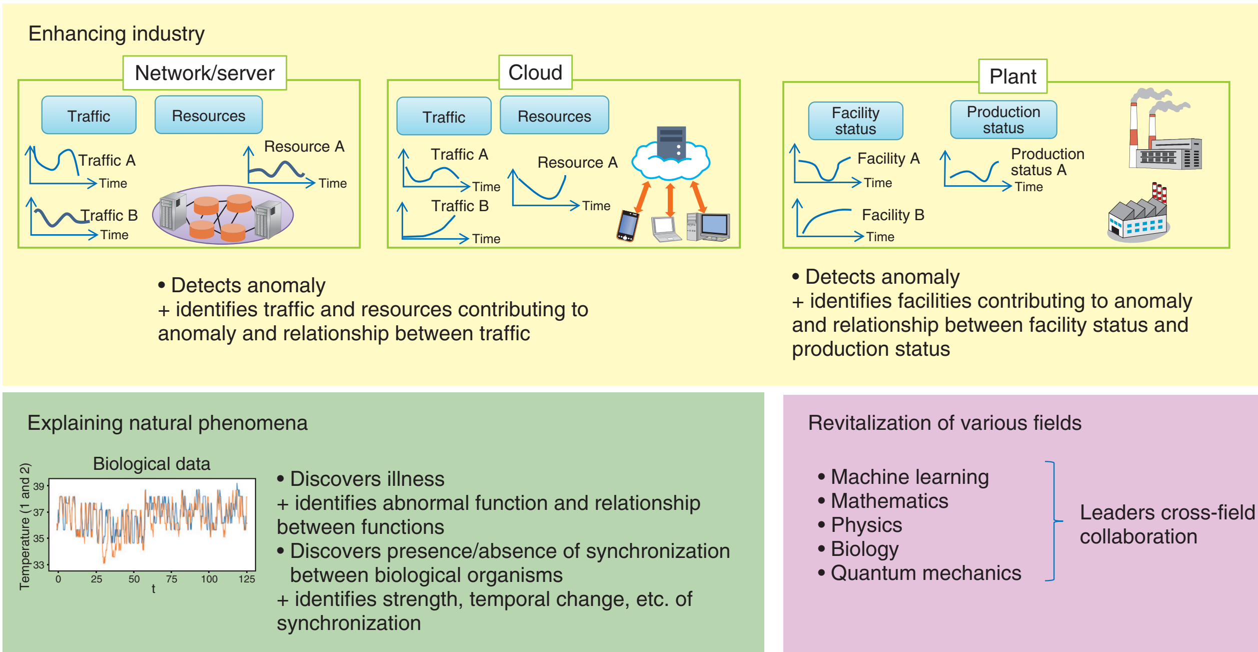
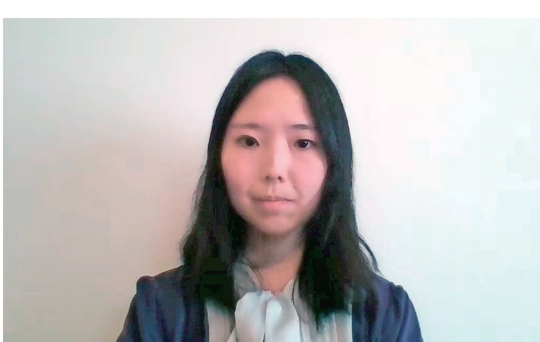


Fig. 2. Application examples of analysis of complex data based on C*-algebra and operator theory.

of complex data, including communication networks, with the aim of solving many social problems. For example, given that light changes continuously, I believe that explaining the properties of light using the framework of analysis of complex data based on C*-algebra and operator theory can contribute to the development of NTT's Innovative Optical and Wireless Network (IOWN).

In addition, problems analyzed in biology have features similar to those of data analysis in communication networks, so as a new research vision to pursue from here on, I would like to explain certain animal properties such as animal sleep in coordination and cooperation with experts in biology. A mathematical framework used in analysis of complex data based on C*-algebra and operator theory is very general in nature, so I would like to broaden my collaboration with people in diverse fields. Thinking that I can apply this technology to problems in various fields and thereby unite issues that up to now have been studied separately, my aim is to help find solutions to diverse problems in industry and the natural world (**Fig. 2**).



—Dr. Hashimoto, please leave us with a message for researchers, students, and business partners.

In my research of analysis of complex data based on C*-algebra and operator theory, I have been working to bridge the gap between application and theory in mathematics. For this reason, there have been many opportunities to conduct research together with a variety of people and there have been many occasions to share results within the company. In such an environment, research being conducted by a small group of people can be shared with another group in the manner, for example, of "I wonder if this technology could be used here as well?" In this way, getting an idea about an application that you have not thought of is very beneficial and can also generate a moment of joy in your research activity. Therefore, I place great importance on pursuing my research while interacting with many people.

NTT conducts a wide range of research from basic research to applied research, and NTT Network Service Systems Laboratories that I belong to works on both application and theory, which makes it a very attractive environment. For example, talking with the people around me involved in actual development enables me to learn quickly about their goals and actual problems and to receive comments from an academic point of view. This helps me to move my research forward. To give an example of this, the department that I belong to researches and develops fundamental technologies for the automation of ICT system operations, so I am surrounded by colleagues having a wealth of knowledge and diverse backgrounds, which gives me daily inspiration in my research.

Of course, specializing in one field is important for a researcher, and your field should not be ignored. On the other hand, you may miss many things by focusing excessively on only one field. In research, it is important to have a broad perspective, so I try to stay active without being stuck in one field as much as possible. To be sure, an environment that promotes joint research with people in related fields makes it easy to obtain an understanding of one's surroundings and to communicate with others, which facilitates research. Yet, by taking a step outside one's everyday environment and listening to people in other fields or participating in academic societies in fields different than usual, you should be able to obtain new ways of looking at things that you had not thought about before. I myself, by cooperating with people in other fields different from those I had so far been exposed to, I have noticed mistakes in my own way of thinking, and when talking to people in other fields and not being able to communicate at all, I have become aware that "I have been thinking in only a very narrow space." I feel that experiences such as these are a huge plus for a researcher.

Taking a step forward by oneself into a new area is difficult, but I think that an interesting world that you have never seen before waits for you there. I too would like to broaden my field of view even further from here on, and to everyone reading this, I would like to ask you first and foremost to try talking to people in fields different than your own. This will open new doors for you!

■ Interviewee profile

Yuka Hashimoto received her Master's Degree in science from Keio University in 2018 and entered Nippon Telegraph and Telephone Corporation (NTT) in the same year. She received her Ph.D. in science from Keio University in 2022. She has been an NTT Distinguished Researcher since 2023 engaged in the research of network operation automation. She received the Yonezawa Award from Keio University in 2021, the Fujiwara Award from Keio University in 2018, and the Encouragement Award at the 78th National Convention of the Information Processing Society of Japan (IPSJ) in 2017.

Design a World Where Everyone Can Flourish by Deciphering the Future of Individuals, Society, and the Earth—Communication Science That Connects the Past, Present, and Future through Diverse Knowledge and Technologies

Futoshi Naya

Abstract

Since its establishment, NTT Communication Science Laboratories (CS Labs) has been engaged in researching basic theories that address the essence of human science and information science and creating innovative technologies that will bring about changes in society to achieve communication that reaches the heart between humans and between humans and computers. This article introduces recent research activities of CS Labs from the perspective of deciphering individuals, society, and the Earth.

Keywords: communication science, artificial intelligence, brain science

1. Deciphering individuals

In everyday communication, a person can make inferences about how another person is feeling or what they are going to do on the basis of their behavior or situation, even if they do not express words or facial expressions. Many current information and communication technology devices require explicit commands, voice, and gestures, but if these devices can understand the other person's state of mind like a human, we can expect more natural and smooth communication between humans and machines.

We at NTT Communications Science Laboratories (CS Labs) have been researching *mind-reading technology* [1], which interprets such latent mental states from unconscious bodily movements and automatic physiological responses. We are conducting research on estimating various cognitive states of people in real time by non-invasively and conveniently measuring eye movements and pupil changes, which is information that appears on the surface of the body. Previous research has shown that the pupil of an observer constricts when they see an attractive face; conversely, when the pupil of an observer constricts unconsciously by changing the luminance contrast around the image of the face, the attractiveness of the face they are looking at increases. This is the first result to show that the constriction of the pupil affects the judgment of preference, while at the same time reversing the conventional theory that the pupil dilates when looking at attractive faces. In another study, we also found that the pupils' response to the brightness of the visual stimulus presented in the direction of the sound to which we are paying attention

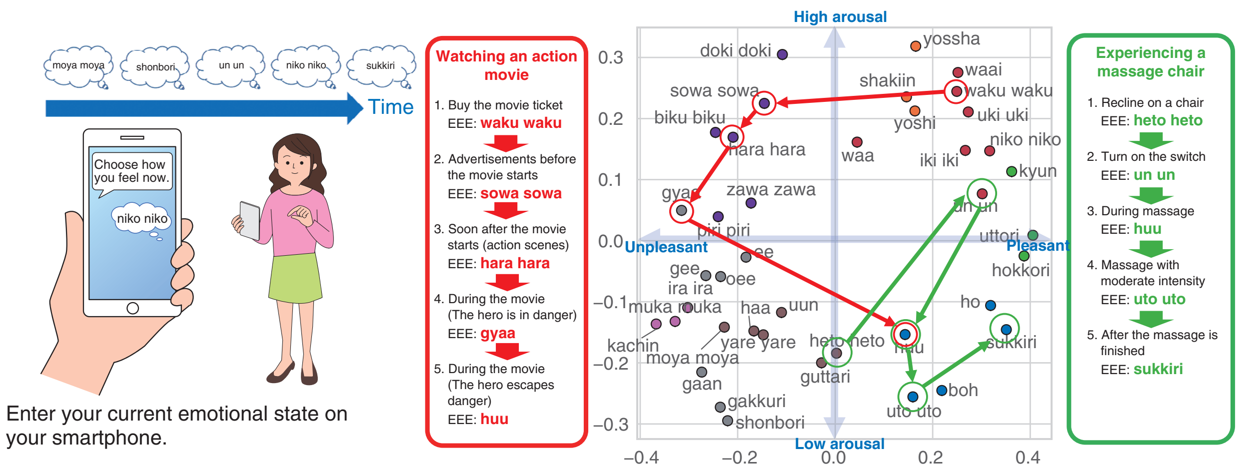


Fig. 1. Intuitive recording and visualization of mental and physical states using EEEs.

reflects which sound we are paying attention to among sounds presented separately to the left and right ears via headphones [2]. This result not only suggests that the brain mechanism of attention is common to some extent between vision and hearing but also the possibility of developing hearing-support devices such as hearing aids by automatically judging and extracting the direction and object of the sound that the user wants to hear from the pupil response.

The aforementioned mental states, i.e., facial preference and attention, are often felt unconsciously, and it is difficult for a person to clearly articulate or become aware of them. An article in this issue introduces the latest research results on mindfulness meditation's physiological, psychological, and neural mechanisms [3], which has attracted attention as a practical method for cultivating the state of being aware of sensations, emotions, and other experiences in the present moment without suppression.

2. Deciphering our society

Next, I will introduce research cases to understand various social situations caused by various human interactions.

To prevent the spread of COVID-19, new lifestyles such as telework and remote classes are becoming more common. However, fewer opportunities for face-to-face interaction have led to an increase in the number of people who feel isolated, alienated, and anxious with a diminished sense of belonging. To understand and pursue people's future well-being, that is, the state of being physically, mentally, and socially fulfilled and alive, it is important to clarify the situations and factors that improve the well-being of individuals. To clarify this issue from the perspective of the relationship between individuals and teams and society, CS Labs developed a scale to measure personality traits of people toward teams and society based on the view of "Self as We" advocated by Professor Yasuo Deguchi of the Graduate School of Literature at Kyoto University. We also developed a method and smartphone application to measure the well-being of individuals and teams in a multifaceted and sustained manner, which was released in 2020 [4]. To capture changes in an individual's subjective mental and physical states, the smartphone application records intuitive and physical experiences as *embodied emotional expressions* (*EEEs*), which uses exclamation words, onomatopoeia, and pictograms, and these records are visualized in two dimensions using the *embodied emotional expression map* (Horizontal axis: pleasant/unpleasant; Vertical axis: high/low arousal) (**Fig. 1**). This makes it possible to capture subjective and ever-changing mental states before and after various experiences while reducing the burden on the user. This can also be used by members of a group who are having a shared experience to analyze the relationship between group well-being and mood changes such as meeting satisfaction.

We also developed a method for visualizing and sharing values about what improves the well-being of individuals. We analyzed 3900 responses to a questionnaire survey from about 1300 people asking them to list 3 things (values) that are important to them. The results indicated that those values can be classified into 4 categories: self-related (I), relationships with others (We), relationships with local communities and society (Society), and relationships with the world and nature (Universe). Our Well-being Cards (**Fig. 2**), which are based on this classification of values, are used in various workshops for elementary school students as a tool to deepen their understanding of their values and the diversity of the values of those around them by sharing them with each other. Our Well-being Cards are available for download from the web with instructions on how to use them [5].

We have seen a lot of news and articles about ChatGPT, which is a generative artificial intelligence (AI). At CS Labs, we are conducting somewhat unusual research using interactive AI technology. We developed a dialogue agent that helps users who have difficulty in directly communicating with others, such as patients with depression, to disclose their problems and communicate them to experts [6]. After establishing a trusting relationship through a conversation with a chatbot that is an interactive agent and allowing both parties to self-disclose, we conducted an experiment to determine how the trust relationship between users and experts changes when the chatbot introduces a trusted human expert.

In the experiment, 47 participants chatted with the chatbot for about 15 minutes every day for 4 weeks. The experimenter interviewed them online for 1 hour. The participants who only built trust with the chatbot as Step 1 and those who were later introduced to an expert by the chatbot as Step 2 were asked to rate their trust in the chatbot and the expert on a 7-point scale (1: not at all trustworthy to 7: very trustworthy). There was no change in the level of trust in the chatbot between the cases in which Step 2 was not conducted and those in which Step 2 was conducted. The level of trust in the chatbot was as high as 6, while that in the expert was significantly higher when Step 2 was conducted. We also found that when the chatbot asked the participants if they could share what they had disclosed to it with the expert, they were more likely to be positive and motivated by it. Most research on interactive agents had focused on the relationship between people and agents, but this research is unique in that it aims at connecting people through agents. Technology that learns the relationship between people from conversations and situations will become increasingly important, and CS Labs is conducting research that uses AI to recognize the purpose of dialogue and dialogue situations from multimodal information such as audio, image, and

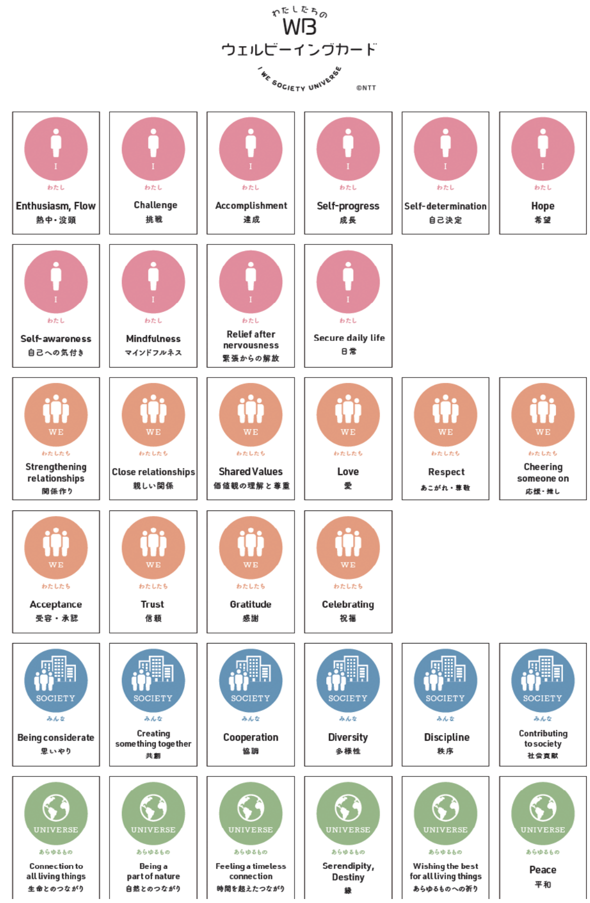


Fig. 2. Our Well-being Cards.

language information in dialogue scenes [7].

3. Deciphering the Earth (universe)

It is the ultimate goal of science to clarify and reproduce the structure and laws behind all things in nature. Advances in sensing technology have led to the acquisition and distribution of high-definition and high-quality image data, for example, observations of typhoon development by the Geostationary Metrological Satellite Himawari. With the increasing number of natural disasters, expectations for predicting the future of complex physical phenomena related to fluids, such as weather and ocean currents, are increasing by accurately modeling their development from observation data and reproducing them through simulation. Humans have manually discovered the laws behind physical phenomena (e.g., Newton's laws of motion, equations of motion, etc.) from observed data. However, the more complex the phenomenon, the more difficult it is to model, and the more limited it is to design equations manually. The discovery of such laws and the automatic simulations that faithfully reproduce phenomena using AI is a very challenging task. In an article in this issue, the research of physical simulation based on the data-driven approach is introduced in detail as a machine-learning technology that reproduces physical phenomena only from observation data without manually designing equations in advance [8].

The above is an example of research aimed at modeling physical phenomena. For complex analyses such as meteorological data, it is necessary to conduct enormous calculations at high speed. There are increasing expectations for quantum computers, which are increasingly being reported for practical use. However, overcoming quantum errors is an extremely important issue to resolve to put such computers into practical use. Quantum computers can execute high-speed parallel calculations using quantum bits, which is quantum mechanical superposition information. However, since errors due to noise are likely to occur in quantum calculations, it is important to have a technique to verify whether the calculation results of a quantum computer are correct. An article in this issue describes methods for efficiently verifying the correctness of quantum-computer calculation results [9].

In terms of understanding the universe, the Greek philosopher and mathematician Pythagoras preached around the 6th century BCE that “All Is Number” and believed that everything in the universe could be understood by mathematics according to the laws of numbers rather than human subjectivity. From the latest research results of the Institute of Fundamental Mathematics established in CS Labs in October 2021, we developed a method for calculating the heat kernel, which is the basic solution for the time evolution of a mathematical model that describes the minute interaction between light and matter, such as atoms, using an algebraic theory called representation theory [10]. This study also reveals an interesting relationship between the heat kernel and zeta function in the Riemann hypothesis, a well-known open problem in modern mathematics.

4. Designing our future

In this article, I have introduced research efforts at CS Labs from the viewpoint of deciphering individuals, society, and the Earth (universe). In addition to AI, technological progress will continue to accelerate, but we are also being asked about our responsibility and ethics in creating and using technology. We will deepen our understanding of the diversity of individuals, societies, and the Earth, which is constantly changing, and pursue the truth of the universe. We will also design a sustainable and better future society in harmony with individuals, societies, and the changing global environment and conduct further research and development toward this goal.

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Machine Learning That Reproduces Physical Phenomena from Data

Yusuke Tanaka

Abstract

Machine learning has made remarkable progress and has been used successfully in various applications. Our research goal is to use machine learning to simulate physical phenomena. In this article, I introduce machine-learning models that can accurately reproduce physical phenomena from observed data by using prior knowledge of physics. I also discuss the prospects of and value that can be created with this research.

Keywords: simulation, physical laws, physics-informed machine learning

1. Machine learning and physics simulation

The dynamics of many physical phenomena are described with differential equations. Traditionally, experts in various fields have designed equations to reproduce physical phenomena through observation and theoretical investigation (top of **Fig. 1**). Solving these equations can simulate physical phenomena under various conditions using a computer without real-world experiments. Physical simulations are used in various real-world applications, such as weather forecasting and aircraft design. However, the design of equations is very costly, and there are limitations in modeling complex phenomena, such as weather, in the real world.

Advances in information and communication technologies have attracted attention to data-driven approaches. Machine learning has revealed that various real-world problems can be solved with extremely high accuracy by using large-scale data.

Is it possible to simulate physical phenomena using machine learning? To answer this question, my research colleagues and I are studying machine-learning models for accurately reproducing physical phenomena from observed data. Unlike the conventional approach of handcrafting differential equations described above, we are developing a model for automatically constructing a highly accurate physics simulator from data without the need to design equations for the phenomena (bottom of Fig. 1).

2. Limitations of current machine-learning models

Behind the data-driven approach for physics simulation was a technological breakthrough: Neural ordinary differential equation (NODE) [1], published in 2018. NODE uses observed data to learn the neural-network parameters to represent a phenomenon without designing an equation (see the orange box "Machine-learning model" in Fig. 1).

Is it possible to simulate physical phenomena by naively applying NODE to observed data? Unfortunately, achieving a highly accurate simulation is difficult. **Figure 2** shows the results of an experiment using a pendulum as an example of a simple physical system. We provide the dynamics of a pendulum in the upper center of Fig. 2, with the angle on the horizontal axis and the angular momentum on the vertical axis. Due to the energy conservation law, the black dot (i.e., the system's state) continues to move in the green orbit. Given the observed data of such motion (upper right of Fig. 2), the simulation result using NODE is the lower part of Fig. 2. The simulated trajectory deviates from the true orbit depicted in green. The simulation accuracy significantly degrades when

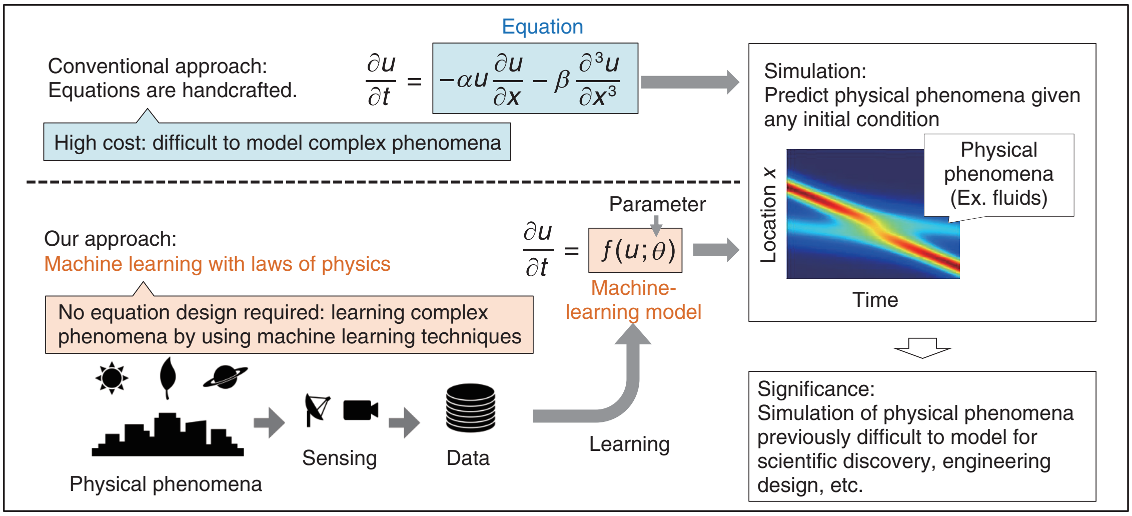

Fig. 1. Differences in approaches.

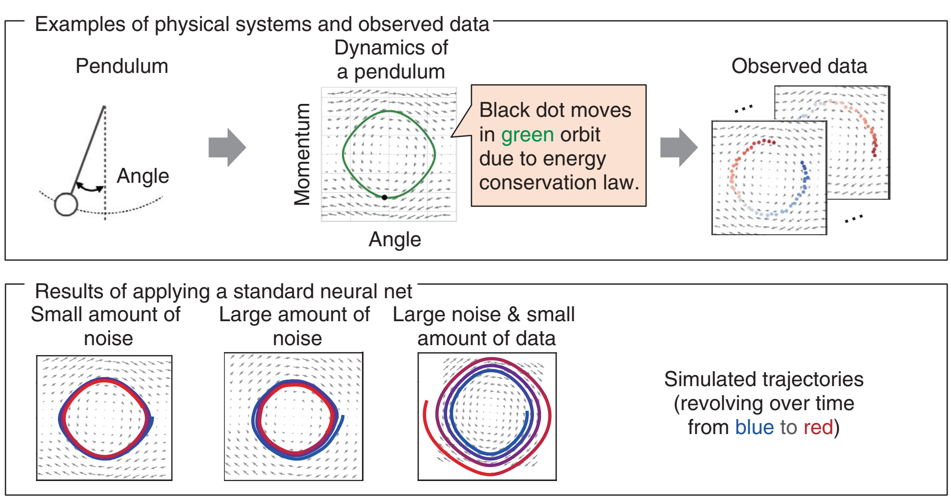

Fig. 2. Limitations of current machine-learning models.

only a small amount of data containing a large amount of noise is available.

3. Difficulty in learning

Why did we obtain these results? Machine-learning models are known to be highly expressive and have the potential to accurately model large and complex physical phenomena. Due to their high expressive power, it is not easy to identify a model that accurately reproduces a physical phenomenon from the vast search space of machine-learning models (the gray region in **Fig. 3**). Learning becomes even more difficult when only a small amount of data containing a large amount of noise or missing values is available.

4. Introducing prior knowledge of physics

When data are scarce containing a large amount of noise or missing values, it is effective to introduce prior knowledge that can provide hints to guide appropriate learning. The research field that aims to use prior knowledge from physics for training is called physics-informed machine learning [2] and has

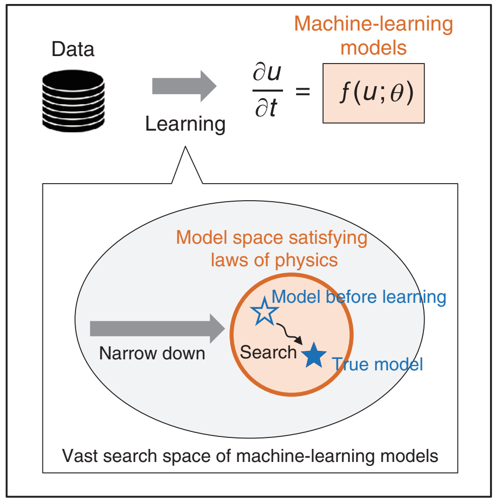

Fig. 3. Narrowing down search space via prior knowledge.

been gaining attention. It is expected to narrow the search space and effectively identify models that accurately reproduce physical phenomena (see orange region in Fig. 3). The simplest way to introduce prior knowledge is to assume an equation, as with the conventional approach illustrated in Fig. 1, and learn the physical parameters (α and β in Fig. 1) in the equation from the data. However, this approach narrows the search space too much. It does not take advantage of the high expressive power of machine-learning models, making it difficult to apply to complex phenomena that cannot be represented with known equations. Therefore, we focused on using the laws of physics as prior knowledge. This enables us to maintain the expressive power of the machine-learning model while appropriately narrowing the search space.

5. Machine-learning model incorporating the energy conservation law

Throughout history, various physical laws have been discovered, including conservation of energy, conservation of mass, and conservation of momentum. I introduce a case study of incorporating the energy conservation law, which is generally obeyed in dynamical systems, into a machine-learning model. The theory of Hamiltonian mechanics is a convenient way to describe physical phenomena that obey the energy conservation law. In Hamiltonian mechanics, instead of designing equations that represent physical phenomena, the energy function of the physical system is designed. Once the energy function is determined, the physical dynamics can be systematically obtained in accordance with the Hamilton's equation. It should be noted that the dynamics derived from the Hamilton's equation can be guaranteed to always obey the energy conservation law. The Hamiltonian neural network (HNN) [3] was proposed to train a model for estimating from data the physical phenomena that follow the energy conservation law by replacing the energy function with a neural network. With neural-network-based models, however, it is implicitly assumed that data of sufficient quality and quantity are available. When such data are unavailable, the models often over-fit to the data, resulting in a loss of accuracy. Therefore, we developed a Gaussian-process model [4] incorporating the theory of Hamiltonian mechanics. The Gaussian process is a machine-learning model advantageous for learning from a small amount of data with a large amount of noise. **Figure 4** shows a schematic diagram of this model. The model has the following three features. The first feature is estimating the energy function by a Gaussian process instead of a neural network. This is expected to avoid overfitting and estimate the energy function even when the amount of data used for training is small. The second feature is deriving the dynamics using the Hamilton's equation. It can be guaranteed that the Gaussian process will always satisfy the energy conservation law. The third feature is introducing an observation model for noisy data. This enables robust learning even from noisy data. Our model enables effective learning of

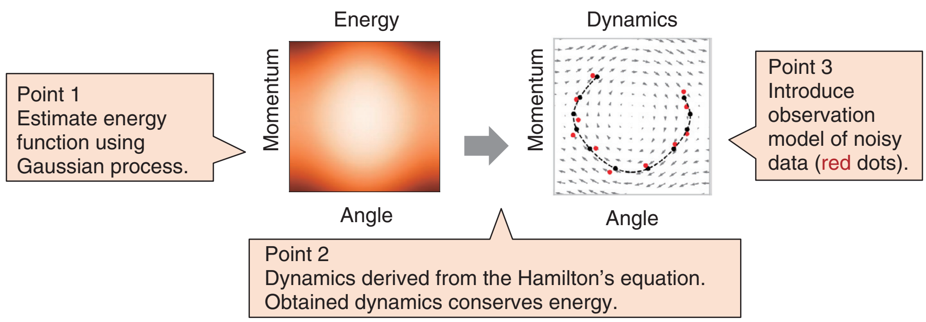

Fig. 4. Our Gaussian-process model.

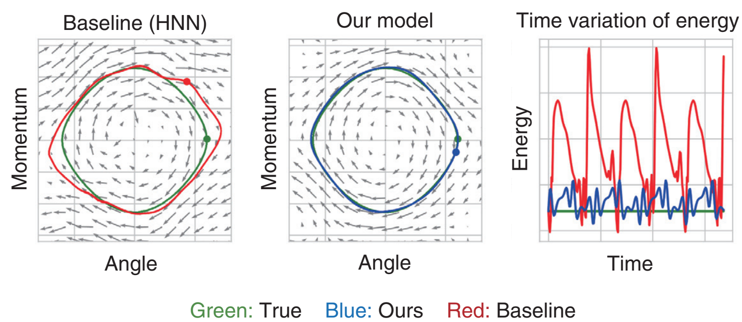

Fig. 5. Simulation results.

physical phenomena that obey the energy conservation law, even when data of insufficient quality and quantity are available and enables highly accurate simulations.

Figure 5 shows the results of simulating the motion of a pendulum using the conventional model (i.e., HNN) and our model. From comparing the left and middle of Fig. 5, our model is more accurate in simulating the true trajectory (in green). The right of Fig. 5 plots the energy variation over time. The true value (in green) is constant due to the energy conservation law. Our model captures the energy value more accurately than the conventional model. These results indicate that our model accurately simulates physical phenomena while obeying the energy conservation law.

6. Prospects and applications

There are still limitations in the input data required for training and the types of physical phenomena that can be handled. We will aim to reproduce more complex phenomena on the basis of more realistic observations for real-world applications. In the research introduced in this article, we assumed that physical variables, such as the angle of a pendulum, can be observed. However, as physical systems become more complex, it is not easy to obtain such variables directly. However, sensor values, images, and videos related to physical phenomena may be relatively easy to observe. We need a technology that can reproduce physical phenomena even when such types of inputs are given. In addition, complex real-world phenomena, such as meteorological phenomena, are often represented with a partial differential equation, and it is desirable to extend the technology to such equations.

As this research field develops, it is expected to have a variety of applications. For example, weather forecasting can address environmental issues, such as climate change, or reproduce phenomena such as typhoons and tsunamis for disaster prevention. The simulation of complex weather phenomena in the real world, which cannot be represented with manually crafted equations, is expected to provide more accurate forecasting. Aircraft, automobiles, semiconductors, and other products are designed using physics simulation. If physics simulators can be automatically acquired from observed data, it will be possible to make simulators more accurate and efficient when creating new products. A simulator can also be applied to artificial-intelligence tasks, such as scene understanding by robots. For example, when a human sees an image of a messy stack of packages, they can infer that it may collapse. If robots can learn physical phenomena using the ideas in this research, we believe it will be possible for them to avoid risks in such situations.

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Understanding Mindful Awareness in Mindfulness Meditation—Investigation of the Psychological, Physiological, and Neural Mechanisms of Mindfulness Meditation

Masahiro Fujino

Abstract

Mindfulness meditation, which is used to cultivate a state of awareness of the experience of the present moment as it is (called *mindful awareness*), has been shown to contribute to enhancing well-being. There are two types of mindfulness meditation: focused attention meditation and open monitoring meditation. To understand mindful awareness, our group focused on the psychological, physiological, and neural mechanisms of open monitoring meditation thought to be involved in mindful awareness.

Keywords: mindfulness, mindful awareness, open monitoring meditation

1. The importance of awareness of the present moment experience as it is

Mindfulness is the state of receptive attention to and awareness of ongoing events and experiences as they are. "Receptive attention" means, as opposed to intentionally focusing attention on a specific object, the spontaneous broadening of attention by letting go of such an intention. "Awareness" means the bringing to consciousness of previously unaware experiences. "Experiences" means the sensations, feelings, and thoughts that arise one after another in one's body and mind. "As they are" means an attitude of not reacting, judging, or inhibiting the experiences within awareness after broadening of attention. We call this kind of awareness *mindful awareness* in this article.

Many studies have shown that mindful awareness of negative experiences can alleviate symptoms such as depression and anxiety [1]. However, it has also been reported that people who think they are aware of negative experiences as they are may react or suppress them unconsciously, resulting in adverse events such as increased anxiety or tension [2]. Considering these studies and reports, it is clear that the key to increasing effectiveness while reducing adverse events of mindfulness practice is to be aware of the experience as it is, that is, mindful awareness. To understand this mindful awareness, we need to elucidate its mechanism.

2. Focused attention and open monitoring meditations

There are two types of mindfulness meditation: focused attention meditation (FAM) and open monitoring meditation (OMM) (**Fig. 1**). FAM is a method of intentionally focusing attention on a specific object [3]. For example, we focus our attention on breathing, which occurs naturally. However, when distracting stimuli arise, such as stronger sensations or emotions, our attention is captured by them. When we become aware of this, we try to shift attention back to the specific object. This shifting attention allows it to be diverted away from the distracting stimulus. Repeatedly doing this can improve the ability to focus attention on a target object. However, focusing attention on a specific object does not enable us to become aware of experiences that occur one after another in the range other than the narrow range of attention.

OMM, however, is a method for maintaining awareness of the ongoing flow of experiences as they naturally occur one after another, without selectively focusing on specific objects [3]. With this method, since there is no specific object, the range of attention is broadened, and every breath, sensation, and emotion that arises one after the other becomes an object of awareness. However, when distracting stimuli, such as stronger sensations or emotions, arise, our attention is captured by them. When we become aware of this, we try to be aware of the stimulus as it is, rather than moving our attention away from it. The distracting stimulus is then returned to the object of awareness, and the range of attention that was captured by the stimulus is naturally broadened. By repeating this process, it becomes possible to maintain awareness of various sensations, feelings, and thoughts as they are, without differentiation between selected and deselected objects.

Our group has been working to elucidate the psychological, physiological, and neural mechanisms of OMM to clarify the mechanism of mindful awareness. I describe three of these studies in the following sections.

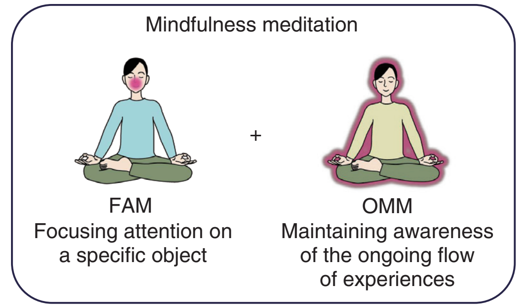

Fig. 1. Two types of meditation methods comprising mindfulness meditation.

3. Study 1: Investigation of the psychological mechanism of OMM

When we concentrate on a task, we subconsciously inhibit distracting stimuli that are irrelevant to the task, such as visual stimuli. Such inhibition is fatiguing. It is believed that mindfulness meditation reduces such inhibition. However, previous studies have not confirmed that FAM and OMM as well as mindfulness meditation reduce inhibition to distracting stimuli at the behavioral level. Therefore, we designed a cognitive task to assess the degree of inhibition against distracting stimuli and examined the effects of FAM and OMM on inhibition [4].

The experiment was conducted by dividing 72 meditation-naïve participants into three groups: FAM, OMM, and relaxation. A 30-minute intervention was first given using voice instruction [5], followed by a questionnaire to measure the state of relaxation, then two tasks were performed (**Fig. 2**). In Task 1, 24 face images that included 3 facial expressions of 8 people were presented repeatedly in turn, and the participants were asked to respond as quickly and accurately as possible to the orientation of the letter presented in the center of the face images. In this task, the face images were distractors. In Task 2, participants were asked to rate their attractiveness toward the eight neutral face images presented in Task 1 and another eight neutral face images that were not presented. Based on previous research [6], if the face images were not inhibited, the attractiveness toward the face images that were presented repeatedly would be expected to increase. However, if the face images were inhibited, we would not see such an increase in attractiveness.

The results indicated that the relaxed group did not increase their attractiveness toward the face images they were repeatedly exposed to in Task 1 (**Fig. 3**). This indicates that the relaxed group inhibited the face images during Task 1. However, the FAM and OMM groups showed increased attractiveness toward the face images they were repeatedly exposed to in Task 1 (Fig. 3). This indicates that, compared with the relaxed group, the FAM and OMM groups reduced inhibition to the face images during Task 1. Interestingly, in the FAM group, those who were more relaxed immediately before Task 1 showed less inhibition to the face images, while those who were less relaxed showed more inhibition to the face images (**Fig. 4**). In contrast, no such relationship was observed in the OMM group (Fig. 4). This indicates that the attention-regulation strategy of the FAM

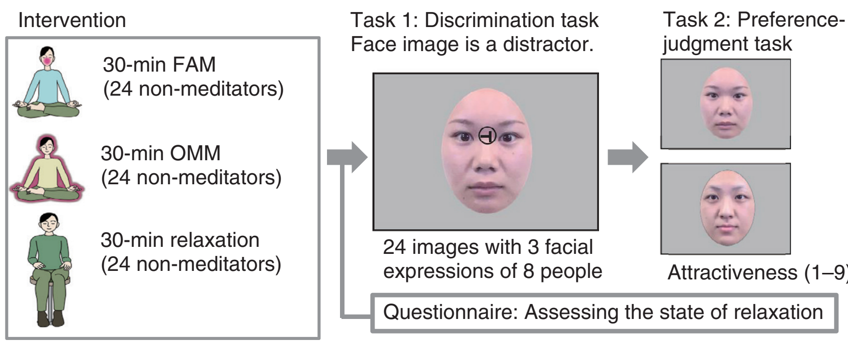

Fig. 2. Experimental design for investigating the psychological mechanism of OMM.

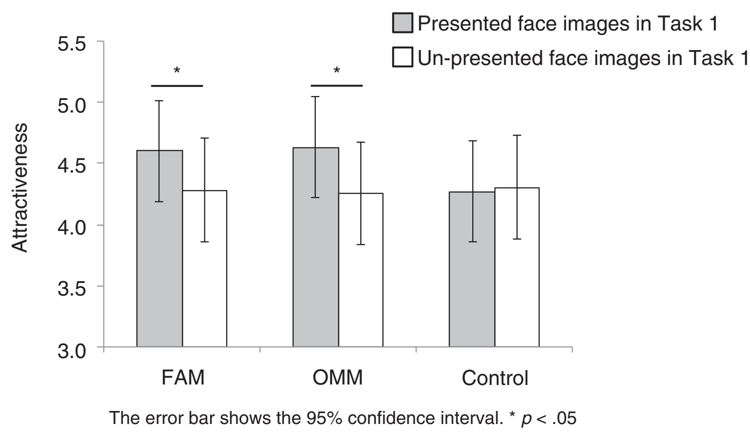

Fig. 3. Attractiveness to face images.

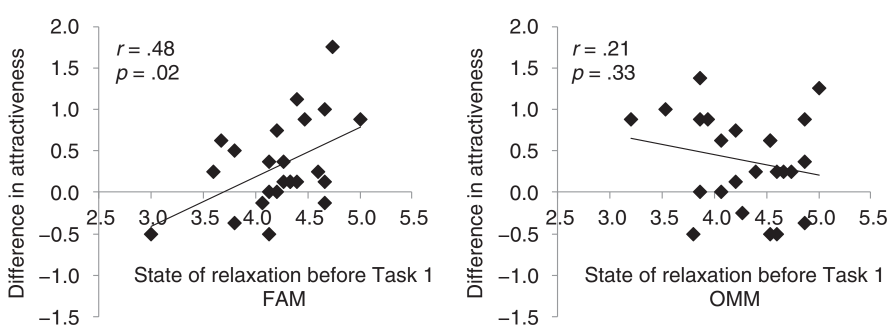

Fig. 4. The correlation between the difference in attractiveness between presented and un-presented face images and the state of relaxation before Task 1.

group was influenced by the relaxation state, whereas that of the OMM group was not influenced by the relaxation state.

4. Study 2: Investigation of the physiological mechanism of OMM

The popular image of mindfulness meditation is

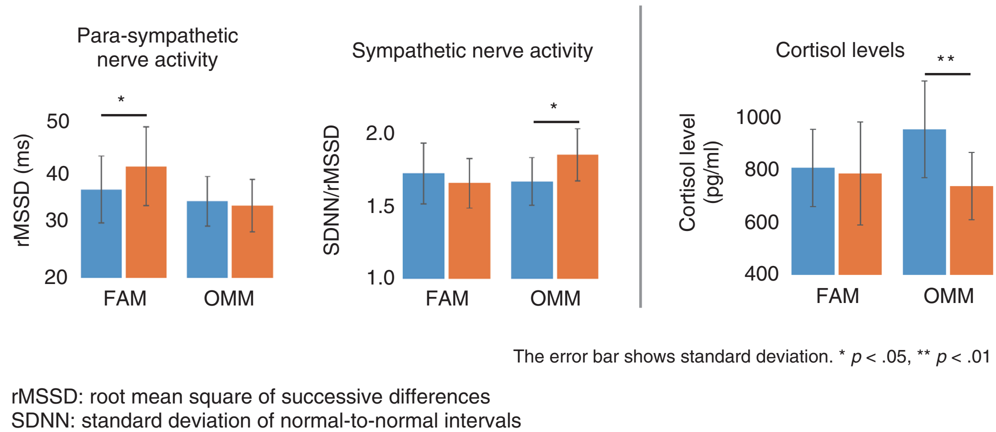

Fig. 5. The effect of FAM and OMM on the autonomic nervous activity and salivary cortisol levels.

that it relaxes the mind. However, in the field of meditation research, it has been thought that mindful awareness is not simple relaxation since it is a state of being aware of various sensations, emotions, and thoughts. Therefore, the effects of mindfulness meditation on physiological indices related to relaxation and stress have been investigated, but the results have varied. The reason for this is thought to be that mindfulness meditation was examined without considering FAM and OMM separately. Therefore, we focused on them separately and examined their effects on physiological indices [7].

In the experiment, 41 meditation-naïve participants were asked to perform 30 minutes of FAM and OMM, respectively [5], and the effects of each meditation on heart-rate variability before and during meditation and on cortisol levels in saliva before and after meditation were examined.

The results indicated that parasympathetic nerve activity increased during FAM (**Fig. 5**). This indicates a higher state of relaxation. These results also suggest that by focusing attention on a specific object, the participants were less likely to be distracted by other sensations, emotions, and thoughts, thus were able to relax. During OMM, interestingly, sympathetic nerve activity increased while cortisol levels decreased (Fig. 5). This indicates that the stress level was lower despite the higher arousal level. These results suggest that OMM is not simply a state of relaxation but may be a state in which the participants were aware of various sensations, emotions, and thoughts but were less able to react to or inhibit them.

5. Study 3: Investigation of the neural mechanism of OMM

What type of activity occurs in the brain during mindful awareness of various sensations, emotions, and thoughts? Previous studies have not clearly shown the difference in brain activity during FAM and OMM. Therefore, we designed an experiment for extracting brain activity during meditation and identified brain activity during FAM and OMM [8]. This study was conducted while I was a member of the Graduate School of Education, Kyoto University.

The experiment included 17 meditation practitioners. Conventional studies comparing brain activity during FAM and OMM have mainly used a block design, for example, 6 minutes of FAM, 6 minutes of rest, and 6 minutes of OMM, during which brain activity was measured with functional magnetic resonance imaging (fMRI). However, as a meditation practitioner, I realized that it is difficult to achieve an optimal meditative state in a 6-minute meditation session. Therefore, we measured brain activity during 6 minutes using fMRI immediately after 1 hour of meditation in a soundproof room. Because I had felt that the meditative state continued for a while after the 1-hour meditation, we divided the days of FAM and OMM conditions into two separate days.

Functional connectivity analysis, which examines the correlation between activities of brain regions, was used for the analysis. Mindfulness meditation is known to involve a wide range of brain regions because it involves various cognitive functions such as attention control, emotion regulation, awareness of bodily sensations, and change in perspective on the

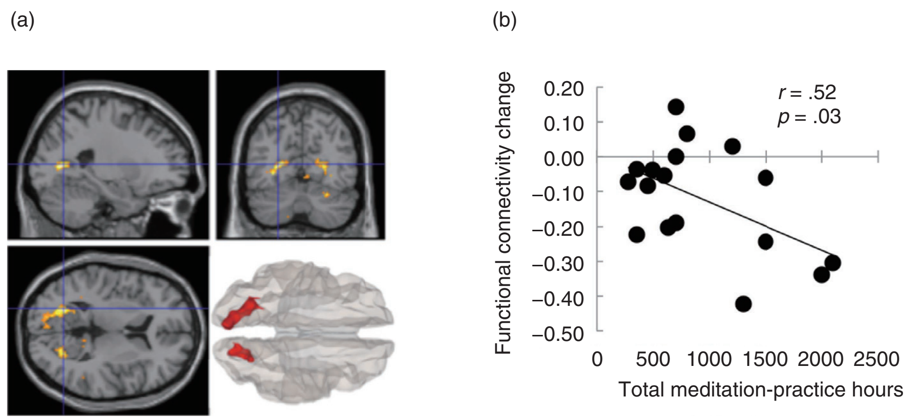

Fig. 6. (a) The retrosplenial cortex showing reduced functional connectivity with the ventral striatum during OMM. (b) The correlation between total meditation-practice hours and altered functional connectivity from the resting state to the OMM state between the right retrosplenial cortex and left ventral striatum.

self. The striatum, which is located below the cerebral cortex, forms multiple different circuits with each brain region of the cortex and involved in various functions such as movement, attention, emotion, motivation, learning, and memory. By examining changes in functional connectivity between the striatum and each brain region, we identified brain activities specific to FAM and OMM and estimated the functions of meditation from these activities.

The results indicated that the functional connectivity between the ventral striatum and visual cortex increased during FAM while it decreased during OMM. This functional connectivity is thought to be related to intentional attention control directed at a specific object. The results support the conventional understanding that FAM enhances intentional attention control, while OMM reduces it. Functional connectivity between the ventral striatum and retrosplenial cortex was also reduced during OMM (**Fig. 6(a)**). Notably, the longer the lifetime of meditation practice, the greater the decrease in functional connectivity (**Fig. 6(b)**). This functional connectivity is thought to be related to the degree to which one is captured by memories. This suggests that when the participants were aware of sensations, feelings, and thoughts during OMM, there may have been a decrease in brain activity that connected these experiences to past memories.

6. Summary

In light of the three aforementioned studies, let me summarize the concept of mindful awareness. Mindfulness is the state of receptive attention to and awareness of ongoing events and experiences as they are. We call this type of awareness mindful awareness. OMM is considered more effective than FAM in cultivating mindful awareness. We have found that OMM reduces inhibition to distracting stimuli. This is consistent with the understanding that mindful awareness does not distinguish experiences as the target object and other distracting stimuli but rather receives everything as an object of awareness. In addition, the physiological parameters of mindful awareness of these experiences revealed that the participants were not merely relaxed but in a state of low stress despite their high arousal levels. We were also able to identify the possibility that such a low stress state may be related to not associating their experiences in the present moment with their past memories.

7. Future perspectives

On the basis of these findings, we are currently developing biomarkers to quantify mindful awareness. We believe that the establishment of such a technology will contribute to increasing the effectiveness of mindfulness-meditation interventions while reducing adverse events. Therefore, we are working to contribute to people’s well-being by elucidating the mechanisms of mindful awareness and developing technologies by using this understanding.

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Dilemma between Quantum Speedup and Computational Reliability—Overcoming Errors with Efficient Verification Methods for Quantum Computing

Yuki Takeuchi and Seiichiro Tani

Abstract

Quantum computers are expected to solve several problems faster than any classical computer. However, they may sometimes output incorrect answers because they are prone to errors. Therefore, to develop reliable quantum computers, it is essential to develop methods of verifying whether the outputs of quantum computers are correct. In this article, we introduce our recent research results on our verification methods.

Keywords: quantum computer, cloud quantum computing, quantum information processing

1. Advantages and issues with quantum computers

In 1994, Shor proposed a quantum algorithm that efficiently factors large integers [1]. It is strongly believed that factorization is a hard problem for classical computers, and this hardness conjecture is used as evidence of the security of several modern cryptographic protocols. Shor's algorithm is a well-known instance showing the computational advantage of quantum computers, and since his proposal, quantum computers have been extensively studied. The quantum computational advantage is known for several problems, such as the simulation of physical and chemical systems and the approximation of Jones polynomials. Despite these advantages, quantum computers face implementation challenges due to environmental noise. There are various methods for designing qubits; a qubit is the basic unit of information in quantum computers. When superconducting circuits are used as qubits, for example, errors can occur due to temporal fluctuations in the resonant frequency. In factorization, such errors are not significant. This is because the correctness of the output (i.e., the answer to a factorization) can be easily checked by executing multiplication on a classical computer; hence, it is easy to determine whether errors have occurred during the quantum computation. As mentioned above, quantum computers can also be applied to various problems other than factorization. For instance, when using a quantum computer to approximate Jones polynomials, there is no known classical method for efficiently checking whether the output is an accurate approximation. In other words, there is a dilemma caused by quantum superposition. This enables high-speed calculations of quantum computers but makes it difficult to verify the correctness of the outputs. To leverage the high computational power of quantum computers, it is necessary to address the impact of errors and develop techniques for resolving this dilemma.

Table 1. Quantum error correction and verification of quantum computation.

	Error correction	Error detection	Applicability
Quantum error correction	✓	✓	× (Error prob. must be small.)
Verification of quantum computation (**topic of this article**)	×	✓	✓ (Large error prob. is allowed.)

2. Techniques to protect quantum computers from errors

This section discusses two techniques to suppress the impact of errors during quantum computations: quantum error correction and mitigation and verification of quantum computation. Quantum error correction is a technique that detects and corrects errors. The information of a single qubit is encoded using multiple physical qubits. Since it is currently challenging to prepare a large number of physical qubits, the implementation of quantum error correction is still limited to small-scale experiments. To overcome this limitation, quantum error mitigation has been proposed, which suppresses the impact of errors by repeating small-scale quantum computations instead of increasing the number of qubits. However, quantum error mitigation is applicable only to limited tasks, such as calculating expectation values, and generally requires an exponential number of executions of quantum computations. To apply quantum error correction or mitigation, some knowledge about the errors is required. Several quantum-error-correction protocols and quantum-error-mitigation methods cannot be used unless the error probability is sufficiently small.

Verification of quantum computation can be used even when the error probability is large. However, it cannot correct or mitigate errors; it can only detect errors. By solving the same problem multiple times with a quantum computer and verifying each answer, it is possible to extract the correct answers, i.e., the output that is not affected by errors. Therefore, verification can be considered effective for addressing the impact of errors.

As a summary, quantum error correction can correct errors but is applicable to limited situations with small error probabilities. Verification of quantum computation, however, can be used even when error probabilities are large but can only detect errors. Quantum error correction thus compensates for the verification drawbacks and vice versa. Therefore, both techniques are crucial for developing highly reliable large-scale quantum computers (see **Table 1**). In the following sections, we introduce some of our research results on our methods for verifying quantum computation.

3. Several verification methods

3.1 Verification of measurement-based quantum computation

There are several models of quantum computing. One is measurement-based quantum computation (MBQC). In the conventional approach known as the quantum circuit model, quantum computation is executed by first initializing qubits then applying quantum gates to them, followed by measurements. In MBQC, once a specific entangled state* called a graph state is prepared, any quantum computation can be carried out by sequentially measuring individual qubits. Since the graph state is independent of the problems to be solved, it can be prepared in advance before starting to solve the problems. When we design qubits by using light (more precisely, photons), single-qubit gates and measurements are relatively easy to conduct. However, the implementation of two-qubit operations is challenging and can only be done probabilistically (in linear optical quantum computing). In MBQC, two-qubit gates are only required during the preparation of the graph state. After starting to solve the problems, only simple operations, i.e., measurements, are needed. This is a significant advantage over the quantum circuit model. Therefore, MBQC has been applied to various quantum-information-processing tasks such as quantum cryptography and quantum communication.

When a quantum computer is developed in accordance with MBQC, the step of preparing a graph state is the most error-prone. Therefore, several methods have been proposed for verifying whether the graph

* Entangled state: A quantum state with quantum correlation. It can be generated using two or more qubits. It plays an essential role in various quantum-information-processing tasks.

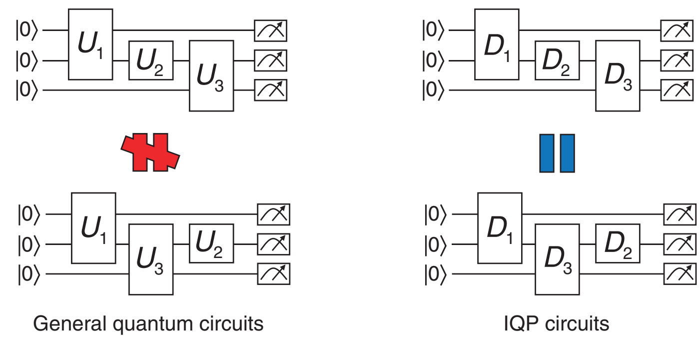

Fig. 1. IQP and general quantum circuits.

state is correctly prepared. In 2019, we devised an efficient verification method, which was superior in efficiency to other verification methods at that time [2]. To achieve this improvement, we were the first to apply a mathematical technique, which was previously used in quantum key distribution, to verification. Subsequently, we applied our verification method to quantum sensing [3] and experimentally demonstrated it in a small-scale optical experiment [4]. These developments indicate a significant impact and expansion of our research in this field.

3.2 Verification of quantum-random-number generation

We extended the graph-state verification mentioned in the previous section to more complex quantum states called weighted graph states. This extension enables the verification of a family of quantum circuits called instantaneous quantum polynomial-time (IQP) circuits. This family of circuits can only execute a limited set of computations obtained regardless of the order of quantum gates to be applied (see **Fig. 1**), although this property may make the physical implementation of IQP circuits easier. Consequently, the computational power of IQP circuits should be weaker than that of an ideal full-fledged quantum computer since the computation on the latter heavily depends on the order of quantum gates. By using *ideal* IQP circuits, however, it is possible to generate random numbers that is difficult on classical computers. It is not easy to determine whether the generated numbers follow an ideal probability distribution or noisy one that is easily reproducible with classical computers. In 2019, we made it possible to efficiently check whether the random numbers are correctly generated by conducting verification of IQP circuits [5].

3.3 Verification of noisy intermediate-scale quantum computers

Quantum computers with computational capabilities weaker than full-fledged quantum computers, such as IQP circuits, are referred to as non-universal quantum computers. Some non-universal quantum computers are currently in use or expected to be developed in the near future. They are called noisy intermediate-scale quantum (NISQ) computers, which are small or medium-scale quantum computers with inevitable noise. As reviewed in another article in this journal [6], we proposed a verification method tailored for NISQ computers [7].

3.4 Verification of quantumness of quantum computers

Our methods introduced above require small-scale quantum measurement devices to execute verification. In other words, these methods verify the outputs of various quantum computers, such as MBQC, IQP circuits, and NISQ computers, by using another smaller quantum computer. To make verification of quantum computation more practical, it would be desirable to enable efficient verification using a classical computer. In 2018, Mahadev proposed a classical verification method [8] by using post-quantum cryptography, which is modern cryptography secure even against quantum attacks. Her method was a significant breakthrough in the field and was subsequently extended by many researchers. In 2022, by applying her technique, we also proposed a verification method for verifying the correct preparations and measurements of a special quantum state, so-called magic state [9]. Quantum computation without magic states (specifically, computations limited to Clifford unitary operations) can be efficiently simulated with classical computers. Therefore, verifying magic states can be used to determine the presence of essential quantum properties in quantum computers.

4. Outlook

We proposed various verification methods that make several types of quantum computers verifiable. Further improvements in many directions are necessary for their practical use. A possible direction would be to improve our methods and apply verification of quantum computation to cloud-quantum-computing systems. Companies, such as IBM and Amazon, provide cloud-quantum-computing systems, but they lack the verification features for users to check the correctness of their received results. By incorporating verification methods into existing systems, users can verify the accuracy of their received answers for themselves, and the companies providing the systems can transparently demonstrate the high performance of their quantum computers. Our goal is to achieve a society where anyone can benefit from quantum computers from anywhere. Toward this goal, we will continually contribute to the development of fundamental technologies in quantum computing.

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Technical Trends in ISO/IEC Joint Technical Committee 1

Hideaki Yamamoto

Abstract

The International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) Joint Technical Committee (JTC) 1 is an organization established by ISO and IEC and is responsible for international standardization in the field of information technology. This article introduces the activities being addressed by subgroups directly under JTC 1, which were identified in Resolutions from recent ISO/IEC JTC 1 Plenaries.

Keywords: ISO/IEC JTC 1, Plenary, Advisory Group

1. Introduction

The International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC) Joint Technical Committee (JTC) 1 [1] was established by ISO [2] and IEC [3] and is responsible for the international standardization of information technology. Formerly, ISO/Technical Committee (TC) 97 (established in 1960) and IEC/TC 53 (established in 1961) independently promoted standardization activities in the information-technology field, resulting in the duplication of certain technical fields between these organizations [4]. JTC 1 was established in 1987 to solve this problem. The secretariat of JTC 1 is the American National Standards Institute (ANSI). As of September 2023, JTC 1 comprises 40 P-members (active participants) and 62 O-members (observers).

The Plenary is JTC 1's highest decision-making meeting, and the main agenda is as follows:

- Establishment and/or disbandment of Subcommittees (SCs), Working Groups (WGs), and Advisory Groups (AGs) under JTC 1
- Appointment of JTC 1 Officers
- Revision of operational rules
- Reports on SC activities

2. Organization of ISO/IEC JTC 1

The organization of JTC 1 is shown in **Fig. 1**. The development of standards is carried out by 23 SCs and 5 WGs directly under JTC 1. Discussions on management issues, such as the review of Directives, and on technology issues, such as examination of issues with a view to development of future standards, are carried out by AGs under JTC 1. JTC 1 has established liaisons with organizations other than JTC 1, including IEC/TC 65 (Industrial-process measurement, control, and automation), IEC/TC 100 (Audio, video, and multimedia systems and equipment), ISO/TC 215 (Health informatics), ISO/TC 307 (Blockchain and distributed ledger technologies), ITU-T (International Telecommunication Union - Telecommunication Standardization Sector), and Ecma International.

Japan has been in a significant position regarding the management of JTC 1 as follows:

- P-members in all 23 SCs and 5 WGs directly under JTC 1
- Chairs of SC 2 (Character code), SC 23 (Digital storage media), SC 28 (Office equipment) and Committee Managers of SC 2, SC 23, SC 28, SC 29 (Media encoding), SC 34 (Document description and processing language)
- Approximately 90 Project Editors (as of the end of March 2023)

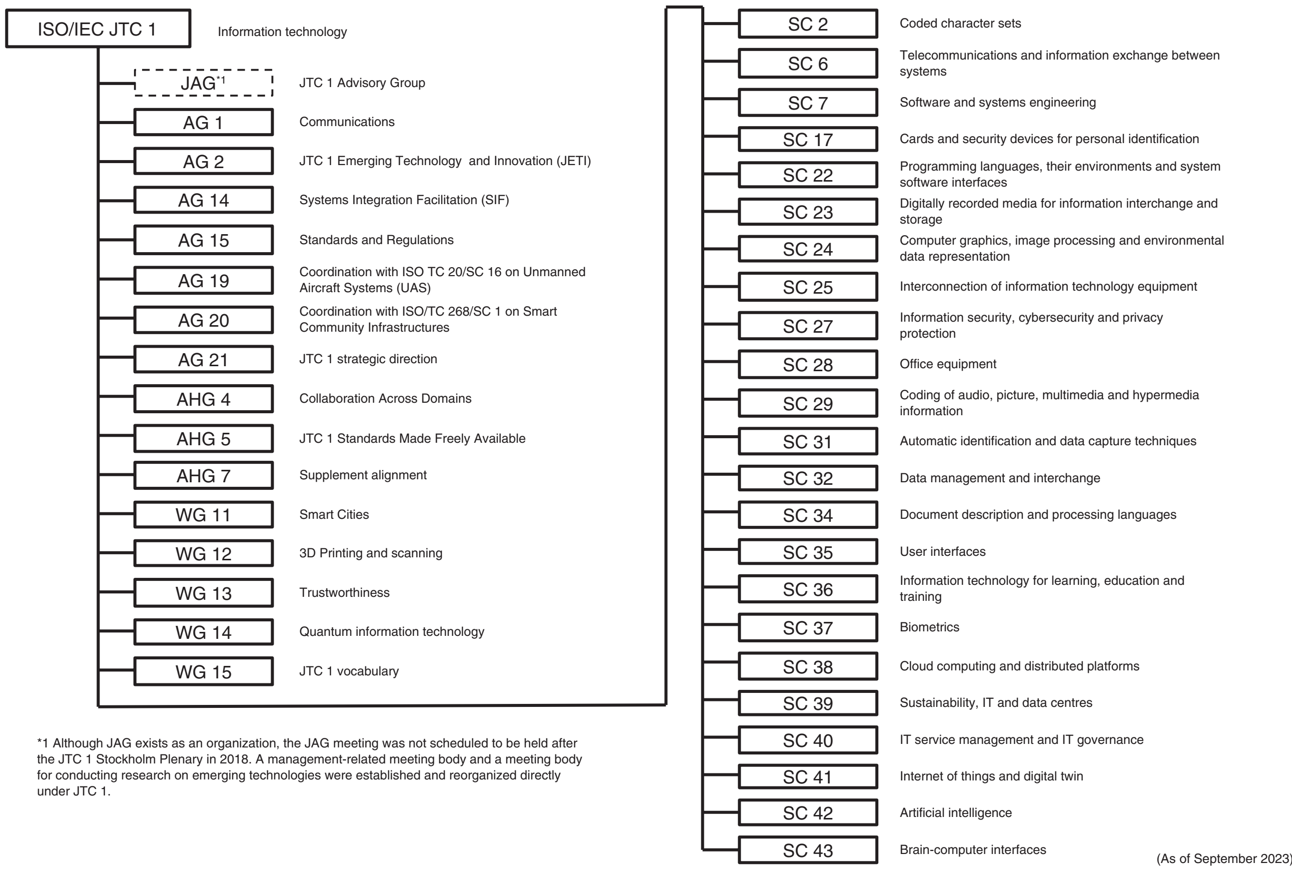

Fig. 1. Organization of ISO/IEC JTC 1.

- Hosts of JTC 1 Plenary (4 times)

JTC 1 Plenary has been held twice a year (spring and fall) since 2019. The two most recent JTC 1 Plenaries were held in Tokyo (Japan) in November 2022 and in Paestum (Italy) in May 2023, both in the format of "face-to-face mode with some remote participants"[*1]. At both Plenaries, Japan has greatly contributed to steering JTC 1 by proposals through more than a dozen contributions, participation in the Drafting Committee and hosting Tokyo Plenary[*2], which was the first face-to-face JTC 1 Plenary during the COVID-19 pandemic.

The following sections introduce several trends in JTC 1 subgroups and activities for JTC 1 in the Japanese National Body (NB)[*3].

3. Latest trends in JTC 1 subgroups

3.1 SC on information technology for smart cities

In JTC 1, WG 11 addresses standardization items related to information technology for smart cities. To coordinate activities related to smart community infrastructure between ISO TC 268/SC 1 (Smart community infrastructures) and JTC 1, AG 20 was established according to the Resolution of the JTC 1 virtual Plenary in May 2022. At the JTC 1 Paestum Plenary in May 2023, Chinese NB submitted a contribution describing that a new SC should be established for smart cities, which was addressed by WG

*1 "Face-to-face mode with some remote participants" is the name of a meeting format that uses both face-to-face and virtual modes, as defined in Standing Document (SD) N 19 (Meetings) of ISO/IEC JTC 1. Although this SD defines a similar meeting format "hybrid mode," there are differences between these two formats, such as the maximum meeting hours per day and whether remote participants have the right to pause the meetings when they lose remote connectivity.

*2 When preparing to host JTC 1 Plenary in Okayama (Japan) in November 2020, the format of the Plenary changed to virtual due to the COVID-19 pandemic. Japan therefore re-invited the Plenary in November 2022.

*3 NB: ISO uses the term MB (Member Body), and IEC uses NC (National Committee). As ISO/IEC JTC 1 is common to both organizations, it is called NB.

Table 1. Examples of WG/AG/AHG under ISO/IEC JTC 1.

Theme	Quantum Information Technology (JTC 1/WG 14)	JTC 1 Strategic Direction (JTC 1/AG 21)	Collaboration Across Domains (JTC 1/AHG 4)
ToR	1. Serve as a focus of and proponent for JTC 1's standardization program on Quantum Information Technology. Identify gaps and opportunities in Quantum Information Technology standardization; 2. Develop and maintain a list of existing Quantum Information Technology standards produced and standards development projects underway in ISO/TCs, IEC/TCs, JTC 1 and other organizations; 3. Develop deliverables in the area of Quantum Information Technology; 4. As a systems integration entity, maintain relationships with other ISO and IEC TCs and other organizations that are involved in Quantum Technology standardization.	1. Identify stakeholders, assess market and technology evolution; 2. Perform a Strengths/Weaknesses/ Opportunities/Threats (SWOT) analysis of JTC 1, including reference to ICT standardization outside of JTC 1; 3. Assess JTC 1 Subcommittee activity (critical mass, technological maturity); 4. Assess intensity of collaborative work (within JTC 1, with ISO and IEC TCs and with external SDOs); 5. Prepare recommendations including • JTC 1 governance and operations • JTC 1 system work and collaborations • Optimal structure	1. Review ITTF's draft revision of SD 15 (JTC 1 N16195), as well as the US comments on the ITTF draft (JTC 1 N16247), and propose any further changes that might be necessary by the 1st deadline (18 September 2023) for the November 2023 JTC 1 Plenary.

(As of September 2023)

Source: Approved Resolutions of the 14-18 November 2022 JTC 1 Plenary in Tokyo (ISO/IEC JTC 1 N 16159) and Resolutions of the 8-12 May 2023 JTC 1 Plenary in Paestum, Italy (ISO/IEC JTC 1 N 16364)

SDO: standards developing organization
ITTF: Information Technology Task Force
SD: standing document

11. During the Plenary, there was a great deal of discussion resulting in no consensus, and the decision was scheduled on approval of Resolutions on the last day. Japanese NB expressed its opposition because of concerns that the scope of the new SC would overlap with that of other organizations related to smart cities. As a result of the vote, the establishment of the 44th SC was approved by a majority of the P-members present at the Plenary. This new SC will be chaired by Heng Qian (China), Convenor of WG 11, and WG 11 will disband when the new SC is inaugurated. Note that this new SC has been approved by the JTC 1 level at the time of writing this manuscript and it will be inaugurated after approval by the votes of the management boards of ISO and IEC (ISO Technical Management Board and IEC Standardization Management Board).

3.2 WG on quantum information technology

The standardization activities of quantum information technology at JTC 1 are initiated by the Study Group (SG) on quantum computing, approved at JTC 1 Stockholm Plenary in November 2018. Taking over its activities as SG, WG 14 was established according to Resolution of JTC 1 virtual Plenary in June 2020, starting the development of standards on quantum computing. At the JTC 1 Tokyo Plenary in November 2022, Preliminary Work Item (PWI) on quantum simulation was approved, and its structure was discussed. It was agreed to expand the activities of the existing WG 14 because it would be inefficient to establish a single WG specific to quantum simulation. The title of WG 14 was renamed from "Quantum computing" to "Quantum information technology," and its Terms of Reference (ToR) was also changed to support a wider range of quantum information technologies. This WG is chaired by Hong Yang (China) and its ToR is indicated in **Table 1**.

3.3 AG on JTC 1 strategic direction

AG 21 was established in response to a contribution submitted by Canadian NB to the JTC 1 Tokyo Plenary in November 2022. The purpose of this contribution is to determine JTC 1's optimal structure, because JTC 1 has not reviewed its structure, governance, or mode of operation in the light of its current mission for more than 20 years although there have been major changes in not only the information and communication technology (ICT) market and technical landscape but also in the way ICT is used in our global society. This AG is chaired by Norbert Bensalem (France) and its ToR is indicated in Table 1.

3.4 Ad Hoc Group on collaboration across domains

Ad Hoc Group (AHG) 4 was established in response to a Japanese NB's contribution for JTC 1 virtual Plenary in May 2021. The purpose of this contribution is to propose a restructure of WGs addressing application-layer areas, including the restructuring of WG 11 and WG 12. Although the Plenary could not reach a consensus, it decided to continue this discussion by establishing an AHG. Several proposals were contributed by AHG 4 to JTC 1 Plenaries, including monitoring of liaison activities, long-term plan for across-domain activities and transfer of AHG 4 to AG, which were not adopted as Resolutions. This AHG is chaired by Jacqui Taylor (UK) and its ToR is indicated in Table 1.

4. Activities in Japanese NB

In Japan, SCs under JTC 1 and WGs/AGs/AHGs directly under JTC 1 are mainly operated by Information Technology Standards Commission of Japan (ITSCJ)*4 [5]. Each mirror subcommittee for WG 11 through WG 15 directly under JTC 1 has been established in ITSCJ to share the status of deliberations and address international ballots. Since 2018, JTC 1 Subgroup Subcommittee has been active in ITSCJ, which comprehensively addresses the issues that the AGs are required to participate in as NB. JTC 1 Subgroup Subcommittee shares deliberations of each AG and discusses how to deal with AGs. This Subcommittee also addresses standardization items for SC 43 (Brain-computer interfaces).

In addition, Subcommittee for Directives is active in ITSCJ, as Japanese companies and organizations other than the members of the subcommittee mentioned above are highly interested in ISO/IEC Directives.

5. Future Plenaries

The upcoming Plenaries will be held in Berlin (Germany) in November 2023 and Australia (city to be determined) in May 2024.

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He received the FY 2011 Industrial Standardization Award from the Ministry of Economy, Trade and Industry for his outstanding contributions to activities regarding ISO/IEC SC 17/WG 8 (contactless cards). He is a member of the board of directors of ITSCJ and Vice Chairperson of Task Force for wireless card systems in the Association of Radio Industries and Business of Japan. He served as Chair of the November 2022 JTC 1 Tokyo meeting preparatory committee.

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*4 SC 17, SC 28, SC 35/WG 1 (Keyboards, methods and devices related to input and its feedback), SC 35/WG 2 (Graphical user interface and interaction), SC 35/WG 4 (User interfaces for mobile and wearable devices) and SC 35/WG 6 (User interfaces accessibility) are operated by the Japan Business Machine and Information System Industries Association (JBMIA). SC 25/WG 3 (Customer premises cabling), WGs under SC 31 and SC 39 are operated by Japan Electronics and Information Technology Industries Association (JEITA).

A Case Study of Malfunction of Wireless Communication System Caused by Electromagnetic Disturbance at a Construction Site

Technical Assistance and Support Center, NTT EAST

Abstract

In this article, we explain a case study of a malfunction of a wireless communication system caused by electromagnetic disturbance at a construction site and countermeasures to prevent such a malfunction. This is the seventy-eighth article in a series on telecommunication technologies.

Keywords: electromagnetic disturbance, inverter, isolation transformer, conducted disturbance

1. Introduction

Various construction units require high-capacity and low latency wireless communication for remote video monitoring and remote control. An alternating-current (AC) motor is widely used to control AC frequencies by using an inverter. Inside the inverter, the AC power source is converted to a direct-current (DC) power source, then a high-speed switching operation is carried out to convert the DC power source to an AC power source with the desired frequency. This switching operation becomes a cause of electromagnetic disturbance and may affect the operation of surrounding telecommunication units.

In this article, a case study of a malfunction of a wireless communication system caused by electromagnetic disturbance generated by a motor, the cause of the malfunction, and countermeasures are described.

2. A case study of malfunction of telecommunication unit in high-capacity wireless communication system

At a construction site, a customer reported that a wireless communication system has been rebooting on weekdays. Therefore, Technical Assistance and Support Center (TASC), NTT EAST was asked for technical assistance.

2.1 Equipment configuration and malfunction status

The configuration of the wireless communication system is shown in **Fig. 1**. The wireless communication system has control and radio units. The control unit is located in a telecommunication box, and the radio unit is located outdoors. The radio unit has optical, power, and ground lines. Each line is connected to the control unit, uninterruptible power supply (UPS), and earth bar. The UPS is powered by a temporary power supply through the power supply for telecommunication. A temporary power supply also supplies power to the site office, various construction

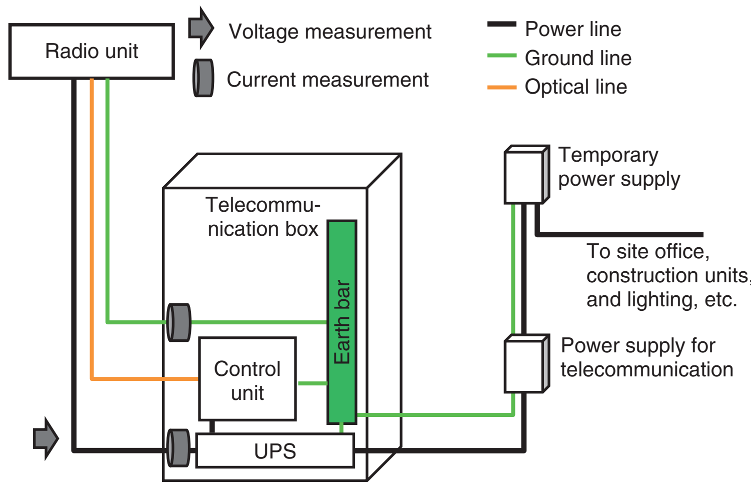

Fig. 1. Configuration of units and components composing wireless communication system.

Input connector	• Original connector • BNC connector
Maximum input voltage	5 V peak
Measurement voltage range	Two ranges • Range 1: –30 to 0 dBV • Range 2: –50 to –20 dBV
Frequency bandwidth	100 Hz to 30 MHz Separated into 7 bands • 1-kHz band: 500 Hz to 3 kHz • 15-kHz band: 7.5 to 22.5 kHz • 70-kHz band: 5 to 105 kHz • 250-kHz band: 125 to 375 kHz • 1-MHz band: 0.5 to 1.5 MHz • 3-MHz band: 1.5 to 4.5 MHz • 20-MHz band: 10 to 30 MHz

BNC: Bayonet Neill Concelman

Fig. 2. Specifications and image of Noise Search Tester.

units, and outdoor lighting.

Regarding the status of the malfunction, the radio unit repeatedly rebooted at certain hours of the day during which a conveyor belt operated for transporting sand at the construction site.

2.2 Results of field survey

There are two types of electromagnetic disturbance that affect telecommunication equipment. One is radiation disturbance that propagates through the air. The other is conducted disturbance that propagates through wired cables. In this construction site case, we focused on measuring conducted disturbance because it seems to have an effect by the belt conveyor. To investigate the effect of conducted disturbance, we measured the common mode voltage and current of a conducted disturbance on the power line and ground line, as shown in Fig. 1.

To detect the malfunction, we first measured the common mode voltage using Noise Search Tester [1] developed by TASC. This tester can be easily installed on site with a contactless voltage probe (**Fig. 2**). The screen graphically displays common-mode-voltage levels in the 1-kHz, 15-kHz, 70-kHz, 250-kHz, 1-MHz, 3-MHz, and 20-MHz frequency bands.

Screenshot of Noise Search Tester

Frequency band of maximum voltage level	15 kHz (7.5 to 22.5 kHz)
Measured voltage value	More than 0 dBV

Measurement setting

Fig. 3. Results of measuring common mode voltage using Noise Search Tester.

(Photo source: Yokogawa Electric Corporation website) [2]

(Photo source: TOYO Corporation website) [3]

Fig. 4. Photograph of oscilloscope (left) and current probe (right).

The screenshot of Noise Search Tester measuring common mode voltage is shown in **Fig. 3**. We confirmed that the highest common-mode-voltage level exceeded 0 dBV in the 15-kHz band, as shown in the white circle in Fig. 3.

Next, we used an oscilloscope and current and voltage probes to measure the disturbance in detail (**Fig. 4**). To clarify the relationship between the conducted disturbance and operation of the radio unit, we measured the common mode voltage and current during radio anomalies (when a reboot occurs) and normal conditions, i.e., when the conveyor belt is operating and when it stops.

The measurement results are shown in **Fig. 5**. During the reboot period, it was found that the common mode voltage, which is the voltage between the cold and earth of the power line (Cold–E), was 323 Vp-p and common mode current on the power line was 2.7 Ap-p (Fig. 5(1)). The common mode current on the ground line was 1.2 Ap-p. At the same location, during the non-reboot period, the values were 38 Vp-p, 25 mAp-p, and 11 mAp-p, respectively (Fig. 5(2)). These results indicate that a large common mode voltage and current were generated during a reboot. Comparing the common mode current in the power line (Fig. 5(b)) and in the ground line (Fig. 5(c)), we confirmed that the common mode current on the power line is larger than that on the ground line.

To clarify the frequency of the disturbance, we analyzed the common mode voltage during the reboot and non-reboot periods using the fast Fourier transform (FFT) method. As shown in **Fig. 6**, the analysis results indicate that the disturbance had a wide frequency range of 2 kHz to 1 MHz.

2.3 Estimation of malfunction cause

The above results indicate that (i) the radio unit reboots when the conveyor belt is operated and (ii)

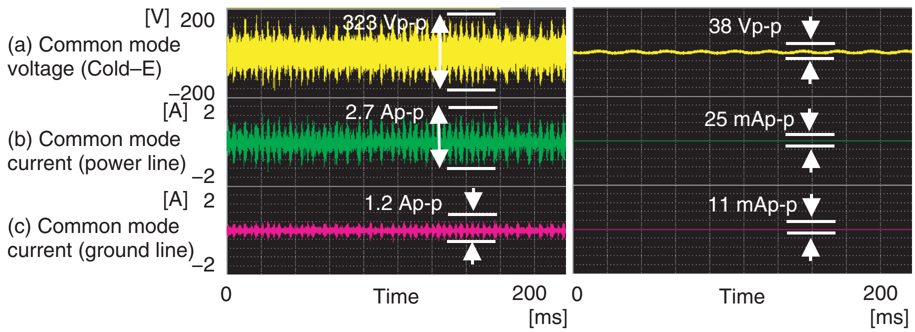

Fig. 5. Results of measured common mode voltage and current.

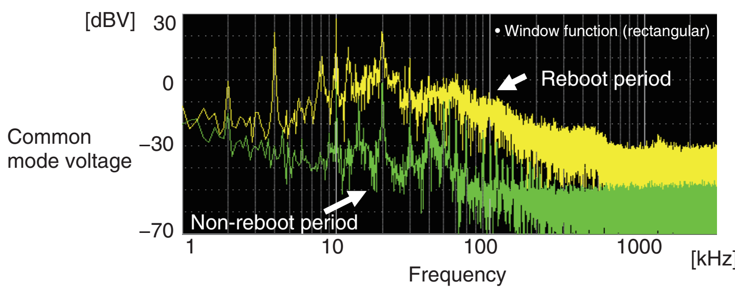

Fig. 6. Results of FFT analysis of common mode voltage on power line.

high-level common mode voltage and current appear on the power and ground lines during the operation of the conveyor belt. Therefore, we estimated that the conducted disturbance generated from the motor of the conveyor belt caused the reboot of the radio unit.

2.4 Countermeasures and Results

Countermeasures against the effects of conducted disturbance on the wireless communication system include the following:

(1) **Isolate or maintain disturbance sources**: We must isolate or remove the disturbance sources from the same power supply of the radio unit. If the disturbance sources could not be isolated or removed, we must maintain the disturbance sources.

(2) **Filter conducted disturbance**: If we could not remove the disturbance sources, we should consider installing a noise filter, isolation transformer, etc. on the telecommunication, power, and ground lines of the paths of the conducted disturbance for filtering it.

Table 1. Characteristics of noise-cut transformer.

	Characteristics of noise-cut transformer
Frequency bandwidth	DC to 30 MHz
Common mode rejection	Above 40 dB

(3) **Replace telecommunication units**: Replace disturbance-affected units that are more resistant to disturbance.

In this case study, it was difficult to apply disturbance countermeasures for the conveyor belt. Since the radio unit is specified in this construction site, we cannot replace it. Therefore, we decided to install a noise-cut transformer (the characteristics of which are shown in **Table 1**) in the power line connecting to the radio unit, which is the path of the disturbance.

The measured common mode current after installation of the noise-cut transformer is shown in **Fig. 7**. This result indicates that the common mode current in the power line (measured at the input and output sides

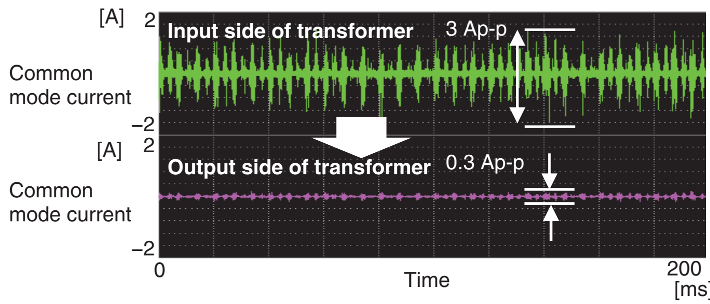

Fig. 7. Results of measuring common mode current after installation of noise-cut transformer.

of the transformer) during operation of the conveyor belt decreased from 3 to 0.3 Ap-p. As a result of the noise-cut transformer action, the radio unit no longer had rebooting issues.

3. Conclusion

A case study of a malfunction of the radio unit of a wireless communication system caused by electromagnetic disturbance at a construction site and countermeasures to prevent the malfunction were described. Though inverters are used to maintain efficiency of the power system at construction sites and in photovoltaic power systems, they can be a source of electromagnetic disturbance that affects telecommunication systems. It is important to investigate the inverters before installation and take necessary countermeasures against such disturbance. At TASC, we will continue to play a role in reducing maintenance operation in the field by providing the knowledge we have accumulated. To reduce malfunctions caused by electromagnetic disturbance, radio, induction, and lightning and improve the reliability of telecommunication services, the EMC Engineering Group of TASC will continue to engage in technical cooperation, development, and dissemination of technology through technical seminars and other activities.

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External Awards

IEEE VTS Tokyo/Japan Chapter 2023 Student Paper Award

Winner: Ei Tanaka, Tohoku University (Co-authors: Yuichi Kawamoto, Tohoku University; Nei Kato, Tohoku University; Masashi Iwabuchi, NTT Access Network Service Systems Laboratories; Riku Ohmiya, NTT Access Network Service Systems Laboratories; Tomoki Murakami, NTT Access Network Service Systems Laboratories)
Date: June 21, 2023
Organization: Institute of Electrical and Electronics Engineers Vehicular Technology Society (IEEE VTS) Tokyo/Japan Chapter

For "Exploiting Reflection Direction Variation for Phase Control in Multiple Simultaneous IRS Links."
Published as: E. Tanaka, Y. Kawamoto, N. Kato, M. Iwabuchi, R. Ohmiya, and T. Murakami, "Exploiting Reflection Direction Variation for Phase Control in Multiple Simultaneous IRS Links," Proc. of 2023 IEEE 97th Vehicular Technology Conference (VTC2023-Spring), Florence, Italy, Mar. 2023.

MVE Award

Winners: Motohiro Makiguchi, NTT Human Informatics Laboratories; Ayaka Sano, NTT Human Informatics Laboratories; Takahiro Matsumoto, NTT Human Informatics Laboratories; Rika Mochizuki, NTT Human Informatics Laboratories; Ryuji Yamamoto, NTT Human Informatics Laboratories
Date: July 13, 2023
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE) Technical Committiee on Media Experience Virtual Environment (MVE)

For "Basic Study on Pointing Methods in Mirror-Transcending Aerial imaging."
Published as: M. Makiguchi, A. Sano, T. Matsumoto, R. Mochizuki, and R. Yamamoto, "Basic Study on Pointing Methods in Mirror-Transcending Aerial imaging," MVE meeting, MVE2022-118, Mar. 2023.

Papers Published in Technical Journals and Conference Proceedings

Velocity and Confinement of Edge Plasmons in HgTe-based Two-dimensional Topological Insulators

A. Gourmelon, E. Frigerio, H. Kamata, L. Lunczer, A. Denis, P. Morfin, M. Rosticher, J. Berroir, G. Fève, B. Plaçais, H. Buhmann, L. W. Molenkamp, and E. Bocquillon

Physical Review B, Vol. 108, No. 3, 035405, July 2023.

High-frequency transport in the edge states of the quantum spin Hall (QSH) effect has rarely been explored, though it could cast light on the scattering mechanisms taking place therein. Here we report on the measurement of the plasmon velocity in topological HgTe quantum wells both in the QSH and quantum Hall (QH) regimes, using harmonic GHz excitations and phase-resolved detection. We observe low plasmon velocities in both regimes, with, in particular, large transverse widths in the QH regime despite a sharp edge confinement profile. We ascribe these observations to the prominent influence of charge puddles forming in the vicinity of edge channels. Together with other recent works, it suggests that puddles play an essential role in the edge state physics and probably constitute a main hurdle on the way to clean and robust edge transport.