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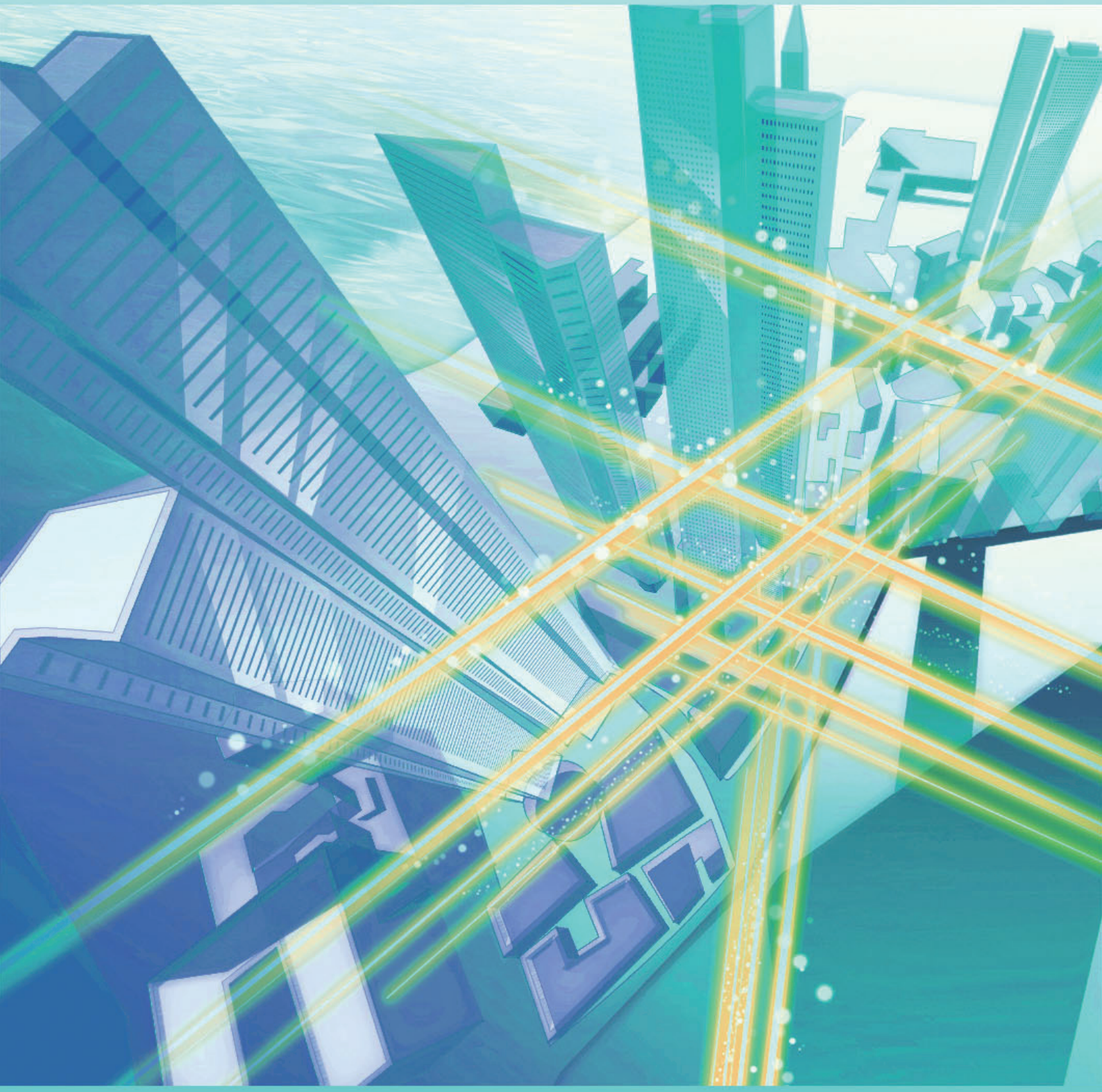

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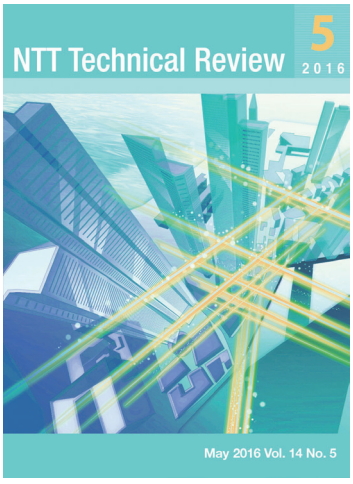

Feature Articles: Artificial Intelligence Research Activities in NTT Group

Regular Articles

Global Standardization Activities

External Awards/Papers Published in Technical Journals and Conference Proceedings

Artificial Intelligence Research Activities and Directions in the NTT Group

Takeshi Yamada, Satoshi Takahashi, Futoshi Naya, Takashi Ikebe, and Shigeto Furukawa

Abstract

The research and development of artificial intelligence (AI) at NTT is advancing along four directions: (1) *Agent-AI* for analyzing information issued by people and understanding intentions and emotions in that information; (2) *Heart-Touching-AI* for analyzing unconscious and unnoticeable aspects of a person's mind and body and understanding deep psychological, intellectual, and instinctual states in that person; (3) *Ambient-AI* for analyzing and understanding just about anything in the world (objects, people, the environment) and instantaneously predicting and controlling those things; and (4) *Network-AI* for organically connecting and cultivating multiple types of AI and optimizing the entire social system. This article introduces the technologies supporting these four forms of AI and specific AI-related activities in the NTT Group.

Keywords: artificial intelligence, machine learning, brain science

1. Introduction

We are now experiencing another artificial intelligence (AI) boom as interest in its possibilities continues to grow in science, business, and the mass media. There are various reasons for this renewed interest in AI. First, research in deep learning, a type of machine learning technology, is progressing and coming to dominate a variety of information-communication fields such as image/voice recognition and understanding [1]. Also, when IBM's Watson question and answer (Q&A) system beat human champions in a television quiz show, it ignited a trend in the use of AI-related technology in the business domain. Finally, the commercialization of various types of humanoid robots has helped to make many people more comfortable about a society in which people and robots coexist. In addition, some researchers predict that a technological singularity in which AI comes to surpass all human ability will occur by 2045 [2]. This possibility is generating a great deal of interest throughout the world.

While it is important to get on board this AI trend without delay and take a lead in advancing the research on it, it is also important to analyze both the technological and business aspects of AI in a calm and thorough manner. For example, deep learning and Q&A systems constitute only a portion of technologies that will be needed in order to make people more comfortable with AI, while in the business domain, the first signs that AI may bring about a revolution in the industrial structure are starting to appear.

In these Feature Articles, we introduce some of the activities underway in the NTT Group that are expected to lead to a genuine implementation of AI. As an introduction to these articles, we explain here the four directions that NTT is taking in the research and development (R&D) of AI.

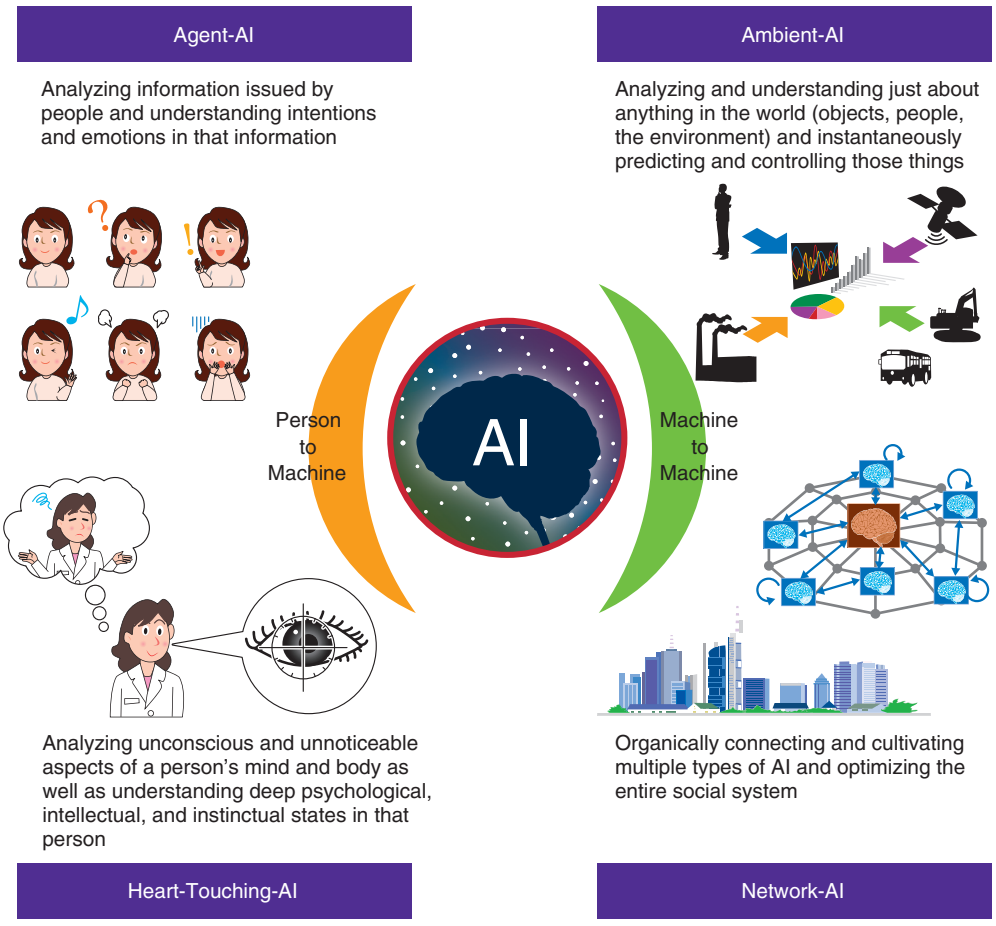

Fig. 1. Four AI directions set by NTT.

2. NTT's four AI directions

The world of AI is quite diverse with many and varied supporting technologies, and people often view AI in different ways. For example, AI is commonly thought of as the pursuit of human-like behavior in a computer, so that the computer, for all practical purposes, appears to be human. However, in today's information and communication technology society, all sorts of devices and sensors are being connected to the Internet to form the Internet of Things (IoT), and the idea that these *things* can have some type of intelligence and behave in an organized manner can also be called AI.

With this in mind, NTT has established the following four concepts or directions reflecting different forms of AI that can be useful to society (**Fig. 1**).

(1) Agent-AI for analyzing information issued by people and understanding intentions and emotions in that information. If we consider Q&A-type AI to be a typical example of conventional AI, then Agent-AI would be located far out on the development line extending from that. Agent-AI can also be called AI in the pursuit of human-like behavior.

(2) Heart-Touching-AI for analyzing unconscious and unnoticeable aspects of a person's mind and body as well as understanding deep psychological, intellectual, and instinctual states in that person. It is thought that deepening our knowledge of the mechanisms underlying the human brain and mind will lead to a new world in which people and AI can interact in a more direct manner.

(3) Ambient-AI for analyzing and understanding just about anything in the world (objects, people, the environment) and instantaneously predicting and controlling those things. This type of AI would analyze information from things and the environment in addition to people and feed

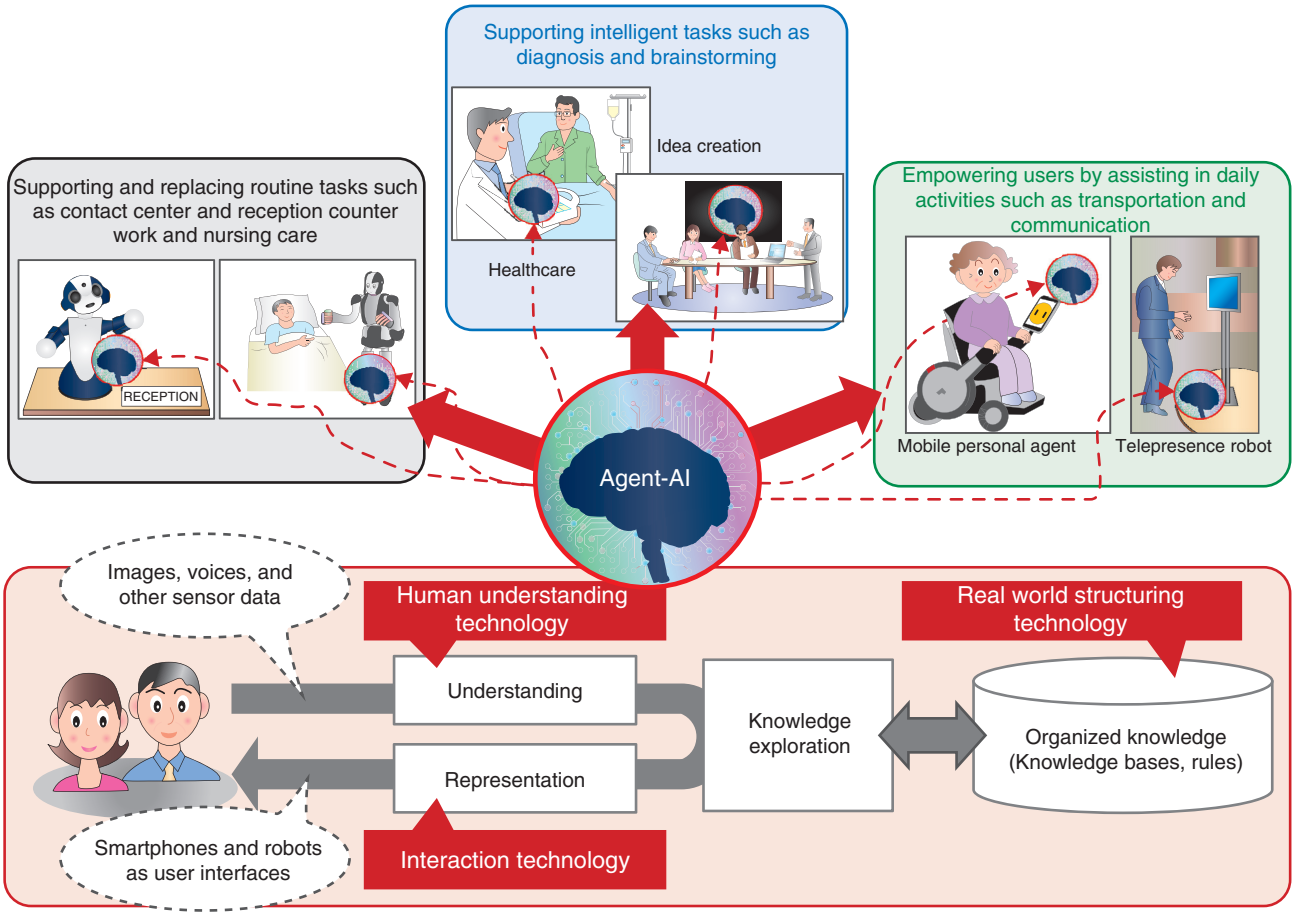

Fig. 2. Agent-AI.

the results of analysis back to the real world.

(4) Network-AI for organically connecting and cultivating multiple types of AI and optimizing the entire social system. Reassessing the network as an infrastructure from an AI perspective should make it possible to create a completely new social system.

2.1 Agent-AI

As the name implies, Agent-AI is aimed at achieving advanced interaction with human beings as a personified intelligent agent typified by a robot. This would be accomplished in diverse ways such as by understanding people and the conditions surrounding them through voice, language, images, and other types of media (human understanding technology), by performing multimodal interaction that includes human facial expressions, body language, and gestures (interaction technology), and by being conversant in multiple languages and performing complicated reasoning based on a huge amount of knowledge (real world structuring technology) (**Fig. 2**).

One example of the above within the NTT Group is the development of an interactive system that is meant to achieve natural conversation with a computer. This is a joint project between NTT and NTT DOCOMO, the latter of which is already providing the *Shabette Concier* (Talking Concierge) voice-agent service for smartphones [3]. Further employing the above technologies and exploiting all relevant data such as the user's profile and vital signs data can enhance contact center operations and customer service operations by partially automating the customer reception process and by providing staff with useful information in a timely fashion according to the circumstances. The main point, however, would be to develop AI that could understand not only the user's intentions but also the user's emotions and that would always create a positive impression in the user. Similarly, in the healthcare field, AI technology could be

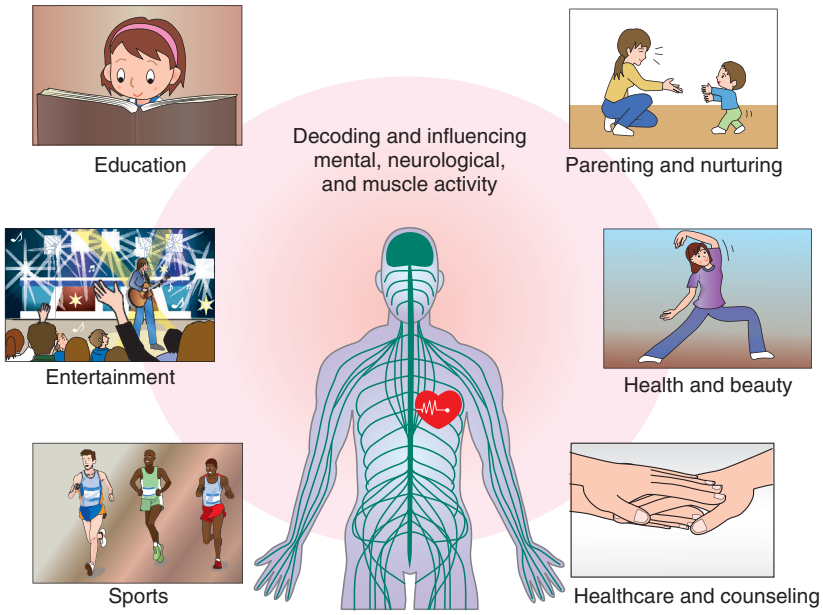

Fig. 3. Heart-Touching-AI.

used to perform first-order processing of huge volumes of vital signs data, thereby reducing the doctor's diagnostics testing load. In addition, intelligent AI support could be used to ease the burden on nursing staff.

In this way, AI will come to replace or support certain human activities, but at the same time, AI and people will coexist and co-create sustainable societies by doing those tasks that each does best. This process will help to enrich people's daily lives. In the future, the aim will be to achieve an agent that can serve as a background assistant throughout a person's life. Such an agent, for example, could enhance the skills and know-how of young people in their 20s by offering specialized advice, enhance the creative skills of experienced staff in their 40s by supporting idea generation, and supplement the physical faculties and memory power of senior citizens to improve their labor force availability and achieve a sustainable workforce. The end result would be a brighter society for both younger and older generations of people.

NTT's current efforts in Agent-AI research and business development are described in separate articles in this issue [4–8].

2.2 Heart-Touching-AI

As described above, Agent-AI is a form of AI that supports people by providing them with knowledge and functions. However, no matter how advanced the knowledge possessed by AI and how complex the reasoning that it performs, there are still doubts as to whether AI can become human-like in character. Against this background, NTT aims to achieve what it calls Heart-Touching-AI (HT-AI) that further pursues human-like characteristics by understanding the mechanisms of human cognition through research in brain science (**Fig. 3**).

HT-AI does not restrict itself to intelligence. It is targeted at understanding the essential and fundamental components of a person—the intellect, instinct, and physical body—and to encourage that person and expand his or her abilities. The idea here is to break down emotional barriers between individuals and between an individual and society or the environment and to overcome physical barriers as well, and to create a comfortable human society. In other areas, too, such as sports and the arts, HT-AI is aimed at enabling anyone to experience the sensations and flashes of inspiration that only professional athletes or accomplished artists are thought to have.

Inside the human brain, the neocortex is the outermost region and the most recent to appear in the evolutionary process. This region is mostly responsible for rational and analytical thought and language functions, which is generally the pursuit of Agent-AI. Underneath the neocortex, there are the cerebral limbic system, brain stem, and cerebellum, which are older parts of the brain. These parts cannot be ignored

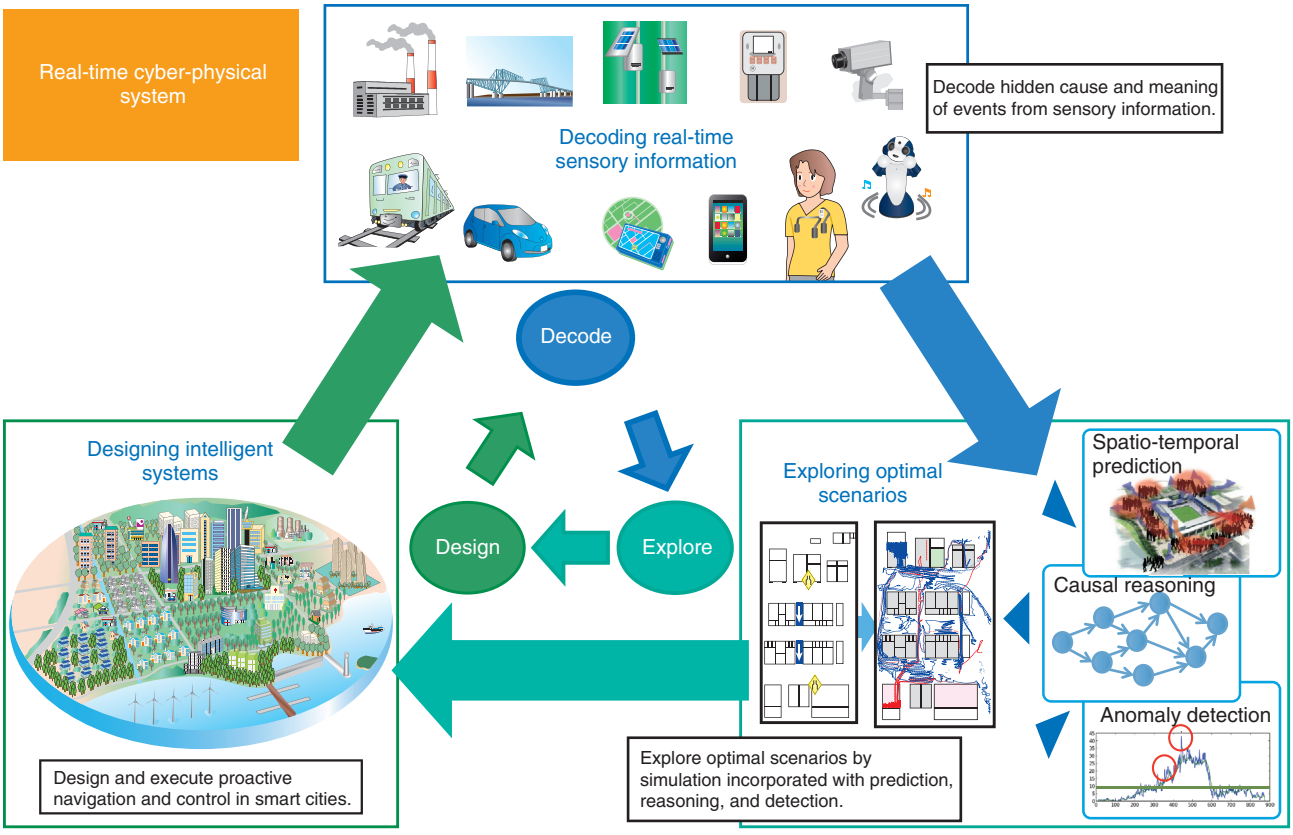

Fig. 4. Ambient-AI.

if we are to understand or influence unconscious cognitive processing, physical movements, and human characteristics such as trust, loyalty, likes/dislikes, amiability, and motivation. These functions and mechanisms, however, are still not sufficiently understood, and measurement and evaluation techniques are still being developed.

HT-AI is therefore a form of AI that aims to decode or influence the state of human brain activity. As the name implies, HT-AI attempts to *touch the heart*. It aims to provide the individual with a comfortable existence rather than simply being useful. The road to achieving HT-AI and enabling people to enjoy its benefits is long, but NTT has already begun activities toward its realization. These efforts are described in a separate article in this issue [9].

2.3 Ambient-AI

Ambient-AI pursues *things* that have some level of intelligence and that behave in an organized manner. The word ambient is similar in meaning to atmosphere and environment. For example, ambient music is meant to create an atmosphere in the listener's mind. In Ambient-AI, things that exist just about everywhere in the environment—that is, devices having sensors and actuators—possess intelligence. Interconnecting them in a network so that they can communicate and interface with each other will enable them to make decisions and act autonomously and to support people in decision-making (**Fig. 4**). In 2006, NTT proposed the concept of *ambient intelligence*, in which the existence of a thing with intelligence can be likened to a fairy or guardian angel "who normally remains hidden while quietly watching over a person but comes to the rescue whenever a difficulty or emergency arises in that person's life" [10]. In the ten years or so that have passed since then, the cloud, big data, and mobile communications have made great inroads in society, and significant progress has been made in IoT and machine learning. It can also be said that the elements essential to achieving ambient intelligence are finally being readied.

The ambient intelligence mentioned above includes elements of Agent-AI as a personified agent. However,

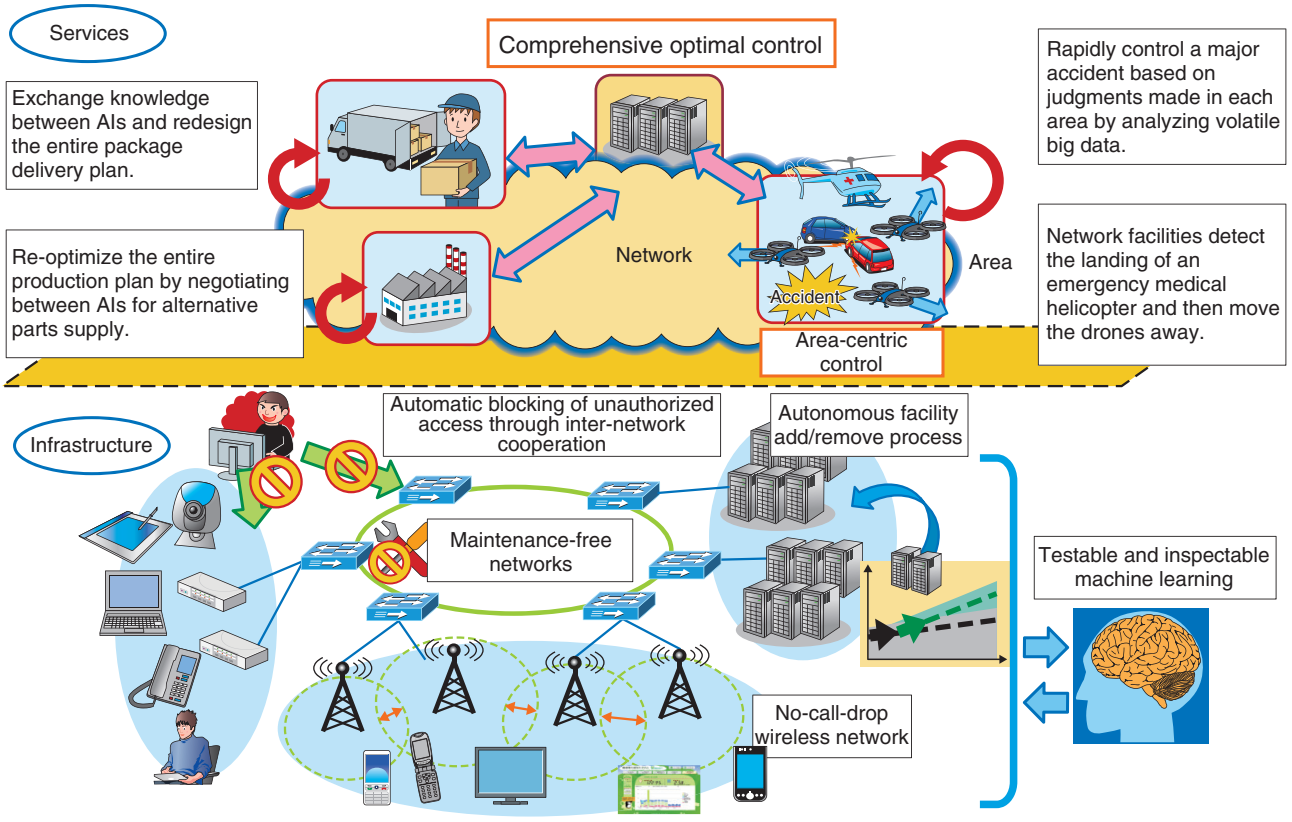

Fig. 5. Network-AI.

the emphasis in Ambient-AI is a real-time cyber-physical system that continuously repeats the three processes of decoding hidden causes of events in the real world through intelligent real-time sensing, exploring optimal scenarios by performing prediction, reasoning, and detection using the cloud environment, and providing feedback based on an appropriate system design. In this way, Ambient-AI will be able to measure the real world (the physical component) in real time through devices and sensors situated ubiquitously in the environment. It will also be able to predict when, where, and what will occur in the near future by combining the above measurements with information on the Internet (the cyber component), to infer cause-and-effect relationships, to detect hidden signs with high accuracy, and based on simulations that incorporate the above, to search out and establish optimal scenarios and perform proactive control. NTT is researching and developing spatio-temporal multidimensional data analysis technology that models space-time relationships and predicts where and when a phenomenon will occur [11].

2.4 Network-AI

If Ambient-AI evolves even further, it can be envisioned that devices, people, and services connected to a low-latency, high-throughput network will become connected and linked as needed to all sorts of resources, thereby bringing about Network-AI, in which the network itself becomes AI. As a result, large volumes of time and space specific data (volatile big data) will be continuously generated at network terminal points and all areas covered by the network. It is important that these data be used effectively (**Fig. 5**).

However, sharing all of these data in the network—even in a high-performance network—is not efficient. It is therefore necessary to process the data first in an area-centric manner and to perform rapid execution and control based on judgments made in each area, even if it is not a 100% perfect solution (area-centric control). For example, in the event of a major disaster, we can envision how network facilities in charge of an affected area could detect the upcoming landing of an emergency medical helicopter and then activate the emergency control of drones already active in that area to rapidly move them away to avoid potential

collisions.

Next, after such processing in local areas has been completed, essential portions of that processing could be hierarchically shared over the network, enabling comprehensive optimal control. For example, we can envision how disaster information generated in certain regions could be used to redesign plans for global delivery of relief supplies. In this way, it is important that a good balance be established between area-centric control, which corresponds to processing in the cerebellum of the human brain, and comprehensive optimal control, which corresponds to the cerebrum.

In addition, it is important that a high-quality, safe, and secure network be provided in both normal and abnormal times by applying AI technology to the network. NTT is already applying machine-learning technology for early detection of signs of network failure and for operation automation and traffic prediction [12]. Future applications of AI may include automatic blocking of unauthorized access through inter-network cooperation, construction of maintenance-free networks, provision of a no-call-drop wireless network, and implementation of an autonomous facility add/remove process. New machine-learning techniques will be required to ensure the safety of these autonomous operations, in which people can test and inspect what is being learned and acquired.

3. Future outlook

This article introduced NTT's approach to AI in four key directions. These four forms of AI are in no way independent of each other but simply reflect different aspects of the broad world of AI. In any service, each of these four forms of AI will appear in one way or another, and the technologies common to them, such as machine learning, pattern recognition, and optimization, are not few in number. In addition, R&D of Agent-AI, for example, is making good progress, while that of the other forms of AI, for instance, Network-AI, is still in its early stages. In any case, NTT plans to further promote R&D in each of these four AI directions going forward. The goal is to achieve an enriching and comfortable society in which AI supports people in their daily lives and AI and people co-create sustainable societies by doing what each does best.

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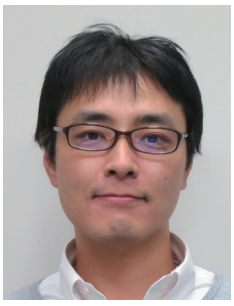

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Natural Language Processing Supporting Artificial Intelligence

Yoshihiro Matsuo, Ryuichiro Higashinaka, Hisako Asano, and Toshiro Makino

Abstract

Natural language processing technology is considered to be essential to achieving artificial intelligence (AI) that can substitute for humans in certain roles. Most robots and AI systems that appear in fiction are equipped with a natural language interface, and it is expected that *clever* AI will learn on its own from encyclopedias, news reports, and other textual sources. Exactly what kinds of AI functions will be achieved through natural language processing technology? This article introduces the role that natural language processing technology can be expected to play in achieving AI.

Keywords: artificial intelligence, natural language processing, knowledge processing

1. Introduction

In artificial intelligence (AI), a technical field that is difficult to define, natural language processing technology appears to be a major element. This is clearly demonstrated by the use of natural language conversations to measure computer intelligence in the Turing test, which is a well-known technique for determining whether a certain machine is intelligent. In measuring the intelligence of something in which intelligence or intellectual level cannot be directly observed, it is natural to adopt an approach in which intelligence is assessed based on responses to queries, since linguistic expression is surely a typical means of exhibiting intelligence.

What kind of relationship does AI then have with natural language processing? A schematic representation of the relationship between AI and natural language processing is shown in **Fig. 1**. Agent-AI, which is introduced in the feature article "Artificial Intelligence Research Activities and Directions in the NTT Group" [1] in this issue, is a form of AI that possesses abundant knowledge and a capacity for making judgments so that it can replace humans in certain tasks and assist humans in their daily lives. Scenarios in which Agent-AI would have a connection to natural language can be broadly divided into reading of documents and interaction with the user. Thus, Agent-AI achieved with natural language processing would read documents extensively and accumulate knowledge, recognize user utterances, and make an appropriate response based on that accumulated knowledge. We consider that the Turing test could be a means of measuring in some way whether Agent-AI is producing effective responses.

In this article, we introduce how natural language processing technology has so far been used in AI industrial applications and the role it is expected to play in the future.

2. Text-to-knowledge technology for understanding the meaning of text

If we assume that natural language expressions demonstrate human intelligence, documents written in natural language should then be filled with intelligent information. The primary role of natural language processing technology is to find information that is needed and beneficial from this text filled with intelligent information. Yet, text itself is no more than a collection of character strings, so evaluating data in this form to find what is needed and beneficial cannot be done. However, if text can be arranged in a machine-readable form through natural language

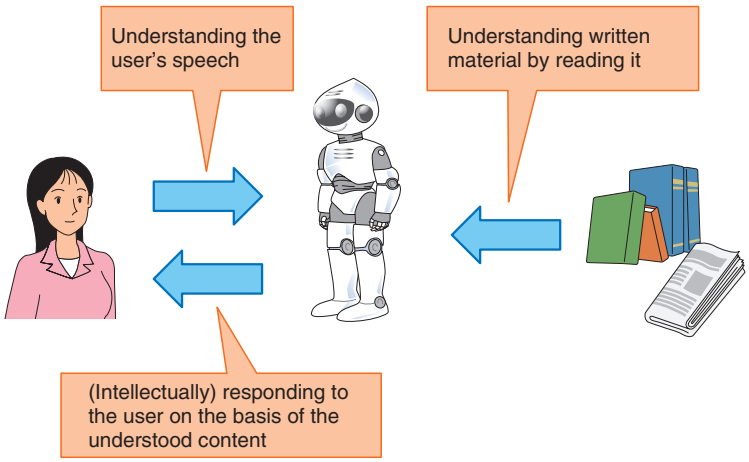

Fig. 1. Relationship between AI and natural language processing technology.

processing, information processing with a computational ability surpassing that of humans will become possible. To this end, we can consider applications of natural language processing to an information-searching technique that looks for desired information from within a huge amount of information, or to a text mining technique that consolidates, arranges, and presents information completely unreadable to humans in its original form in a relatively short period of time.

An example of applying the former technique is a question answering system [2]. A typical approach that most people would take to learn about something would be to search out a related section or entry from an encyclopedia, a textbook, or the web and retrieve an answer from that source. This is the so-called information-searching procedure, but if the sequence of steps in this procedure could be automated, it would be of great assistance in human activities.

Next, examples of applying the latter technique would be the mining of a contact-center log to analyze customers' voices and sentiment analysis of users' comments on the Internet [3]. While it may be possible to uncover valuable information straight from the voices and comments of consumers, differentiating what is good and bad from such a huge amount of information is not an easy task. Furthermore, such analysis would take time, so if this information was to be applied to some sort of decision-making, it could hardly be used for making rapid decisions. Thus, the ability to analyze a large volume of documents in a short period of time would be beneficial to corporations and organizations that need to conduct such tasks.

What kind of language processing technology is therefore needed to meet the above requirements? That would be technology capable of extracting information from documents written in natural language and organizing that information as knowledge. We have undertaken the research and development of *rich indexing technology* for extracting semantic information from text and have been successful in extracting named entity expressions and opinion information and in identifying the meaning of named entities [3]. The automatic extraction of such information from text will enable the detection of answers in retrieved documents and the tabulation of information from large volumes of text.

3. Utterance understanding technology for a natural language ICT interface

Another function expected of natural language processing technology is a computer interface based on natural language.

Exchanges between humans and computers are normally carried out according to a specialized communication format consisting of menus, icons, and commands manipulated by a keyboard, mouse, or other device. This type of interface has been designed with efficient computer operation in mind, and a user who becomes proficient in its use can indeed perform efficient and effective operations. However, communication with a computer can be quite difficult for those uncomfortable with such an interface, and this problem is thought to be one of the factors giving rise

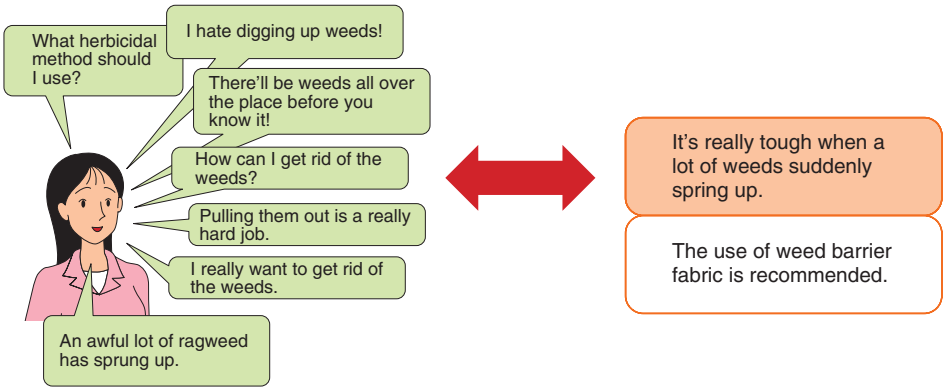

Fig. 2. Determining sameness between user questions and FAQ on paper.

to the so-called digital divide. In contrast, natural language can be viewed as an extremely basic human communication medium. Of course, a certain level of proficiency is also necessary to communicate with natural language, but this is a basic ability that most people come to possess through daily life and education.

The development of an information and communication technology (ICT) interface using natural language will create value in two ways. The first is that people will be able to use ICT and enjoy its benefits without having to develop special skills, and the second is that a standard means of communication between human beings and computers in the form of natural language will enable people and AI to coexist in society.

One example of the former is a voice agent. The operation of a smartphone is still rather complicated, and learning how to use its functions well is not that easy. Furthermore, while much knowledge can be obtained by querying a search engine, a certain amount of information technology literacy is needed in order to use a search engine effectively. Consequently, if questions could be posed to AI by voice using natural language, a further expansion of ICT users and usage scenarios could be expected.

An example of the latter type of value creation is a customer-service support terminal for use at a contact center or retail store. At contact centers, customers talk with operators by telephone. We can envision how a computer could listen in on these conversations and provide just the right information at just the right time. This kind of capability could make solving customers' problems more efficient. Similarly, at a retail store, a small robot could be positioned next to a salesperson at a cash register or information counter. When the salesperson was discussing products with customers, the robot could promptly offer relevant brochures or documents when needed, thereby serving as a very capable assistant.

Common to the above examples is the need for utterance recognition technology. Several ways of recognizing an utterance can be considered. One would be to translate natural language into a computer language such as Structured Query Language (SQL), which is commonly used for database searching [4]. If a natural language query could be translated and entered into the SQL search conditions field, it would then be possible to search databases by using natural language. Another way of recognizing an utterance would be to judge the equivalence of an utterance in terms of its intention (**Fig. 2**). For example, let's consider a frequently asked questions (FAQ) search. An FAQ document consists of frequently asked questions, where knowledge is represented by pairs of questions and answers (Q&A). In this search, a user poses some kind of question (query). However, the query rarely agrees with a question at the character string level, but if it can be determined that the query has the same intention as a certain question, the correct answer can be provided.

4. Casual conversation technology for achieving human-like dialogue

The technologies described so far serve to make human life much more efficient, but they are not sufficient in themselves to achieve Agent-AI. If a human being and Agent-AI are to become true partners, they must be able to trust and understand each other and

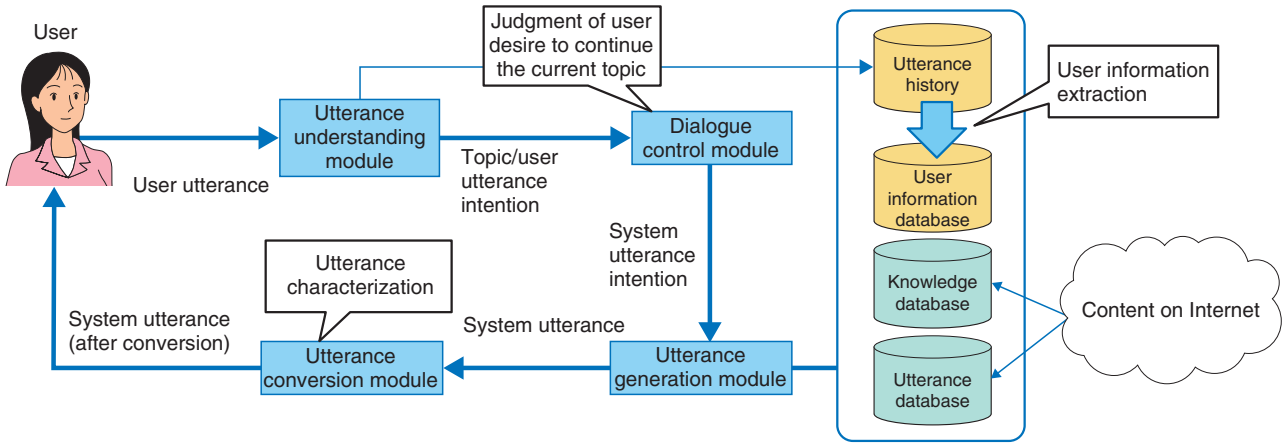

Fig. 3. Configuration of casual conversation technology.

even share emotions. When two people meet each other for the first time, they would hardly start talking about work from the start. It is only after they have become more familiar with each other that they would begin to talk freely. Furthermore, in times of need, partners should help, comfort, and emotionally support each other. Agent-AI must also be equipped with such functions. As is known from the Media Equation [5] theory, a human being interacting with a computer tends to behave as if the computer were human. Thus, the more intelligent a computer becomes, the more human in character it should be. In human society, a *casual conversation* is often the occasion for two people to get to know each other or to become emotionally closer.

With this in mind, NTT Media Intelligence Laboratories has been researching casual conversation technology [6]. This technology will enable a user to converse with a computer in everyday language on any topic. Casual conversation is, of course, easy for human beings but extremely difficult for computers. This is because current technology cannot easily handle the many and varied topics that a user may want to talk about, and it cannot develop a deep understanding in the way that a human can of complex subjects raised by the user. In the AI field, the former problem is known as the frame problem and the latter as the symbol grounding problem. Against this background, we have undertaken the development of casual conversation technology and have succeeded in achieving a certain level of casual conversation with a computer by combining large-scale text data and language processing technology. This technology is being used in casual-conversation application programming interfaces for developer use and in commercially available communication toys.

A system based on casual conversation technology structures large volumes of content on the Internet (blogs, microblogs) using language processing technology and constructs an utterance database and knowledge database (**Figs. 3** and **4**). When a user utterance is input, the system recognizes the topic and intention of that utterance based on the context. It then produces a response in line with the user's intention by searching for an appropriate system utterance from an utterance database or by generating a system utterance using a knowledge database. If the user utterance is a question, the system uses question answering technology to obtain a word or phrase from the Internet as a response. This mechanism enables the system to produce responses on a variety of topics that may appear in casual conversation.

However, it is not sufficient in itself to achieve human-like behavior. Achieving Agent-AI that can form an attachment as a partner and carry on extended conversations will require mechanisms for remembering things about the conversation partner, expressing individuality, and understanding emotions. For this reason, we are equipping Agent-AI with techniques for user information extraction, utterance characterization, and judgment of user desire to continue the current topic. These techniques will enable the construction of user information databases based on user utterances, conversion of system utterances to ones expressing a personality, and a change of topic if the system detects that the user appears to have lost interest in the current topic.

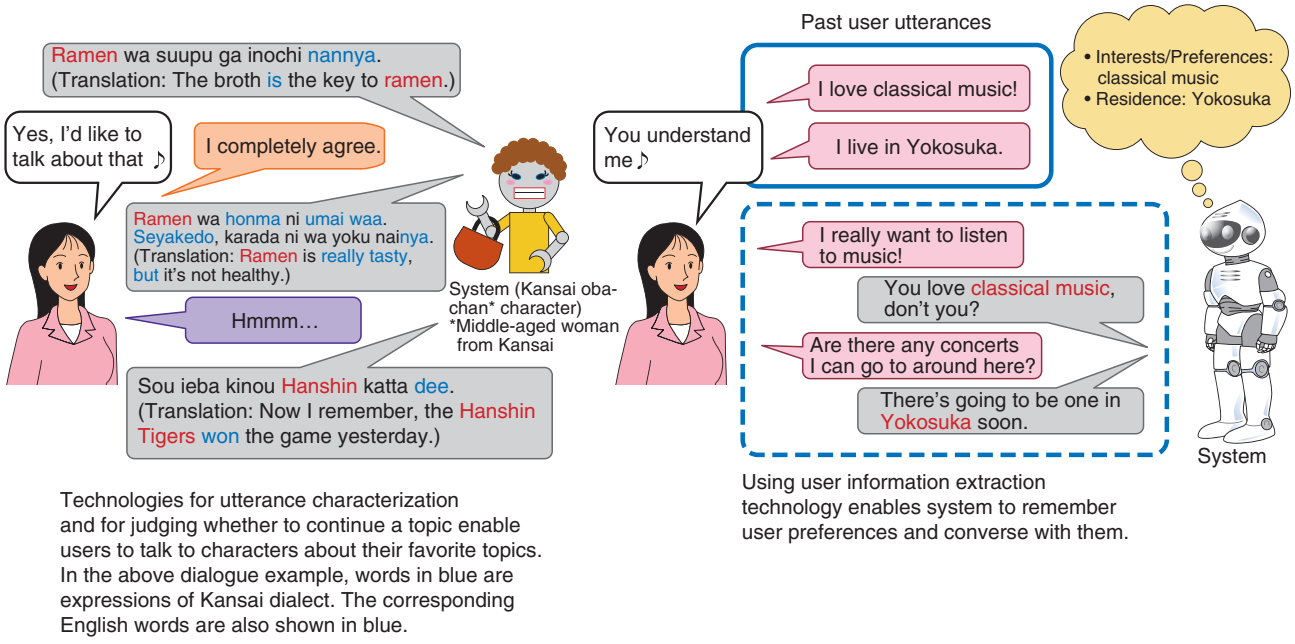

Fig. 4. Example of conversation enabled by casual conversation technology.

5. Future outlook

Finally, we would like to touch upon the Todai Robot Project (Can a Robot Get into the University of Tokyo?), a major AI project that has been attracting attention. This project is a grand challenge led by Japan's National Institute of Informatics to develop AI that can pass the entrance exam of the University of Tokyo. Specifically, it aims to achieve a high score in the National Center Test for University Admissions by 2016 and to pass the University of Tokyo exam by 2021. Passing the latter will require the development of AI that can take and pass tests in a variety of academic disciplines.

NTT has been participating in this project since 2014 and has been placed in charge of English as a target discipline [7]. In addition to learning vocabulary and grammar, English presents a variety of problems, including the reading and comprehension of long sentences and conversational text, the matching up of text with tables and figures, and the use of diverse language processing skills. Solving problems that human beings actually solve is what achieving Agent-AI is all about. The program that we have constructed for solving these English problems can presently achieve a level of performance equivalent to that of an average human examinee. Our aim, however, is to achieve Agent-AI that is useful in problem solving and supportive to people through the experiences gained in this project and the results of researching and developing casual conversation technology.

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Cloud-based Interaction Control Technologies for Robotics Integrated Development Environment (R-env™)

Tomohiro Yamada and Hiroshi Yoshikawa

Abstract

Communication robots are able to detect the surrounding situation through cameras or sensors, and they use motion to show non-verbal expressions. Furthermore, automobiles and personal devices such as vacuum cleaners are being robotized with the application of verbal communication technology. In the near future, it will become very important for various robots to be able to connect to and work together with devices that surround us in order to support human activities and enhance our lives. This article introduces R-env™, a cloud-based Interaction Control technology.

Keywords: multi-modal interaction, cloud robotics, networked robot

1. History of robots and artificial intelligence

The word *robot* was reportedly first used by Czech playwright Karel Čapek in his 1920 science fiction play "Rossum's Universal Robots" [1]. The robot's role in the play was to replace some human labor. Čapek's robot would exert physical power or intellectual power far beyond that of humans according to the task intended. In one scene of the play, a highly intellectual robot with conscious awareness communicates with humans. In the literary and theatrical world, robots demonstrate human-like physical and/or intellectual capabilities that in some cases exceed those of humans. The role of robots in society is a question often asked since the early days of the introduction of robots. In the technology field, robots and artificial intelligence (AI) mutually influence each other's development.

Some key events in the development of robots include the establishment of the Robotics Society of Japan in 1983 and the first International Conference on Robotics and Automation in 1984 organized by the Institute of Electrical and Electronics Engineers (IEEE). In 1986, the Japanese Society for Artificial Intelligence was established, and in 1988, NTT launched the Human Interface Laboratory Intelligent Robot Research Project with a mission to introduce robot control technology into production sites in Japan. Thus, research commenced on computer vision, motion control, and methods of training robots to understand the goals of the work assigned to them, otherwise known as robot-teaching technology [2].

Technological development has been centered on industrial robots until fairly recently. However, research on the interaction between humans and robots has advanced a great deal and is now quite active. In 1991, IEEE established RO-MAN (International Symposium on Robot and Human Interactive Communication) to focus on communication between humans and robots.

In 1999, Sony Corporation launched AIBO, a dog-type pet robot, which made it possible for the general public to actually see and experience high level communication robots that until then had been limited to research laboratories. AIBO's algorithms and sensors enable it to understand the intention of users and to express its reactions by using light, sound, and motion [3].

Honda Motor Co., Ltd. in 2000 announced ASIMO, a humanoid robot that was able to walk like a human [4].

2. NTT's development of robotic technology

NTT began researching and developing a network robot platform to permit the collaboration of multiple robots over the network. Part of this work was conducted under contract from the Ministry of Internal Affairs and Communications (MIC) of Japan as "Comprehensive research and development of network-human interface (network robot technology)" from 2004 to 2008. Network robot platform technology research was conducted with one aim being to realize a novel networked society where various services could be used anywhere, any time by connecting sensors, appliances, and robots, thereby enabling them to work in collaboration over a highly advanced network [5].

Three types of robots were developed:

(1) A tangible type of humanoid robot called a *visible robot*
(2) A *virtual robot*, which was a software agent on appliance software
(3) An *unconscious robot* consisting of sensors in the surrounding environment

We also developed a mechanism enabling these different types of robots to be connected and to work in collaboration by exchanging necessary information over the network.

To enable various kinds of information to be exchanged between different types of robots manufactured by different companies, we devised a description method to handle core information related to the user (4W: who, when, where, and what of actions and behavior) and core information related to the robot (4W1H: who, when, where, what (its capabilities are), and how the robot is behaving).

A network robot platform that incorporates this technology makes it possible to integrate robots that were previously difficult to connect to each other. We conducted an experiment on connecting robots and transferring robot relationship information using four existing description methods over a standard communication protocol.

3. Novel robot collaboration service to expand human potential

As previously described, different types of robots are being released by numerous companies, and they are starting to be experimentally used for various purposes. Furthermore, we are seeing increased sophistication and robotization of appliances and vehicles such as cleaning robots and self-driving cars, which were not developed as imitations of humans or animals. Therefore, it can be assumed that the variety of intelligent robots will only increase.

As reported by robot start inc. [6], the number of communication robots in Japan will reach 2.65 million by the year 2020. In view of the fact that there are approximately 55 million households in Japan [7], this number suggests there will be one communication robot for every 20 households. This number is likely to increase, judging from the number of cleaning robots, which are only now coming into wide use.

What benefits can we expect from intelligent robots with AI? Are the benefits limited to increasing labor efficiency as evidenced by industrial robots or as in the play written by Karel Čapek?

The expression *support of human growth* is the key to new services that we are trying to achieve at NTT Service Evolution Laboratories. We are making efforts to develop a novel service that will enable robots and machines to *understand the situation that surrounds us, encourage us, enhance our ability, and help us perform new actions*.

For instance, with regard to children, the new service will watch over a child, support the child in communicating with others, enhance the child's learning motivation, become the child's good friend, and last but not least, grow up with the child. With regard to the elderly, the new service will enable robots and machines to provide encouragement and support in healthcare and external activities, improve social participation, and support an independent daily life.

For adults who are in their prime, the new service will enable robots and machines to help adults with their daily schedule and task management and support them in their sporting activities so that they can spend their time happily and efficiently. We aim to develop robots that will learn and mature with their human partners over an entire lifetime. However, this does not mean we must continue to use the same robot hardware forever. The robot will store information about the user's preferences and characteristics on the cloud. It will also have a brain so that it can learn and mature with its user. The hardware of the robot may change from time to time or with a change in location. There may even be two or more devices. However, by connecting these robots and devices, we can overcome spatial and temporal distance and achieve a robot that can support human activity over his/her entire lifetime.

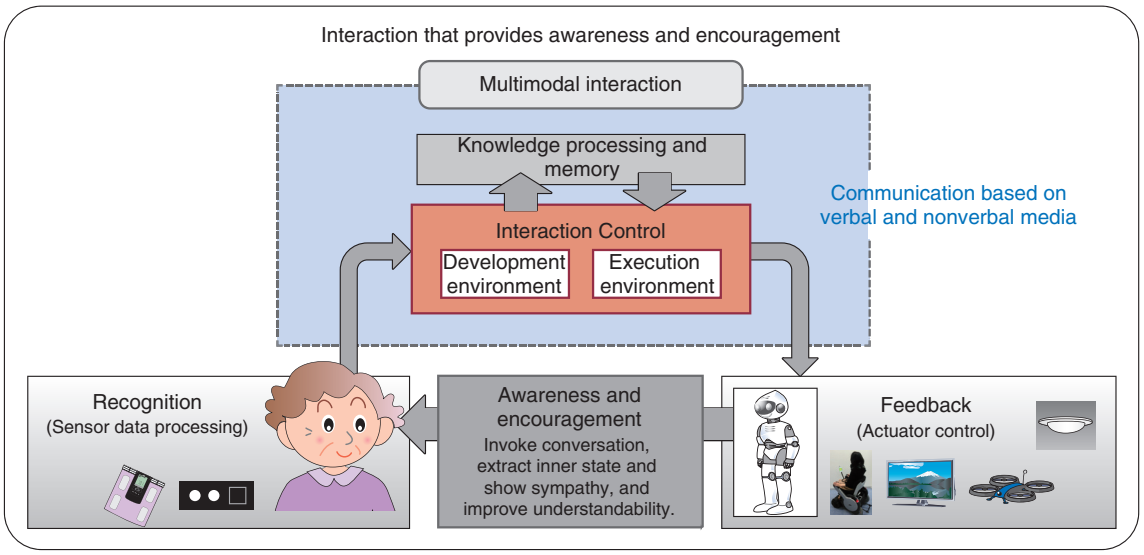


Fig. 1. Cloud-based Interaction Control technologies for robotics integrated development environment (R-env™).

4. Interaction Control technology

One of the key technologies necessary to realize the above goals is the Interaction Control technology used to connect humans and the devices that surround them. This technology will make it possible for the robot to understand a situation by combining the capabilities of various devices (e.g., voice from a microphone, facial expressions from a camera, and health data from electronic health devices) and also to deliver messages that include emotion by combining verbal and nonverbal communication methods. We have developed this interaction technology as the cloud-based Interaction Control technology called 'R-env™' (**Fig. 1**).

In the past, a high level of background knowledge of robot operating systems and programming languages was required in order to develop services based on robots or applications that involved the collaboration and control of multiple devices. To spread the use of robot-enabled services, we believe it is necessary to increase the number of application developers and to communicate the requirements for knowledge-processing and robot control components to facilitate the development of robot applications.

To do this, we built a new technology comprising a robot services execution environment and an integrated development environment (IDE). The former environment is known as a PaaS (platform as a service), and it can permit a single system instance to support the use of multiple applications by multiple tenants (users), enable management of mapping between devices and users, and enable devices to be easily connected. The latter environment involves an IDE for software as a service (SaaS). The close cooperation between the execution environment and the development environment makes it possible for SaaS to do the following:

(1) Simplify the debugging and execution of applications
(2) Enable easy development of device feature management
(3) Enable easy application development using only a web browser up to a certain level

R-env enables anyone to easily add new devices to existing services (**Fig. 2**). It is based on an architecture that supports advances in interaction technology with the addition of the emotion-enhancing technology being developed at NTT [8].

The use of R-env in our homes will make it possible to develop services that will integrate home appliances, healthcare devices, and robots with web services such as mail, schedulers, and weather forecasts. Furthermore, extending the scope of R-env outside the home will facilitate easy development of services using personal devices such as smartphones (**Fig. 3**).

5. Use cases

An example of how the open innovation of R-env is supporting the robot vendor Vstone Co., Ltd. [9] is shown in **Fig. 4**. Vstone's communication robot was

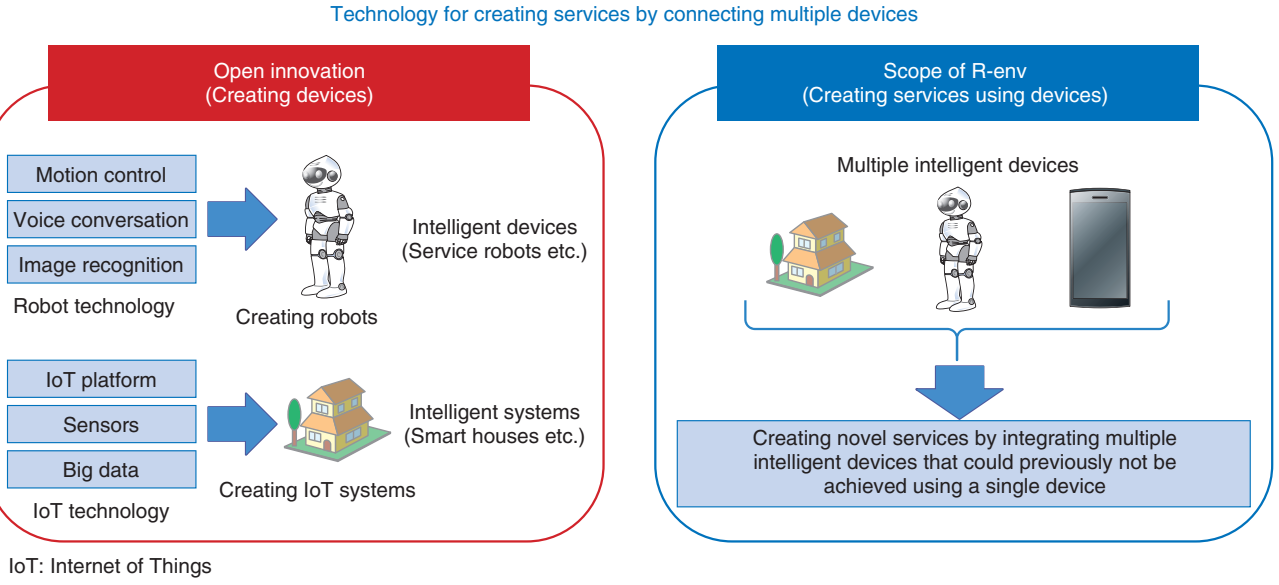


Fig. 2. R-env for robotic device orchestration.

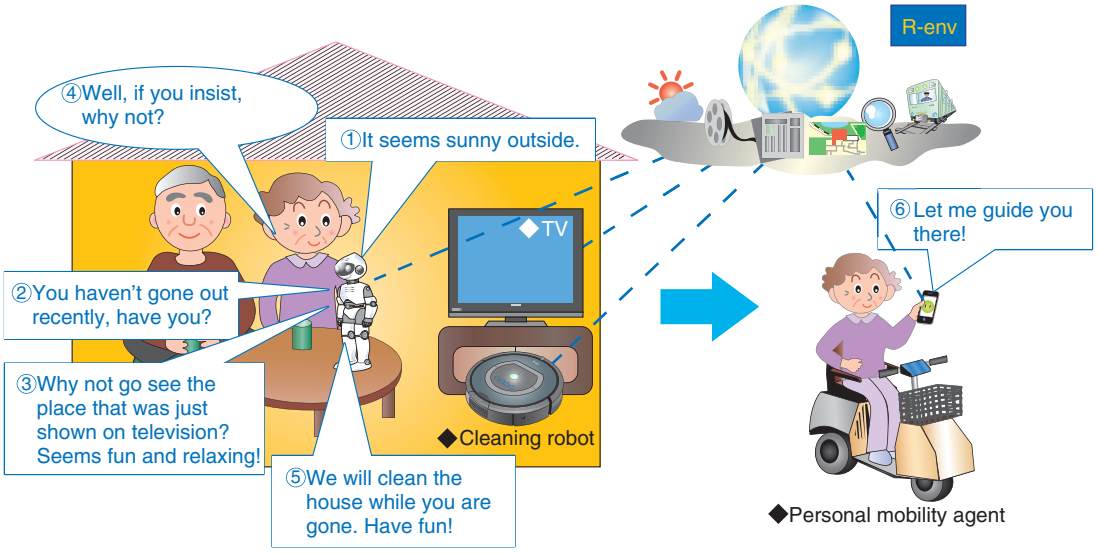
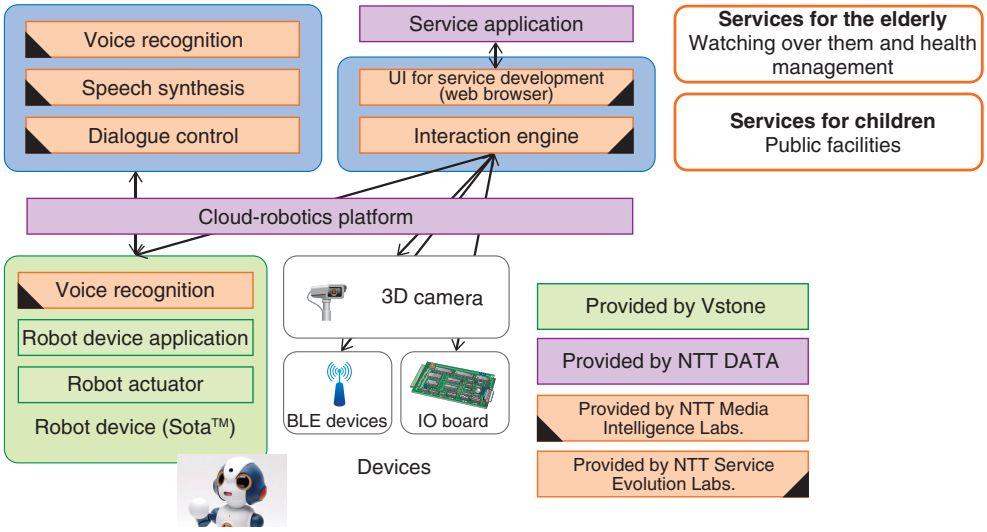


Fig. 3. Service image using R-env.

made intelligent by using NTT's voice recognition technology, dialogue control technology, speech synthesis technology, and sound-gathering technology. We are conducting experiments to confirm that the intelligent robot can, via R-env, collaborate with peripheral devices and/or other robots. For example, our intention is for robots to play an important role in supporting health management in places such as elderly housing and care facilities. The robots in these facilities will:

(1) Promote conversation and conduct health monitoring by *talking* with the elderly residents in collaboration with caregivers
(2) Provide personally tailored encouragement based on the physical condition of each person



BLE: Bluetooth Low Energy
IO: input and output
3D: three dimension
UI: user interface

Fig. 4. Formation of collaborative experiment between NTT DATA, NTT, and Vstone.

6. Conclusion

At NTT, by combining technology that will make devices such as robots more intelligent with technology that will enable easy device collaboration, we believe it is possible for robots to collaborate with each other via the network and to support human activities and growth in various situations.

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The Eyes as an Indicator of the Mind—A Key Element of Heart-Touching-AI

Shigeto Furukawa, Makoto Yoneya, Hsin-I Liao, and Makio Kashino

Abstract

Technology for *reading* the mind is an important element of Heart-Touching-AI, which aims to understand and support the human mind and body. The well-known saying "The eyes are the windows to the soul" expresses the fact that pupil response and eye movement can reveal information about a person's mental state. Research is underway at NTT Communication Science Laboratories to find the principles of understanding a person's mental state from his or her eyes in order to develop basic technologies that can apply such a capability to real-world problems.

Keywords: eye movement, pupil, mind-reading

1. Introduction

Artificial intelligence (AI) continues to advance and is being applied in numerous fields with various objectives, including with the aim of achieving an enriching society that fulfills the needs of mind and body. Accordingly, AI technologies have recently gone beyond machine intelligence for making logical inferences and are now being applied to understand human intellect, sensitivities, and emotions—all aspects related to the human mind. Thanks to advances in machine learning and other technical fields, there are now robots that can recognize human emotions by analyzing facial expressions and vocal patterns.

However, human emotions and psychological states are not always expressed by such explicit information as a person's facial expressions or voice. A machine would not surpass human performance in recognizing another's emotions as long as it uses only explicit information. Consequently, by adding the ability to measure unconscious physiological responses such as eye movement and heartbeat, NTT aims to achieve AI that can *read* a person's implicit mental state in a way that only a computer could recognize and communicate with humans more effectively than even humans can.

The brain-computer interface (BCI) based on electroencephalographic measurements has progressed as a basic technology for learning about a person's implicit mental state. This technology, however, has significant restrictions and suffers from high noise and low robustness, and as a result, its use has largely limited to certain fields such as medical care. Consequently, BCI is not considered to be ready for use in everyday scenarios.

NTT Communication Science Laboratories has developed a basic technology for evaluating a person's mental state by examining the person's eyes, as an alternative to electroencephalographic measurements. This technology has practical advantages in that it enables eye-related information to be obtained by a camera or other device in a non-invasive and non-contact manner and enables data to be measured without interfering with people's natural movements and sensations.

2. Information expressed by the eye

What kind of information can we obtain from the human eyes? The pupil, the black hole surrounded by the iris, adjusts the amount of light admitted to the retina. The light reflex property of the pupil is well known; the pupil constricts in a bright environment (miosis) and dilates (mydriasis) in a dark environment. A number of studies have been published that suggest a relationship exists between pupil diameter and various cognitive processes such as target detection, perception, learning, memory, decision making (e.g., [1]). The factor that determines the pupil diameter is the balance between the mutually antagonist actions of the pupil's sphincter muscle and dilator muscle, which are respectively governed by the parasympathetic nervous system and the sympathetic nervous system. The pupil cannot be controlled consciously (voluntarily).

The eyeball, meanwhile, moves under the control of the external eye muscle governed by the oculomotor nerve. Eye movement can be a voluntary process as when turning one's gaze toward something that one wants to look at. However, it can also be involuntary in the case when one's line of sight moves unconsciously toward a novel or conspicuous stimulus, or when small, jerk-like eye movements (microsaccades) occur in a state of visual fixation. Such involuntary eye movements have been said to reflect a state of caution induced by external stimuli or a state of latent caution (not accompanied with a change of gaze) [2]. Many evaluations of microsaccades have been done to measure their frequency of occurrence, and we as well have taken up a detailed evaluation of their dynamic characteristics and have been achieving results.

A variety of neural pathways contribute in a complex way to the control mechanisms governing pupil diameter and eye movement. This system includes nerve nuclei that are thought to have a deep relationship with cognitive processes. Nuclei whose functions are of particular interest include the locus coeruleus and the superior colliculus in the brain stem.

The locus coeruleus appears to play an important role in alertness, anxiety, stress, attention, and decision-making. These activities interact with various regions of the brain via noradrenaline pathways, and the pupils dilate through actions of the sympathetic nervous system [1, 3].

The superior colliculus, meanwhile, has been said to play a role in spatial attention and in controlling the direction of sight, but recent research has revealed that it can also interact with the pupils via the parasympathetic and sympathetic nervous systems [1, 2]. Neurons inside the superior colliculus react to stimuli associated with visual, somatic, and auditory sensations, and there is a *spatial map* in which the positions of such neurons correspond to different points in space where the stimuli appear. The superior colliculus not only receives input from lower-level sensory systems that it transmits to higher-level sensory areas in the cortex, but it also receives input from those higher-level sensory and associated brain areas via multiple pathways. It also receives projections from the basal ganglia and locus coeruleus as well. Reading the mind via pupil response and eye movement is based on inferences of the cognitive processes that are supported by this complex nervous system.

3. NTT activities in Heart-Touching-AI

We introduce here our recent efforts in developing Heart-Touching-AI. A number of experiments have confirmed that the pupil and eye movements react to the conspicuousness (saliency) of sound and to the degree that the sound differs from what was expected (surprise). Some of these preliminary findings have been presented in previous articles in this journal [4, 5].

In the case of music, the saliency and surprise of tone and melody are thought to be important factors that determine a person's affinity and preference for a particular song or piece of music. We have created a model for estimating a person's affinity and preference for a piece of music by extracting appropriate multidimensional features from pupil response and eye movement and using machine learning technology (**Fig. 1**). We found that with this model, it is possible to estimate a listener's subjective music rating score with a certain level of accuracy [4].

A similar approach can be applied to evaluation of stimuli other than music, for example, fondness (preference) for a face. In an experiment, we presented images of faces to the observers while measuring their pupil responses. At this time, miosis was found to occur when the brightness of those images was changed. However, it was also found that the extent of miosis differed between the presented images even though the change in brightness was the same for all images (**Fig. 2**). We asked the observers to subjectively evaluate facial-image preference and found that the extent of miosis corresponded to the observer's subjective evaluation [6]. Furthermore, using a model similar to the one described above, we confirmed that

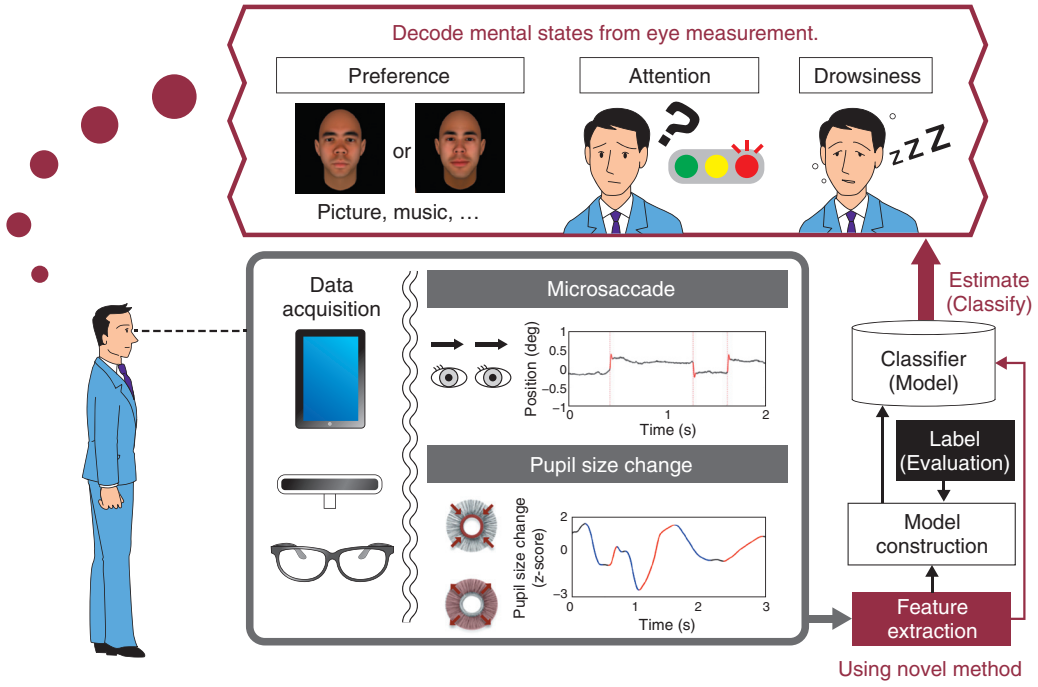

Fig. 1. Model that estimates a person's latent state of mind based on eyeball movements and pupillary reflex.

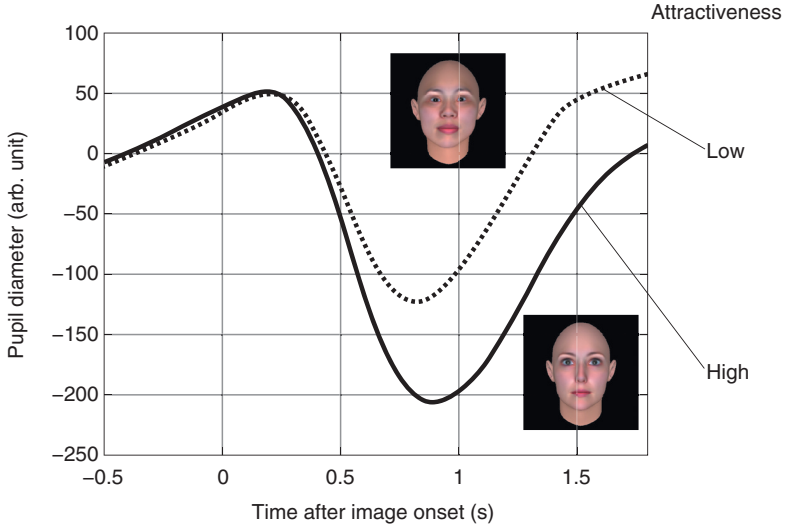

Fig. 2. Example of pupillary response to facial images.

an individual's evaluation with respect to facial preferences could be predicted with high accuracy by combining a variety of features including those of pupil response and eye movement.

It would be natural to say that this correlation between pupil diameter and facial-image preference obtained in the above experiments shows how the cognitive process associated with facial-image preference appears as a change in pupil diameter. However, we also consider the possibility of an inverse cause-and-effect relationship, in which differences in certain features in individual images give rise to

differences in miosis, which in turn acts on the cognitive process.

To examine this possibility, we conducted an experiment on manipulating the amount of miosis by introducing a change in brightness to the background picture instead of to the facial images themselves [6]. We found that the subjective evaluation of facial-image preferences changed in conjunction with the amount of empirically introduced miosis. This finding has important implications. It can be said that the pupil not only expresses the state of mind but that it is also a window that will enable AI to *act* on a person's mind or mood.

4. Future outlook

In research up to now, the emphasis has been on music preferences and facial preferences as targets of estimation. However, targets that can be estimated through eye measurements are not limited to preferences. As explained at the beginning of this article, the pupil response and eye movement are governed by the complex nervous system. Therefore, it is inferred that the eyes latently reflect various cognitive processes such as pleasure/displeasure, drowsiness, tension, and fear. The framework of feature extraction and machine learning at the core of our technologies is generic enough to be applied to any of those cognitive aspects (leaving aside the accuracy of the learning outcome).

However, a necessary condition here for the machine learning is that *correct data* are *correctly* obtained. For example, to learn what types of eye movements occur when people are sleepy, the eye movements of a person in an actual state of drowsiness must be recorded. Up to now, it has been possible to obtain preferences related to targets such as music and facial images through questionnaires administered in a laboratory, so it has been relatively easy to obtain correct data. However, the estimation of feelings such as fear and anger is difficult to record in a laboratory because of ethical issues, and it is also difficult to quantify subjective emotional states, even by the observers themselves.

Another issue here is that pupil response and eye movement can be affected by a variety of external and internal factors, and it is therefore difficult to find simple correspondence with specific cognitive processes or neural activity in real-world situations. In future research, sophisticated psychological and behavioral experiments and independent biological reaction measurements will be necessary to accurately evaluate unconscious cognition. Given that many evaluation methods themselves have not yet been established, the only way to solve these problems is to employ a variety of measurement and analysis techniques while keeping their underlying mechanisms and limitations in mind, thereby enhancing our understanding a little at a time. At NTT, we are addressing these issues through basic research that spans diverse fields from physiology and psychophysics to machine learning technologies and through mutual interaction among those fields.

Of course, development in measurement technology itself will also be necessary. The most common approach to measuring pupil and eye movements is to apply image processing to images captured by camera. Today, the smartphones, tablets, and personal computers that we have all come to use are equipped with web cameras, so we can consider that platforms capable of measuring eye activity are expanding all around us. The frame rate of a typical web camera, however, is only several dozen frames per second (fps). If high-speed image capture becomes possible, we can envision the catching of latent reactions of short duration such as the dynamic characteristics of microsaccades. In our research, we are capturing images at 1000 fps using specialized eye-measurement devices, so one key to applying this achievement to general devices will be the development of high-speed cameras.

Provided that we accumulate basic knowledge, collect substantial data via sound experiments, and upgrade measurement technologies, we feel that the day in which AI will be able to read a person's mind (or act on a person's mind) by looking at that person's eyes is not that far off.

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Business Transformation Using Artificial Intelligence at NTT Communications

Koji Ito, Shoko Nishido, and Tomoaki Yamazaki

Abstract

At NTT Communications, we are actively introducing artificial intelligence (AI) in our operations, solutions, and services. In this article, we introduce some of the efforts underway to transform existing business models using AI at NTT Communications.

Keywords: artificial intelligence, operation, IoT

1. Introduction

NTT Communications held the NTT Communications Forum in October 2015 and had the highest number of visitors ever. Exhibits related to Internet of Things (IoT) and artificial intelligence (AI) attracted a great deal of interest.

We are currently experiencing what has been described as the arrival of the third AI boom. Leading domestic and foreign information technology companies are intensifying their AI-related projects, and the work we are doing at NTT Communications has been receiving a lot of interest from our customers in various fields.

There are three factors that have led to this AI boom. The first is big data. With the advancement of IoT, it is estimated that approximately 50 billion devices will be connected to the network in 2020, with even larger amounts of data collected from those devices. The second is the improvement in processing capacity. We can now process complex calculations that were not possible a decade ago. The third is the technological innovation of deep learning[*1]. This technology has contributed to significant improvements in voice and image recognition accuracy. The conditions are now such that this AI boom will not simply end as a mere phase; we have the potential to apply AI to change the business structure itself in various fields.

2. Enhanced services by using AI

NTT Communications aims to improve its cloud services based on its company slogan *Global Cloud Vision* by using AI technology and also to contribute to its customers' business innovations. We introduce here some of the latest AI services and functions NTT Communications plans to launch in 2016. These services embody the concept of Agent-AI that the NTT Group is developing.

2.1 Cognitive Agent Service

The first one is the Cognitive Agent Service (**Fig. 1**). This new service will understand and engage in natural language[*2] interaction by using cutting-edge technologies including cognitive technology of IPsoft[*3] and the advanced Japanese-language processing technologies that NTT Media Intelligence Laboratories has been developing for four decades. This automated service will respond to a wide range of incoming

*1 Deep learning: Multi-layer structured neural network that mimics the structure of brain nerves; it can acquire a representation of abstract data from fields such as image recognition and voice recognition and has the potential to greatly surpass conventional technology.

*2 Natural language: Conversational and written language; language people use in their everyday communication.

*3 IPsoft: Managed services and PaaS (platform as a service) provider; IPsoft's business is expanding globally.

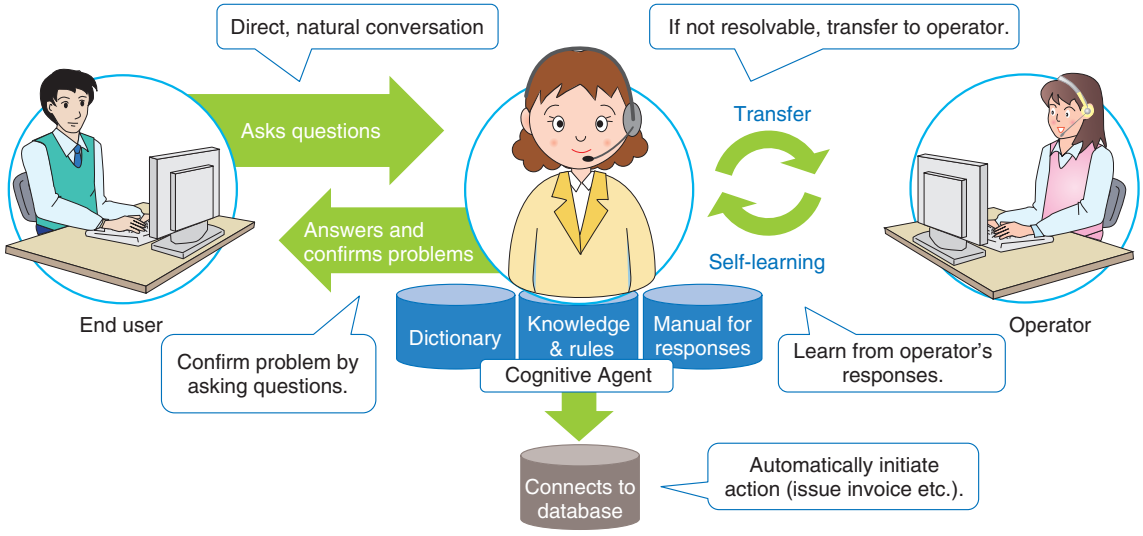


Fig. 1. Example solution: Cognitive Agent Service at contact center.

customer requests and help to diagnose and resolve their problems.

This service will utilize not only basic morphological analysis but also dependency parsing, word conceptual vectorization, and question-answering technology that understands human intention in their dialogues. These NTT technologies will enable the new service to understand natural language and interact with customers smoothly. They are expected to result in the service that differs from similar services and provides a competitive advantage.

While the working population of Japan has been declining, many companies have had to handle a wider range of consumer demands at their contact centers. To meet these demands, NTT Communications will launch this highly automated Cognitive Agent Service in 2016.

2.2 AI technology for consumer services

NTT Communications is also planning to launch new functions for its consumer services enhanced by AI technology in 2016. The first function is AI labeling in its online storage service called My Pocket. This will enable customers to categorize their photographs automatically into life events by using the AI system. The second function will work on NTT Communications' online household bookkeeping application called Kakeibon and will analyze its customers' household accounts and offer financial advice.

Thus, NTT Communications expects to improve the speed of upgrading its AI systems by self-learning of knowledge and big data accumulated on its cloud at an accelerated pace. NTT Communications will develop its products to have a higher level of performance and quality with AI technology.

3. Use cases in customer service

For several years, we have collected and analyzed big data related to service operations such as troubleshooting, service order and delivery records, inquiry histories, and machine logs. However, we also have experienced the limitations of dealing with a huge amount of data manually, and this is why we have focused on AI.

We now introduce two use cases involving customer service.

3.1 Automatic forecasting of estimated time of repair

We have started to provide the estimated time of repair (ETR) in some of our network services. In the past, we tried to calculate ETR based on each operator's skill and experience. Therefore, the accuracy of ETR differed from operator to operator, and it turned into another major task for us. Now, however, ETR is calculated automatically by using big data and correlation analysis of trouble ticket data such as operation logs, alarms, and trouble patterns (**Fig. 2**). We are also using AI to improve the accuracy of ETR with self-learning. It continuously checks the pattern of each problem and the gap between the predicted ETR

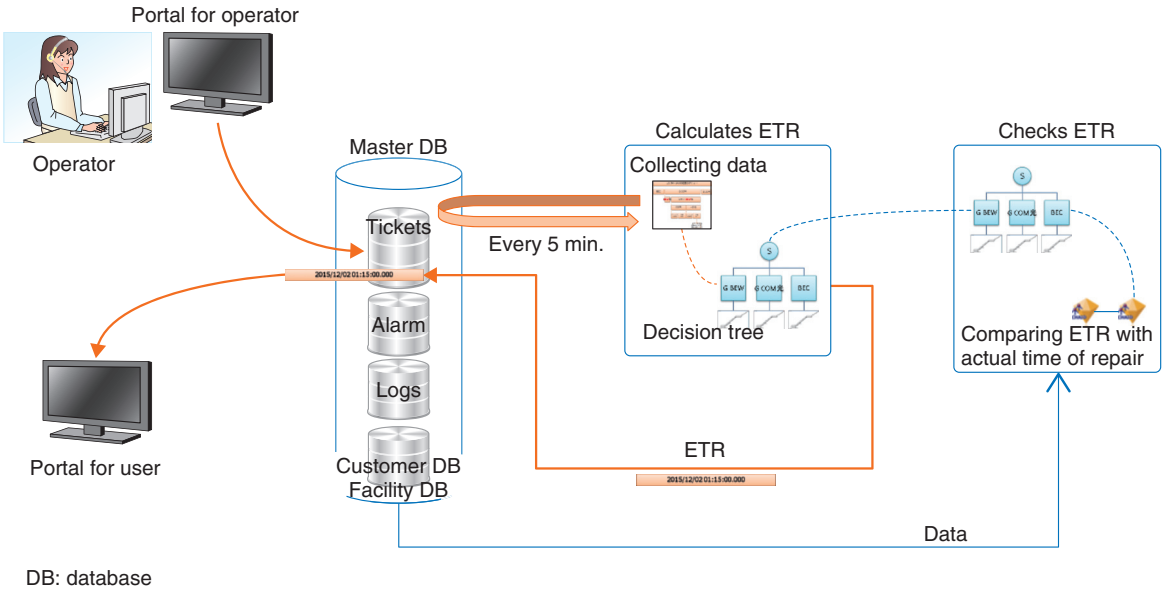


Fig. 2. Automatic forecast of ETR.

value and the actual ETR value. Such data are accumulated and utilized by AI to improve accuracy. We will strive to improve the accuracy of the forecasted ETR and expand the application range to other services.

3.2 Improved customer service

Recently, in collaboration with NTT research and development laboratories, we have been testing ways to improve customer service by utilizing AI in the frequently asked question (FAQ) and question and answer (Q&A) support sections. AI is being utilized to search similar FAQs automatically and to give feedback to improve its own precision (in conjunction with AI technology of Inbenta[*4]). It is also being used to suggest a Q&A list that is related to the content of customer service calls to generate more appropriate answers in each case. Real-time speech-to-text, FAQs applying intelligent search by natural language processing, and automatic analysis of operation logs are some example ways NTT Communications is improving its customer service.

However, a sense of crisis that humans will be replaced by AI has been increasing recently. On the other hand, by using AI, we can concentrate our power and resources more efficiently in places where it is needed. Similarly, the advantages of using AI are also attracting more attention than ever before. NTT Communications will continuously work to improve customer satisfaction through the use of AI and to apply its accumulated experience to support our business customers.

4. Use of deep learning to analyze the meaning of IoT data

Future IoT equipment[*5] is not limited to consumers; it will become widespread in businesses from the industrial field to the entire social infrastructure and is expected to continue growing rapidly. In such cases, it is extremely difficult to analyze the wide variety of big data by human power alone. In addition, each customer demands automated services involving collecting and analyzing big data and taking actions based on them.

To address this situation, NTT Communications is focusing on deep learning. In particular, we aim to develop deep learning technology that can handle time-series data and multi-modal data, because IoT data is generated momentarily, and several different types of data are complexly correlated with each other (**Fig. 3**). This is Ambient-AI, another AI concept the NTT Group is working on.

*4 Inbenta: Natural language processing, AI applications, and FAQ search solutions provider.

*5 IoT equipment: Equipment that can communicate with various other devices that exist in the world.

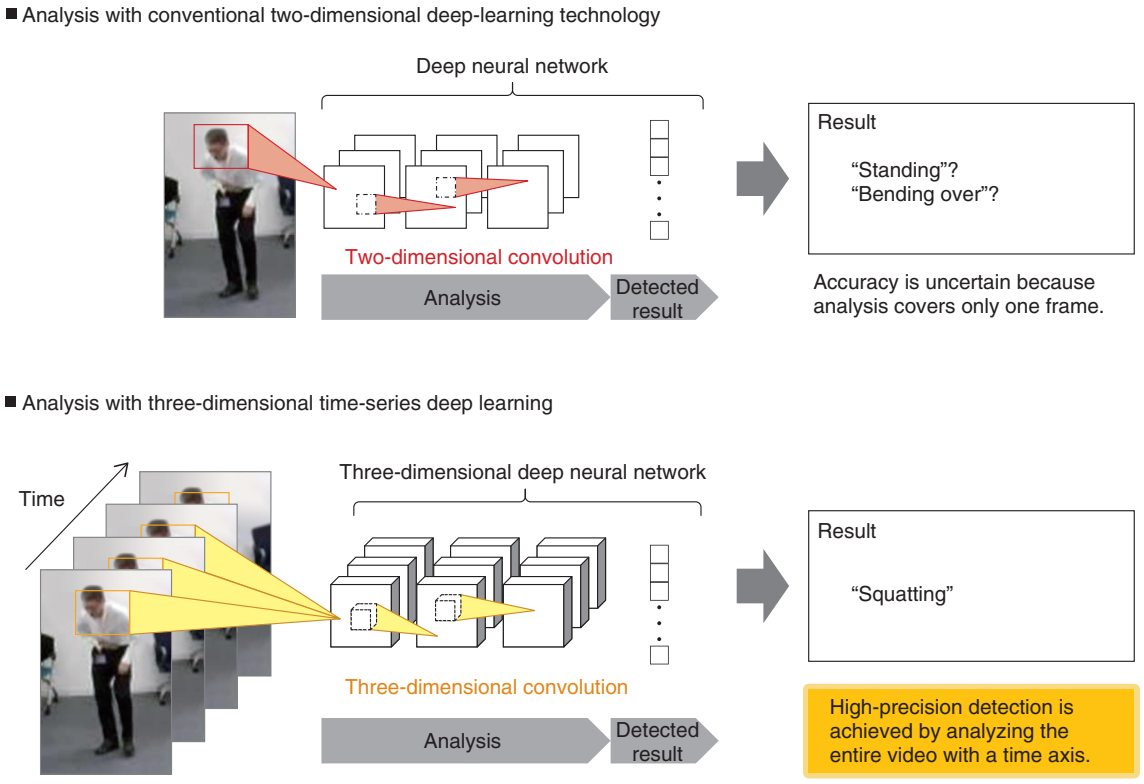


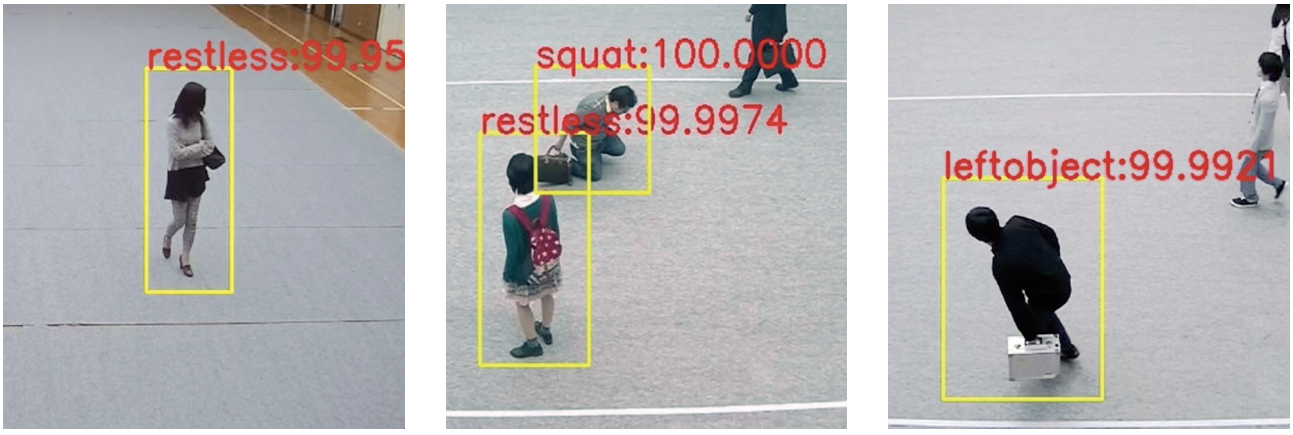
Fig. 3. Time-series deep learning.

In 2015, NTT Communications developed and evaluated time-series deep learning for analyzing the meaning of time-varying images (video). Normally, when executing image recognition using deep learning, we input pixel values of the input image into a neural network for image recognition (typically using a CNN (convolutional neural network), and the neural network repeatedly updates the weights between layers based on the difference between the calculated prediction results and the actual results. The neural network will continue in this manner in order to acquire an abstract feature to recognize the image. In our work, we dealt with not only the target pixels of the same frame as commonly used but also *time information* for treating successive frames at once. As a result of this approach, the machine automatically understood what happened in the video with a high degree of accuracy.

In consideration of possible real-world use cases such as automatically monitoring a suspicious person or a sick person, we tested this by identifying five types of behavior: *leaving an object, restlessness, squatting, standing,* and *walking*, and we were able to identify each behavior using time-series deep learning with approximately 80% accuracy (**Fig. 4**).

In the near future, while still analyzing time-series data, we also plan to investigate how to deal with a variety of data in a complex manner. Such data are referred to as *multi-modal* data. To take advantage of this time-series deep learning, we are looking into providing Video Analysis Platform Services (tentative name) that will enable the automated analysis of video data in a variety of applications such as crime prevention and marketing. This technology will make it possible to detect suspicious behavior of people in stores and manufacturing plants. It can also be applied for crime prevention measures in a number of facilities that are expected to see an increase in the number of visitors in 2020, the year of the Tokyo Olympic and Paralympic Games. We plan to work with a variety of partners to improve this service and technology to a practical level.

Future work in AI, which is said to hold the key to the fourth industrial revolution, has the potential to fundamentally alter the structure of various industries. We will continue to work on the challenge of



(a) Identifying the behavior of "restlessness" (b) Identifying the behavior of "squatting" (c) Identifying the behavior of "leaving an object"

Fig. 4. Image analysis using time-series deep learning.

creating new markets while utilizing AI technology in order to become an ICT partner that contributes to the transformation of existing businesses and the creation of a new business model.

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Artificial Intelligence Technology Development and Its Practical Use at NTT DATA

Otoya Shirotsuka

Abstract

NTT DATA established a new organization called the AI Solution Promotion Office on October 1, 2015, to promote artificial intelligence (AI)-related initiatives and to respond to customer inquiries regarding the utilization of AI. The new organization will promote AI-related technological know-how accumulated in-house, as well as the NTT research and development laboratories' world-class AI technologies. This article introduces some examples of NTT DATA's approaches regarding the utilization of AI technologies.

Keywords: knowledge acquisition, communication robot, traffic simulation

1. Introduction

In recent years, NTT DATA has been receiving inquiries from many customers asking how artificial intelligence (AI) can be utilized in work operations now that AI is experiencing exponential growth. The majority of these inquiries are made with an underlying sense of crisis in which customers wonder if they will be at a competitive disadvantage if they do not introduce AI technology.

The AI Solution Promotion Office was established at NTT DATA on October 1, 2015 in order to respond to these kinds of customer inquiries regarding the utilization of AI and to promote AI-related initiatives. One of the strengths of this division is utilizing NTT research and development (R&D) laboratories' world-class AI technologies, but NTT DATA has also been conducting its own business development and R&D of AI technologies since its establishment as a company in 1988, and it excels at accumulating AI-related technological know-how.

NTT DATA is focusing its AI utilization efforts in three important domains: 1) middle and back office operations such as examinations and analyses, 2) front office operations such as contact desk and call center support, and 3) various social infrastructures developed using large-scale data analysis. The first two are Agent-AI target domains, and the third is an Ambient-AI target domain [1]. Three specific examples of NTT DATA's efforts regarding these domains are described in this article: the efficient examination of credit card member stores using knowledge acquisition technology, retail store customer support using communication robots, and traffic congestion management using multi-agent simulations.

2. Efficient examination of credit card member stores using knowledge acquisition technology

A major task in many industries involves examining the contents of applications, for example, credit card applications, and carrying out the preliminary work of gathering the necessary information to decide whether or not applications can be accepted. Many of these operations are done manually and consist of repetitive tasks to confirm whether there are any problems with the application contents. In addition, there are some cases in which specialized knowledge is needed to make decisions on the contents. There is also a risk of losing business opportunities if too much time is consumed performing the examinations. Consequently, these operations can

take a heavy toll on companies. It is for this reason that NTT DATA is advancing R&D on examination support technology that reduces the burden of these operations.

2.1 Reduced burden of credit card member store management operations

The use of examination support technology began two years ago, and results have already been obtained on six cases.

The credit card industry is one area where results have been obtained. This industry has seen an increase in the number of scenarios in which consumers use their credit cards with the rapid growth of e-commerce and the diversification of payment methods such as payment via smartphone. As a result, there is strong demand to develop secure environments where customers feel at ease when using their credit cards, and therefore, credit card companies are working urgently to increase the security and efficiency of managing a wide variety of retail stores (member stores) that accept credit card payments.

As part of its efforts towards increasing the security and efficiency of examination operations, NTT DATA began working with Sumitomo Mitsui Card Co., Ltd. in October 2013 to jointly initiate verification tests on the efficiency and automation of information gathering for member store examination, and in October 2014, these verification tests were implemented in Sumitomo Mitsui Card's member store management operations. Comprehensive decisions are made after referring to and analyzing a variety of information concerning member store examination operations, but particularly in cases when examinations are conducted on non-face-to-face merchants such as e-commerce and smartphone stores.

For this reason, it is important to determine how precisely and effectively this diverse information can be analyzed within member store examination operations. Examination support technology extracts and collects information necessary for examinations from a vast amount of information existing on the Internet such as reputation information from forums, content on e-commerce sites, and third-party information on the Internet.

A dashboard function has also been implemented that displays gathered information on one screen in an easy-to-understand fashion and increases the efficiency of examination operations such as automatically highlighting and displaying areas that need attention. The AI Solution Promotion Office is focusing on R&D of knowledge acquisition technology that specifies which areas are important in examination operations by adding meanings to text information. In the example of credit card member store examinations, this technology is being utilized to not only specify corporate names, addresses, and hours of operation from e-commerce sites, but also to automatically gather the price range and price ceiling of products that those corporations sell. In addition to performing these tasks, this technology also gathers information on the reputation of the relevant companies and checks to see if there are any entries on social networking sites regarding those companies.

2.2 Semi-automatic generation of rules through the use of machine learning

Knowledge acquisition technology is a technology that estimates the structure of semi-structured and unstructured data such as sentences and lists. This is a combination of original structuring technology in line with the data format of extracted targets. To utilize this technology, rules are necessary to extract objective information, and to generate these rules, there is a need for not only business knowledge but also specialized knowledge on information extraction technology[*1], which is why specialists in the AI Solution Promotion Office have until now been receiving requests and performing operations manually. Consequently, the considerable cost and time required for this have been issues until now.

However, R&D is currently underway on technologies that semi-automatically create rules through machine learning by leveraging knowledge on rule generation that has been conducted manually up until now. For example, when creating rules that specify place names from text information, a person first confirms whether the candidate place name (written in red characters) on a screen listing example sentences is correct or not by selecting either "o" or "x" (**Fig. 1**). Next, the system uses machine learning based on this content to automatically generate new rules. Repeating this step increases the accuracy of the rules. This mechanism for generating rules and technology that increases the efficiency of examinations is collectively called *sensu* (tentative name), and verification tests on and application of sensu are currently progressing.

*1 Information extraction technology: One of several natural language processing technologies that extract useful information from non-structured data such as text information, and converts that information into a format that can be used by computers.

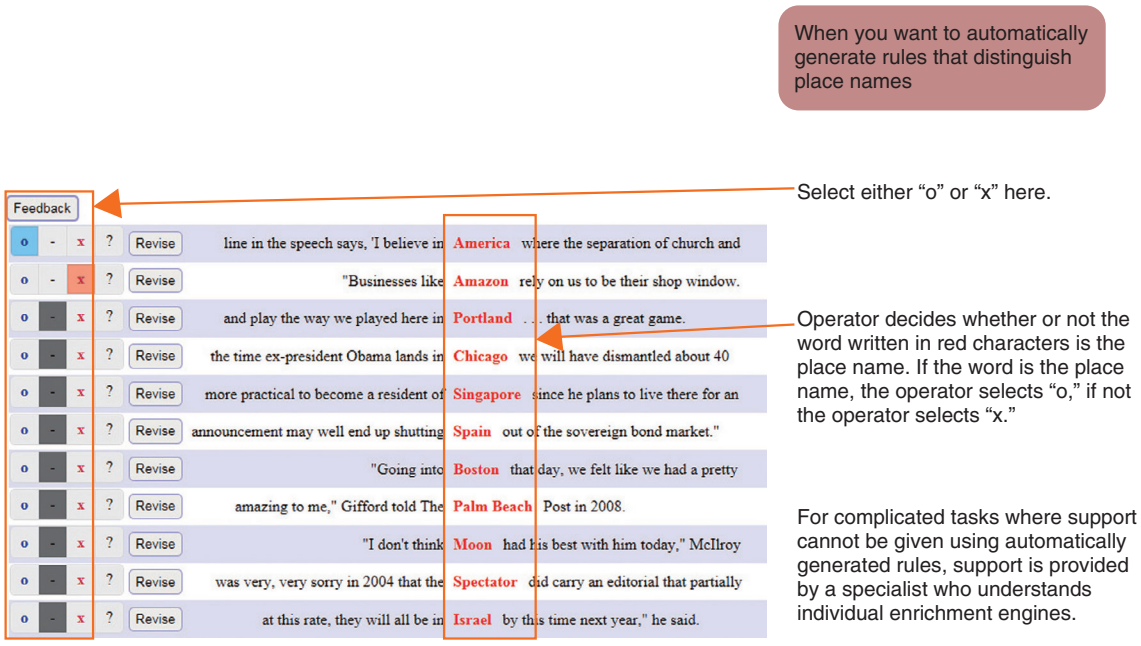


Fig. 1. Rules can be generated through machine learning by performing simple tasks.

3. Retail store customer support using communication robots

The robotics market is expected to rapidly expand, and there is an increasing expectation that the market within the service field will grow quickly. However, issues still remain in terms of cost and technology; for example, robots themselves are expensive, and the data retained by robots must be protected. Accordingly, NTT DATA is making efforts to research and develop Cloud Robotics Platform[*2] that simplifies the robots themselves and reduces their costs by gathering sophisticated functions on a cloud database and by integrating various devices such as robots and sensors connected to a network with various services on the cloud.

3.1 Provision of advanced services at low cost

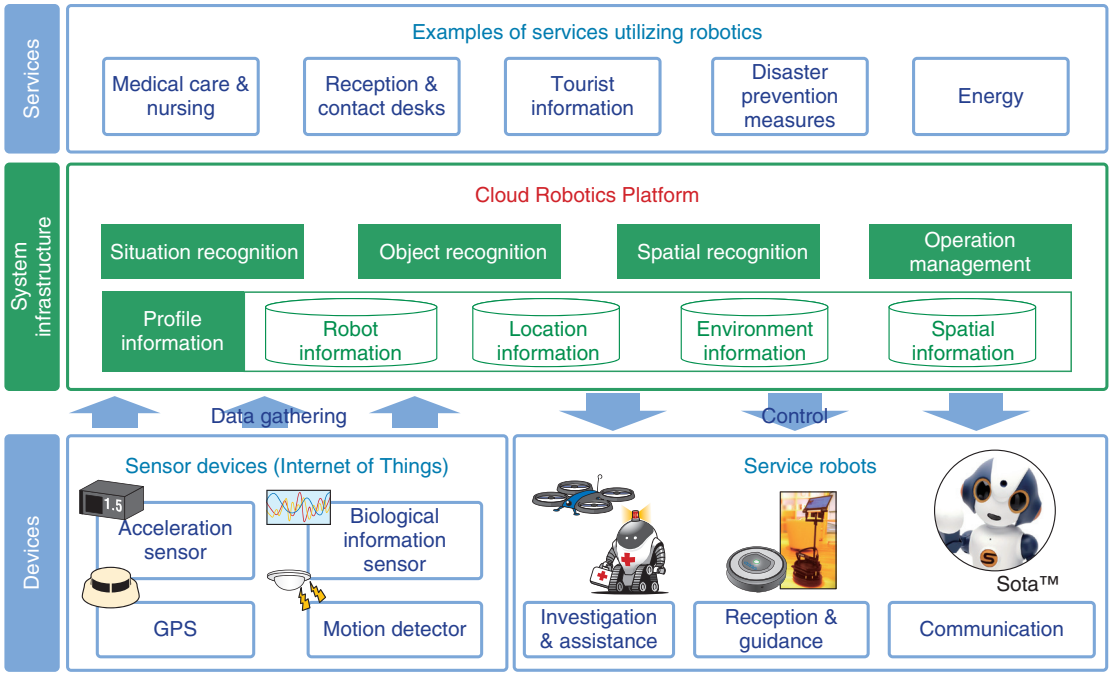
Since data collected from robots and sensor devices are handled in an integrated manner, Cloud Robotics Platform utilizes the R-env™ technology developed by NTT Service Evolution Laboratories to control the integration of cloud support devices as well as the know-how accumulated by NTT DATA on M2M (machine to machine) and IoT (Internet of Things) (**Fig. 2**).

NTT DATA is already conducting verification tests that utilize sensors and Cloud Robotics Platform. Two examples are verification tests of elderly support services in nursing homes and verification tests of visitor survey collected in public facilities. These tests use Cloud Robotics Platform and also leverage technologies such as the communication robot Sota™[*3] manufactured by Vstone Co., Ltd. and technology for speech recognition, dialogue control, and speech synthesis developed by NTT Media Intelligence Laboratories.

3.2 Support of guidance-related operations of bank clerks using sensors and robots

The number of overseas visitors to Japan is expected to increase in 2020, and efforts are therefore increasing to develop contact desk services utilizing communication robots such as those that support customers in multiple languages at reception desks in various industries. Accordingly, NTT DATA has been paying attention to customer support-related operations in financial institutions where there are great expectations for use scenarios involving communication

*2 Cloud Robotics Platform: An information integration platform that collects data from devices, analyzes the data, and controls devices such as robots.
*3 “Sota” is a trademark of Vstone Co., Ltd.



GPS: Global Positioning System

Fig. 2. Cloud Robotics Platform.

robots. NTT DATA and Vstone have been conducting joint verification tests towards realizing customer support using communication robots in actual branches of financial institutions.

The feasibility of providing customer support services via dialogues with communication robots was evaluated in verification tests conducted at the RESONA Bank Toyosu Branch (Seven Days Plaza Toyosu), a newly established branch, from the day of opening on November 15, 2015, until the end of April 2016. During these verifications, we extracted issues in business and operations while listening to the opinions of visitors and bank clerks. For example, high-sensitivity sensors installed in the ceiling above the building entrance on the first floor would detect people entering and leaving the facility and notify the communication robot stationed at the ATM (automated teller machine) corner. Along with communicating with customers by saying "Welcome!" or "Thank you for visiting us," the robot directed visitors to the branch services located on the second floor. High-sensitivity sensors installed at the entrance of the branch notified the communication robot placed at the reception desk when visitors came close. The robot would then start a dialogue with the visitor by greeting them with "Welcome!" and then prompt the visitor to use the self-reception tablet according to the contents of the robot's conversation with the visitor. This endeavor achieved services that supported the guidance-related operations conventionally conducted by bank clerks (**Fig. 3**).

An increasing number of inquiries is being made regarding the utilization of communication robots in customer support-related operations. NTT DATA will continue conducting verification tests and is working to expand the range of support that communication robots provide in customer support-related operations such as customer guidance and product introductions in stores by utilizing AI technology. NTT DATA also intends to promote the early practical use of communication robots.

4. Traffic congestion management using multi-agent simulations

Traffic congestion is an important social issue that affects both advanced and developing countries. There are situations when applying basic solutions such as expanding roads and improving intersections is difficult due to cost and legal issues.

If the effects of multiple traffic congestion mitigation measures can be compared in traffic simulations,

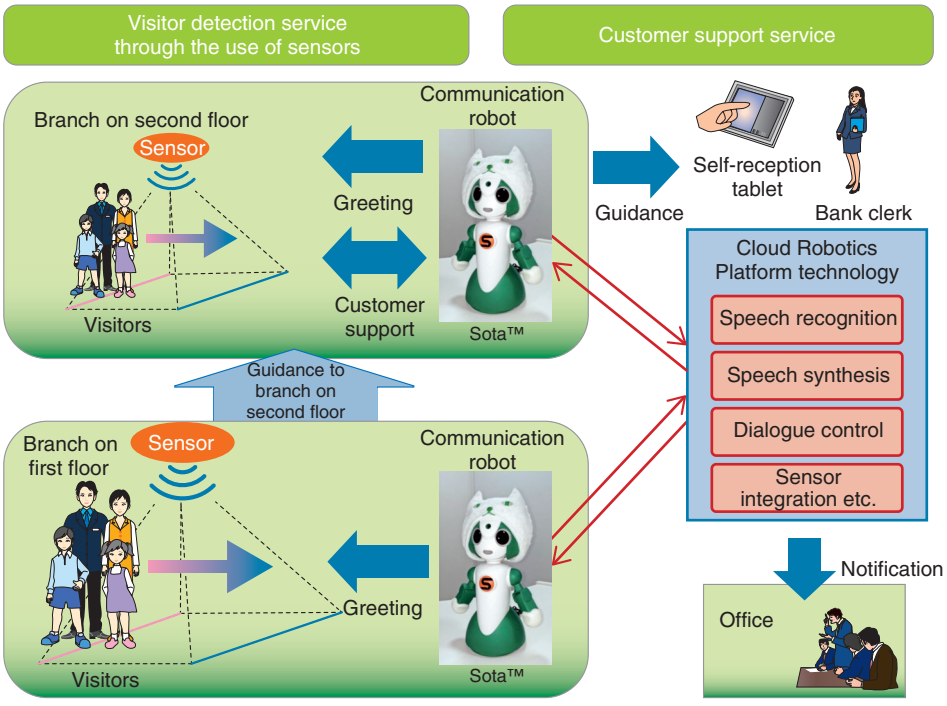


Fig. 3. Branch reception desk robot.

it will be possible to select the most effective measure. Accordingly, NTT DATA is conducting R&D on technologies that predict traffic congestion and control stoplights by utilizing traffic simulation technology.

4.1 Large-scale traffic simulation technology based on parallel distributed processing

NTT DATA's traffic simulation adopts a method using a multi-agent model. In this method, targets that influence cars, stoplights, roads, intersections, and other traffic elements are regarded as agents, and this method reproduces actual traffic congestion situations by operating an enormous number of these agents on a virtual network of roads generated on computers. However, conventional measures require high-spec computer resources to simulate situations where a high density of cars causes congestion in a broad area.

NTT DATA has successfully realized distributed processing by separating an original map into a mesh format and by using multiple general-purpose servers (**Fig. 4**). In addition, since one mesh is assigned to one core of a server and then calculated, distributed processing requires mesh partitions with equal computational complexity. The NTT Software Innovation Center has developed graph data analysis processing technology called equal granularity clustering (**Fig. 5**) with which NTT DATA has succeeded in conducting fast mesh partitions and conducting traffic simulation in real time.

4.2 Mitigation of congestion by optimizing traffic congestion in predictions and signal controls

To verify the effectiveness of traffic control using this traffic simulation technology, NTT DATA cooperated with Jilin City in China in November and December 2014 in conducting verification tests in a city central area. During these tests, Jilin City buses equipped with on-board computer terminals were used to conduct traffic congestion prediction and stoplight control simulations in combination with statistical information such as traffic volume, routes, and information from approximately 200 probe units (the location and speed, etc., of each bus) concerning the eight routes gathered from those on-board computer terminals. Traffic was controlled by reflecting stoplight settings—which were optimized through prior assessments done in simulations—in intersection stoplight machinery found within the city, and the effects of traffic congestion mitigation and the improvement of bus service times was verified. As a

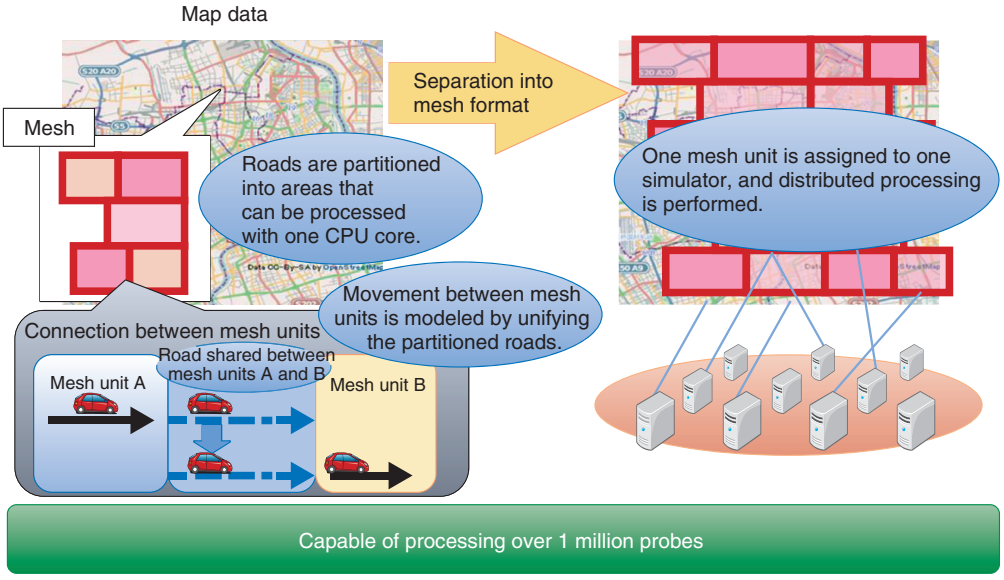


Fig. 4. Image of the use of distributed processing.

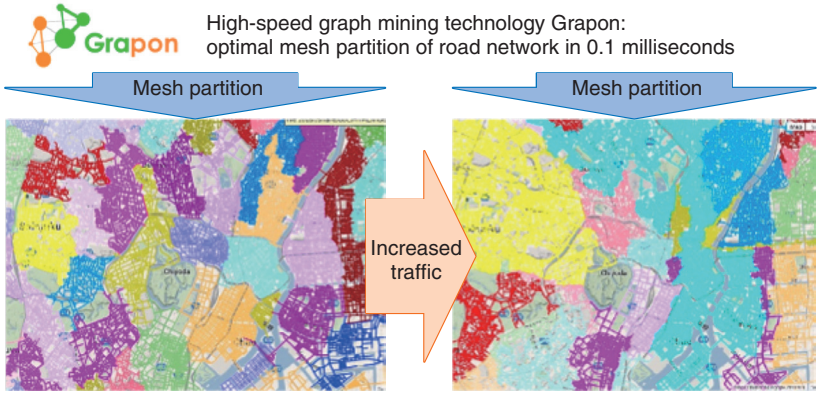


Fig. 5. Illustration of the application of equal granularity clustering technology.

result, the average speed of vehicles moving within the target area was increased, traffic congestion was reduced, and it was confirmed that the average bus service time for target bus routes was improved on average by 7% and up to 27%.

In 2015, NTT DATA cooperated with Guiyang City in China to develop technology that successfully mitigates traffic congestion by performing traffic congestion predictions and stoplight control simulations based on the data analysis results of cameras installed in Guiyang City used for managing traffic. This effort was done in collaboration with the Institute of Software, Chinese Academy of Sciences and was conducted as a horizontal deployment of know-how obtained from the verification tests conducted in Jilin City.

Initiatives promoting the practical use of traffic congestion mitigation solutions in combination with traffic simulation and stoplight control technology are progressing within NTT DATA in an effort towards successfully managing major events in 2020 and realizing smart cities in countries around the world.

5. Future development

This article introduced three important domains where AI technology is being utilized at NTT DATA, related utilization examples, and various types of AI technology applied in each of those cases. In order to broaden the utilization of AI technology within these important domains in the future, it will be essential for AI technology itself to further progress. We at NTT DATA will endeavor to strengthen our alliances with NTT R&D laboratories and other business firms as well as leading-edge research organizations such as universities to develop an assortment of AI technologies with great potential in order to deal with social problems such as decreasing birthrates and aging populations, and to provide global support for disaster prevention and other situations.

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Utilization of Artificial Intelligence in Call Centers

Seiji Kawamura, Kenichi Machida, Kazuhira Matsui, Daisuke Sakamoto, and Marie Ishii

Abstract

In November 2014, IBM Japan, Ltd. and Mizuho Bank, Ltd. issued a press release on the Watson computer system that utilizes artificial intelligence (AI) to support call center operators. Since then, the expectation that AI will be used in the call center sector of major companies has been increasing rapidly. This article introduces AI technology that is being used effectively in call centers now and AI technology that is expected to be widely introduced within the next few years. NTT Software's ForeSight Voice Mining technology is also described.

Keywords: voice mining, artificial intelligence, call centers

1. Introduction

NTT is actively researching and developing four artificial intelligence (AI) domains [1]. Of those domains, NTT Software is focusing its efforts on Agent-AI. Specifically, NTT Software is developing human-like agents that assist operators in call centers. NTT Software launched a product named ForeSight Voice Mining for call centers in May 2014. The product utilizes voice recognition technology, natural language processing technology, and voice mining technology developed by NTT Media Intelligence Laboratories. Since releasing the product, NTT Software has been offering it mainly to call centers of major financial institutions in cooperation with NTT business companies.

In November 2014, IBM Japan, Ltd. and Mizuho Bank, Ltd. issued a press release on the Watson system that uses AI to support call center operators [2, 3]. Watson is defined as a cognitive computing system that understands/learns natural languages and supports a human's decision-making process. Since this press release, there has been a growing awareness of AI and of Watson in the call center sector of major financial institutions, and consequently, the number of inquiries to NTT Software asking about the capabilities of NTT's AI technology has rapidly increased. We introduce in this article the AI functions that ForeSight Voice Mining provides.

2. AI functions of ForeSight Voice Mining

ForeSight Voice Mining utilizes various AI element technologies developed by NTT Media Intelligence Laboratories such as machine learning and natural language comprehension. It therefore provides functions that are useful in various business fields. These functions include a response knowledge recommendation function to support operators' work in call centers and an automatic call summary function to support the after-call work of operators. These functions are implemented with the image of virtual agents (human-like agents). For example, call center operators can see on their computer screen messages from a virtual agent offering help or suggestions during their phone conversations with customers.

2.1 Response knowledge recommendation function to support call center operators

Operators in call centers refer to various information and use know-how based on their experience to solve the problems of customers when answering calls. An issue that arises with less experienced operators is that they tend to frequently place calls on

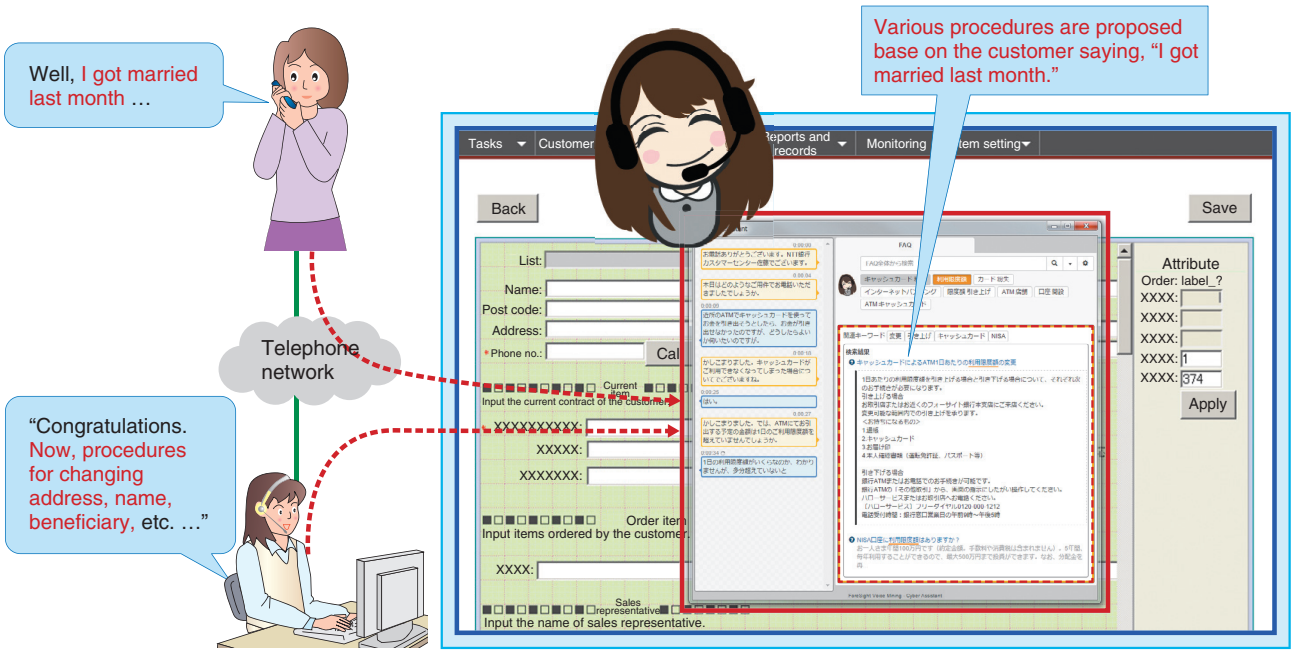

Fig. 1. Response knowledge recommendation function.

hold or to prolong the response time in order to refer to such information, and this makes customers impatient and increases the operating cost of call centers.

As a solution to these problems, ForeSight Voice Mining has a function in which a virtual agent listens to the conversation between operators and customers and promptly gives suggestions on appropriate responses to the operator. This function uses voice recognition of calls on a real-time basis and natural language processing technology to display appropriate responses on the operators' computer screens, and it enables operators to automatically obtain appropriate response knowledge during their conversations with customers and to respond to calls more quickly and effectively.

For example, at a call center of a life insurance company, when a customer says, "I got married last month," a virtual agent responds to the word *married* and instantly displays relevant information on the screen of operators such as *Procedures for address change, Procedures for name change*, and *Procedures for beneficiary change*. In this way, sharing the know-how of experienced operators with the entire call center staff enables less experienced operators to work as effectively with customers as experienced operators, improves customer satisfaction, and reduces the operating cost of the call center (**Fig. 1**).

2.2 Automatic call summary function to support after-call work of operators

Call center operators enter the content of their conversations with customers in the system as response records after completing calls. This is referred to as after-call work. The difficulty with this work is that the description of response records entered as after-call work varies widely depending on operators, and the length of descriptions significantly decreases during busy times.

ForeSight Voice Mining has an automatic call summary function in which a virtual agent summarizes the conversation between operators and customers and proposes summarized sentences to the operator. This function realizes role sharing between machines and humans; that is, AI (machine) is responsible for preventing variations in the lengths of descriptions in response records between busy periods and slow periods and variations in viewpoints of descriptions by different operators, and operators (humans) are responsible for handling calls, which requires them to respond appropriately to customers at all times, whether the customer is exhibiting a pleasant or unpleasant manner. In other words, AI is utilized to substitute for and support a certain part of human activities, and AI and humans take charge of their own areas of specialty.

Summaries created by the automatic call summary function can be categorized into two groups; one is *automatic extraction of the nature of the call* to extract the reasons customers called in the first place, and the other is *automatic extraction of important phrases* to extract only important remarks during the call. In this method, summaries created do not depend on the duration of the call and the key points of calls to be recorded in a concise way. Another method called the *unnecessary sentence deletion method* can also be used for the summary function. The function creates summaries by deleting unnecessary sentences (such as greetings and supportive responses) included in conversations. This method has a low risk of missing information to be recorded and is able to record an overview of the entire call. However, with this method, the length of summaries depends on the duration of the call. Because the summary function method to be used is determined according to how the companies will use the summaries later, NTT Software proposes the optimal method for customers depending on their intended use of summaries.

The use of the response knowledge recommendation function and the automatic call summary function described above requires prior learning exercises by using recorded voices of actual incoming calls to call centers as well as response records before applying the functions in actual situations. Prior learning exercises enable the functions to be adjusted to the work of companies where the functions are to be introduced, and regular additional learning after the start of operation improves the ability of the functions to adapt to the work.

3. Technological advances leading to increased interest in AI use in call centers

There was a boom in interactive voice response (IVR) systems based on voice recognition among call centers from the late 1990s to the early 2000s. In Japan, the U.S. firm Nuance Communications, Inc. and other vendors of voice recognition systems promoted the introduction of the IVR system using voice recognition in some innovative companies. Most voice recognition systems introduced at that time were not able to recognize conversations. They only recognized words (or a series of words) registered in the system beforehand. Now, about 20 years have passed since then, and the throughput capacity of computers has dramatically improved, deep neural networks have been introduced in the algorithms of voice recognition engines, and sufficient accuracy of voice recognition has been achieved for conversations speakers (operators and customers) have without even being aware of voice recognition [4]. These advances in technology prompted IBM Japan and Mizuho Bank to issue the press release about Watson in November 2014, which led to the rapid increase in expectations for the use of AI in call centers.

4. Improved corporate image through the use of AI in call centers

In many cases, call centers of companies represent a sector that is costly, and therefore, reducing costs at call centers is a never-ending task. At the same time, however, improving customer satisfaction and maintaining/improving corporate brands require better customer support, and a high-quality customer experience at call centers is an important factor to maintain/improve brands. In other words, for companies that operate call centers, the coexistence of cost reduction and a high-quality customer experience is a consistent objective. Innovative companies are willing to introduce AI (machine) that will take charge of dealing with customers to reduce costs, and they seek to convey the image of being cutting-edge companies that adopt advanced technology quickly. Conventional thinking used to be that a high-quality customer experience could only be achieved when human operators interact with customers. However, this idea is changing, and it is more often thought that improvement of voice recognition and natural language processing technologies will make it possible to achieve a high-quality customer experience in which AI interacts with customers in some areas to a satisfactory extent. Using AI in customer service will make it possible to achieve stable quality in dealing with customers without having to deal with difficulties in securing sufficient human resources. In addition, a company's corporate image will greatly improve if they can impress customers with the high-quality responses of their AI systems. Therefore, innovative companies are now starting to compete in their use of AI to provide customer support.

5. Future development

NTT Software is using the advanced technology of NTT Media Intelligence Laboratories and promoting products and services in which AI directly interacts with customers. For example, NTT Software is pursing virtual agents that understand and properly respond to what customers say when answering calls

and virtual agents that understand and properly respond to sentences input into websites and social networking services by customers. NTT Software believes that such products and services cannot be achieved overnight but can be achieved within a few years, as strong needs for them exist, and technologies to meet those needs are steadily advancing.

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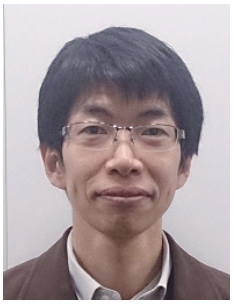

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Optical Switches Using Beam Steering by Computer Generated Hologram

Keita Yamaguchi, Kenya Suzuki, and Joji Yamaguchi

Abstract

We describe a computer generated hologram (CGH) method that is applicable to a multiple input and multiple output (MxN) optical switch based on liquid crystal on silicon (LCOS). The optics of the conventional MxN optical switch require multiple spatial light modulations. In addition, a phase pattern designed using the CGH method achieves a simple MxN optical switch with a single spatial phase modulation. Moreover, the intrinsic loss of the proposed MxN switch from beam splitting can be reduced by routing multiple signals with a single knob control. We demonstrate a 4x4 wavelength selective switch and a 2-degree reconfigurable optical add/drop multiplexer switch based on the above CGH method. The experimental results indicate that these switches work well with a crosstalk of < –20.0 dB.

Keywords: hologram, optical switch, LCOS

1. Introduction

In optical communication networks, wavelength selective switches (WSSs) [1, 2] are used to achieve wavelength provisioning. WSSs can route a specific wavelength channel in a wavelength division multiplexing (WDM) system in any direction without interrupting the remaining channels. WSSs with free-space optics are widely used in networks in order to achieve a high port count and low crosstalk. An optical system of a typical WSS with one input and multiple output ports (1xN) is shown in **Fig. 1** [1, 2]. Liquid crystal on silicon (LCOS) is used for the switching engine. The WDM signals from the input port are demultiplexed by the grating, and each wavelength channel is focused at a different position on the LCOS. The LCOS modulates the wavefront of an input beam at each wavelength channel independently by using pixels arranged in two dimensions. After the wavefront is modulated, the beams are multiplexed by the grating and then connected to one of the output ports. The spatial phase pattern for the modulation controls the diffraction angles of input beams. Therefore, the focus point on a line with output ports can be controlled by such patterns, leading to port switching. In these optics, multiple signals with the same wavelength input from other ports are focused at the same position with different incident angles and modulated by the same phase pattern on the LCOS. Therefore, a WSS cannot control multiple incoming signals with the same wavelength independently.

Multiple input and multiple output (MxN) optical switches have been studied recently as a way to achieve flexible switching [3, 4]. The MxN switch can route multiple signals from multiple directions with one module. For example, a multi-degree reconfigurable optical add/drop multiplexer (ROADM), which needs the MxN switching function, can be realized by using multiple 1xN WSSs and splitters [5]. A 4-degree ROADM node with a broadcast-and-select (B&S) configuration is shown in **Fig. 2**. This configuration requires four 1xN WSSs and four splitters, which is costly and requires a lot of space. The conventional approach to the MxN optical switch is a multiple beam-steering configuration. However, the optics of such a switch are more complex than those of the 1xN WSS, which increases the size and cost. In

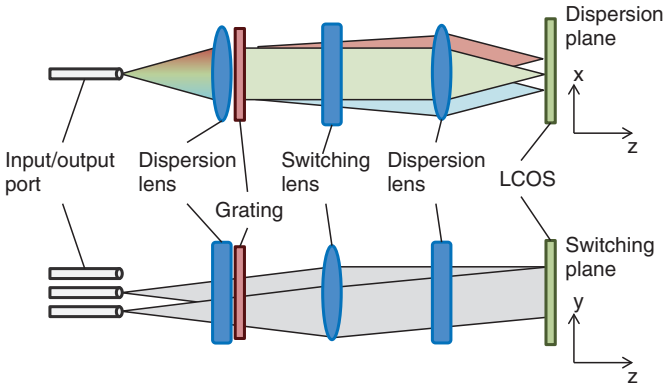

Fig. 1. Optical system of 1xN WSS.

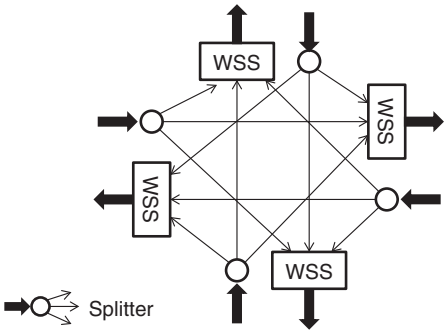

Fig. 2. Schematic of 4-degree ROADM node with B&S configuration.

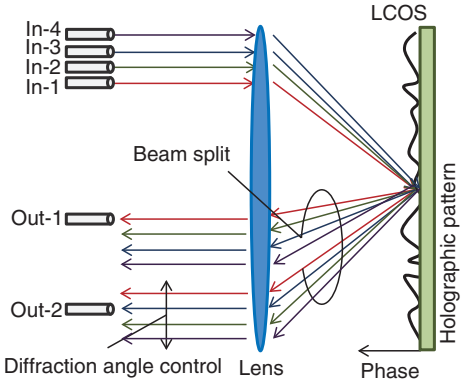

Fig. 3. Optical configuration of 4x2 optical switch based on CGH.

this study, we added the MxN switching function to the 2-f optics by using a hologram method.

2. MxN optical switch using holographic phase modulation

Our MxN switch integrates the B&S function by using holographic phase modulation. The B&S function can be divided into beam splitting (broadcast function) and port selecting (select function). In LCOS 2-f optics, the broadcast function refers to the diffraction of an input beam into multiple angles. The select function refers to the control of the diffraction angle by the phase modulation on the LCOS. If these two functions can be integrated, a B&S type MxN switch can be achieved with the 2-f optics. Holographic phase modulation can achieve both of these functions with 2-f optics. In this study, the spatial phase pattern on the LCOS was designed by using the computer generated hologram (CGH) method. In the calculation of a CGH, the phase pattern is randomly modified along the switching axis. Transmittances for designated ports are then calculated in simulations. These steps are iterated until the transmittances for the ports achieve a target value.

2.1 B&S type MxN switch

An MxN switch that integrates the B&S function via one-time holographic phase modulation has previously been proposed [6, 7]. A 4x2 switch is shown in **Fig. 3**. This switch has the same 2-f optics as the 1xN switch. In the optics, all input beams are split and diffracted at multiple angles (broadcast function). The signal beam connected to each output port is selected from each split bundle of beams by adjusting the diffraction angle (select function). The phase

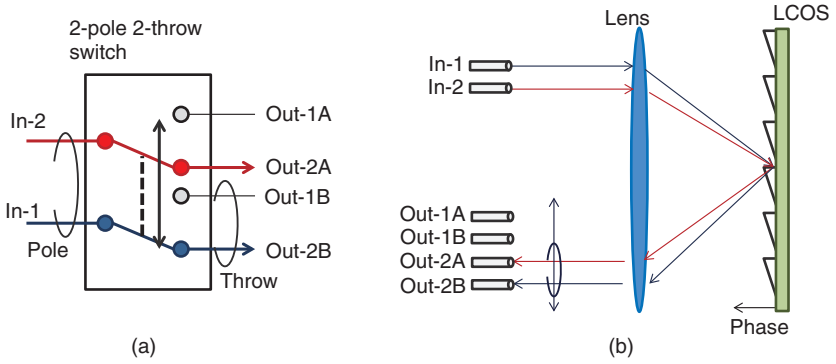

Fig. 4. (a) Switching function and (b) optical configuration of 2-pole 2-throw switch.

pattern, designed by using the CGH method on the LCOS, can split input beams into multiple angles and independently control the diffraction angle of each bundle of split beams [8]. Moreover, the connection state of multiple signals can be switched by the change in the phase pattern. As a result, an input signal from any input port can connect to any output port by using the CGH pattern.

This switch has intrinsic loss caused by beam splitting, which increases with the number of input beams. When the simultaneous switching of multiple signals is enabled, the multi-pole multi-throw (MPMT) switching function can reduce the ramification number and the intrinsic loss in the MxN switch [9].

2.2 MPMT switch array

The MPMT switch controls multiple signals in a set [10]. The function of a 2-pole 2-throw switch is illustrated in **Fig. 4(a)**. In-1 and in-2 can be connected to out-1A or out-1B and out-2A or out-2B, respectively. This switch can control the connection states of two input signals from in-1 and in-2 with a single knob control. Although the switch controls MxN ports, the intrinsic loss caused by beam splitting does not occur. The optical system of the 2-pole 2-throw switch with 2-f LCOS optics is shown in **Fig. 4(b)**. Here, the difference in the diffraction angles from the LCOS is the same as the difference in the incident angles. Therefore, if the output angle differences between the output ports are the same as those of the incident angles between the input beams, multiple input beams from multiple input ports connect to multiple output ports simultaneously by single spatial phase modulation. This is the MPMT function.

When multiple input beams are always switched in a set, the intrinsic loss from beam splitting can be reduced by using the MPMT function. For example, in ROADM networks, the same wavelength channel in the WDM system is used by received and transmitted signals connected to the same node. In other words, when an in-port and drop-port are connected, an input signal from an add-port, which is connected in the same direction as the in-port, should be connected to an out-port. In this case, these input signals from the in-port and add-port can be controlled by using the MPMT function.

The switching function of a 2-degree ROADM switch based on the 4x4 switch with MPMT function is shown in **Fig. 5(a)**. There are two connection states, that is, the add/drop state and the through state. In the add/drop state, west-in and east-in are respectively connected to the west-drop and east-drop ports. At this time, west-add and east-add are respectively connected to west-out and east-out. In the through state, west-in and east-in are respectively connected to east-out and west-out. The others are not connected to any ports. Here, the input signals in bundle-1 and bundle-2 can be controlled independently. This 4x4 switch with MPMT function can reduce the ramification number in the 4x4 switch from four to two compared with the B&S type 4x4 switch, which can independently route all input beams, resulting in a reduction of the intrinsic loss from 6 dB to 3 dB. An optical configuration of the proposed multicast-MPMT switch is shown in **Fig. 5(b)**. The configuration is the same as that of the CGH based MxN switch. We arrange the output ports so that the difference between diffraction angles equals the difference between diffraction angles connecting the out ports, leading to the MPMT function.

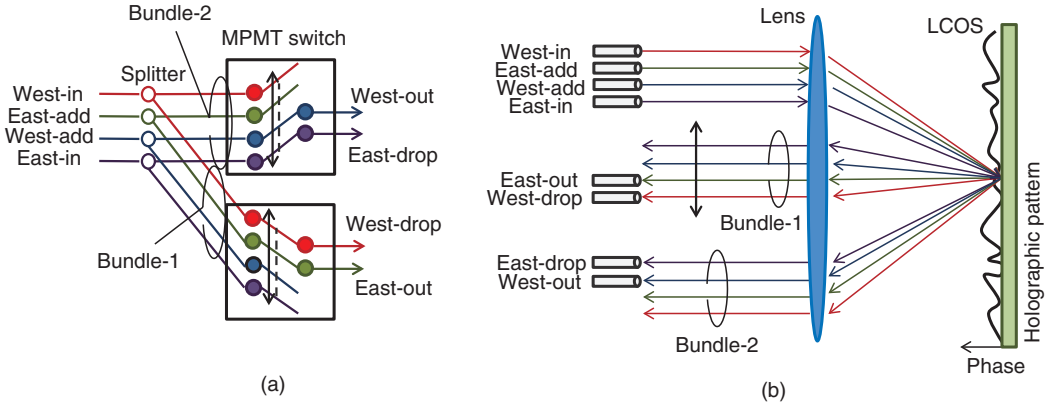

Fig. 5. (a) Switching function and (b) schematic illustration of 2-degree ROADM switch based on 4x4 switch with MPMT function.

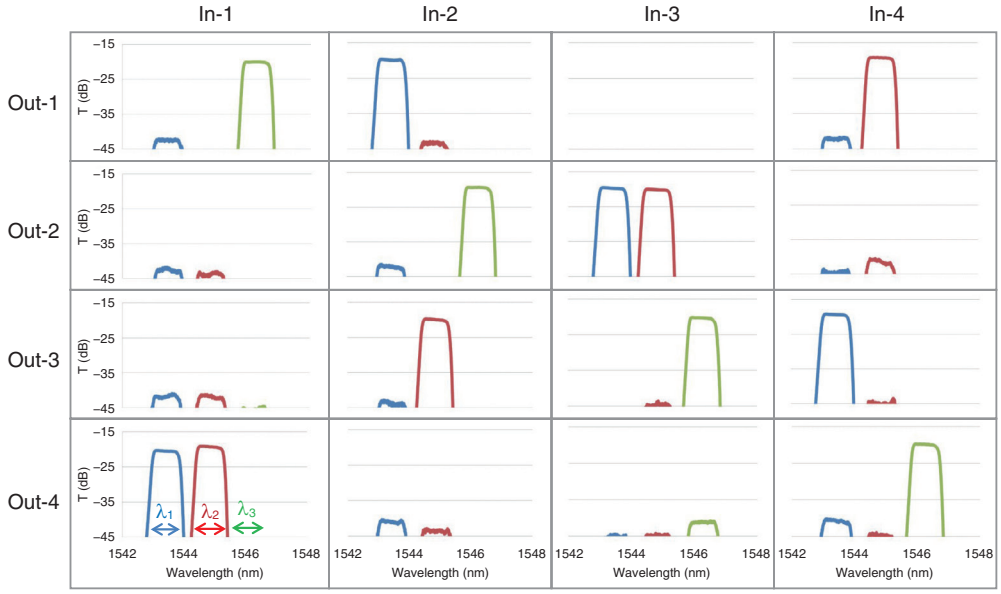

Fig. 6. Transmission spectra of B&S type 4x4 WSS based on CGH.

3. Experimental results

We describe here the experimental results for the B&S type 4x4 WSS, which can connect any input and any output ports, and the 2-degree ROADM switch with MPMT function. The patterns for spatial phase modulation on the LCOS were designed by using the CGH method [11]. The wavelength band was divided into three segments in the 4x4 WSS and two segments in the 2-degree ROADM switch. These separated wavelength bands were indexed as λ_1, λ_2, and λ_3 from short to long wavelength.

The experimental results are shown in **Fig. 6**. Diagrams lying in the same horizontal line show the measured transmittance (T) for the same output port, and diagrams lying in the same vertical line show the measured T from the same input port. Here, each wavelength channel is set in each switching state, as indicated in **Table 1**. This result shows that this 4x4 switch worked well. At this time, the maximum port crosstalk (XT) was –20.0 dB, and the increase in insertion loss above the basic level for switching was 6 dB for beam splitting and from 0.9 dB to 3.1 dB due to imperfections in the CGH.

Table 1. Connection states in experiment performed on B&S type 4x4 WSS based on CGH.

	In-1	In-2	In-3	In-4
λ_1	Out-4	Out-1	Out-2	Out-3
λ_2	Out-4	Out-3	Out-2	Out-1
λ_3	Out-1	Out-2	Out-3	Out-4

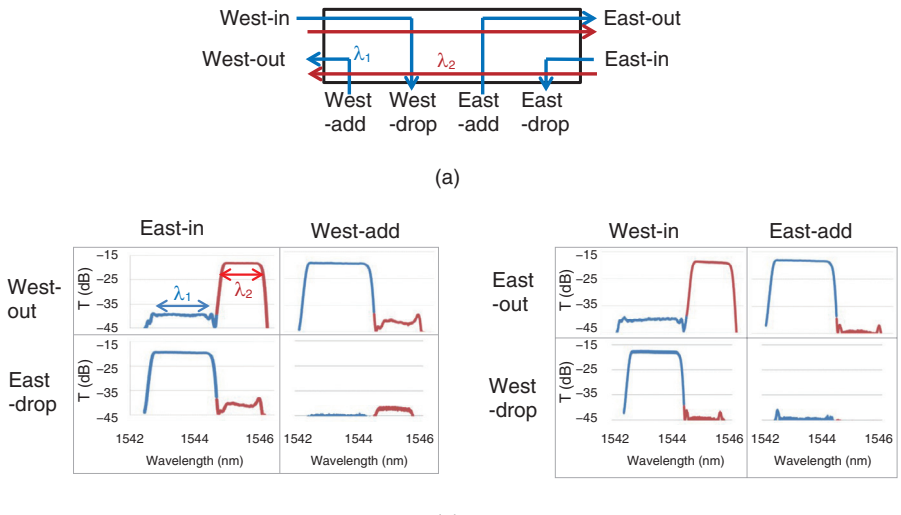

Fig. 7. (a) Connection plan and (b) transmission spectra of proposed 2-degree ROADM switch with MPMT function.

The experimental results with the 2-degree ROADM node with MPMT function are shown in **Figs. 7(a)** and **(b)**. Channels λ_1 and λ_2 were set in the add/drop and through states, respectively, as shown in Fig. 7(a). The increase in the insertion loss from the MPMT switching function was 3 dB for beam splitting and 3 dB to 4.1 dB due to the imperfection of the CGH. The maximum port XT was less than –20.0 dB.

4. Conclusion

We reported on MxN optical switches with 2-f optics. These switches use holographic spatial phase modulation for the integration of the B&S function. The switches integrate the B&S function, which can control multiple input signals independently, by using a phase modulation pattern designed using the CGH method. The CGH pattern can split input beams (broadcast-function) and control the diffraction angle of split beams (select-function). Moreover, the MPMT function can reduce the intrinsic loss of this MxN switch. We found that in a B&S type 4x4 switch without the MPMT function, the increase in insertion loss above the level for basic switching was 6 dB for beam splitting and from 0.9 dB to 3.1 dB due to imperfections in the hologram. In comparison, in a 4x4 switch with the MPMT function, the increase in insertion loss above the level for basic switching was reduced from 6 dB to 3 dB for beam splitting and from 3 dB to 4.1 dB due to imperfections in the hologram. Moreover, the crosstalk between ports was less than –20 dB.

The port XT and insertion loss can be improved by optimizing the design of the phase modulation patterns. We expect that the development of this switch will lead to new applications.

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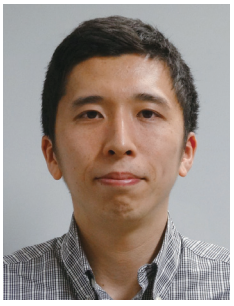

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Edge Router System that Distributes Traffic Flexibly According to Services

Masaaki Omotani, Takeshi Osaka, Ichiro Kudo, Akiko Kuboniwa, Chiharu Morioka, Taizo Yamamoto, Yuta Watanabe, Akira Misawa, and Tsukasa Okamoto

Abstract

In the future, communication networks will need to provide various services more flexibly and efficiently according to the diversified needs of customers and service partners. NTT Network Service Systems Laboratories is researching and developing an edge router system that distributes traffic flexibly to various service functions in a network. This system is being developed in order to reduce costs by increasing transfer capacity and reducing power consumption, and to respond to service needs flexibly by employing traffic distribution and policy control functions.

Keywords: edge router system, DPI, traffic control

1. Introduction

The Internet of Things (IoT) is a network of various physical objects—*things* that exchange data and have network connectivity. As IoT development has progressed and 4K/8K video has become popular, the demand for information communications has been increasing. The required quality and capabilities of communications vary widely from single very high speed sessions to numerous low speed sessions, depending on use cases, applications, and devices. In addition, for development using a B2B2X (business-to-business-to-X) business model, it is also important to provide services rapidly and flexibly according to service partners' needs.

We are researching and developing networks that have the capabilities to respond to various needs. In the NetroSphere concept [1] devised by NTT laboratories, network functions are separated into components and modules, and services are provided rapidly and flexibly by combining necessary components and modules. A key element to realize this concept is an edge router system under development that accommodates many users, classifies the service to be applied to user traffic, and distributes traffic flexibly to appropriate service functions in the cloud. This system also has a larger transfer capacity, higher power efficiency, and higher reliability than current edge routers, which will reduce network costs. Furthermore, this system has a policy control[*1] function that enables new services to be provided, leading to increased revenue.

2. Cost reduction and reliability enhancement of edge router system

2.1 Larger transfer capacity and higher power efficiency

The traffic volume in communication networks has increased as the demand for video transfer services has grown, video definition has become higher, and the number of mobile devices has rapidly increased. A high performance edge router is needed in order to efficiently respond to such traffic increases. That is, the edge router system requires a large transfer capacity that supports 100-GbE interfaces and accommodates many users. This will make it possible to

*1 Policy control: Control of user traffic such as filtering, priority control, and rate limiting, according to rules (policy) defined for certain kinds of traffic.

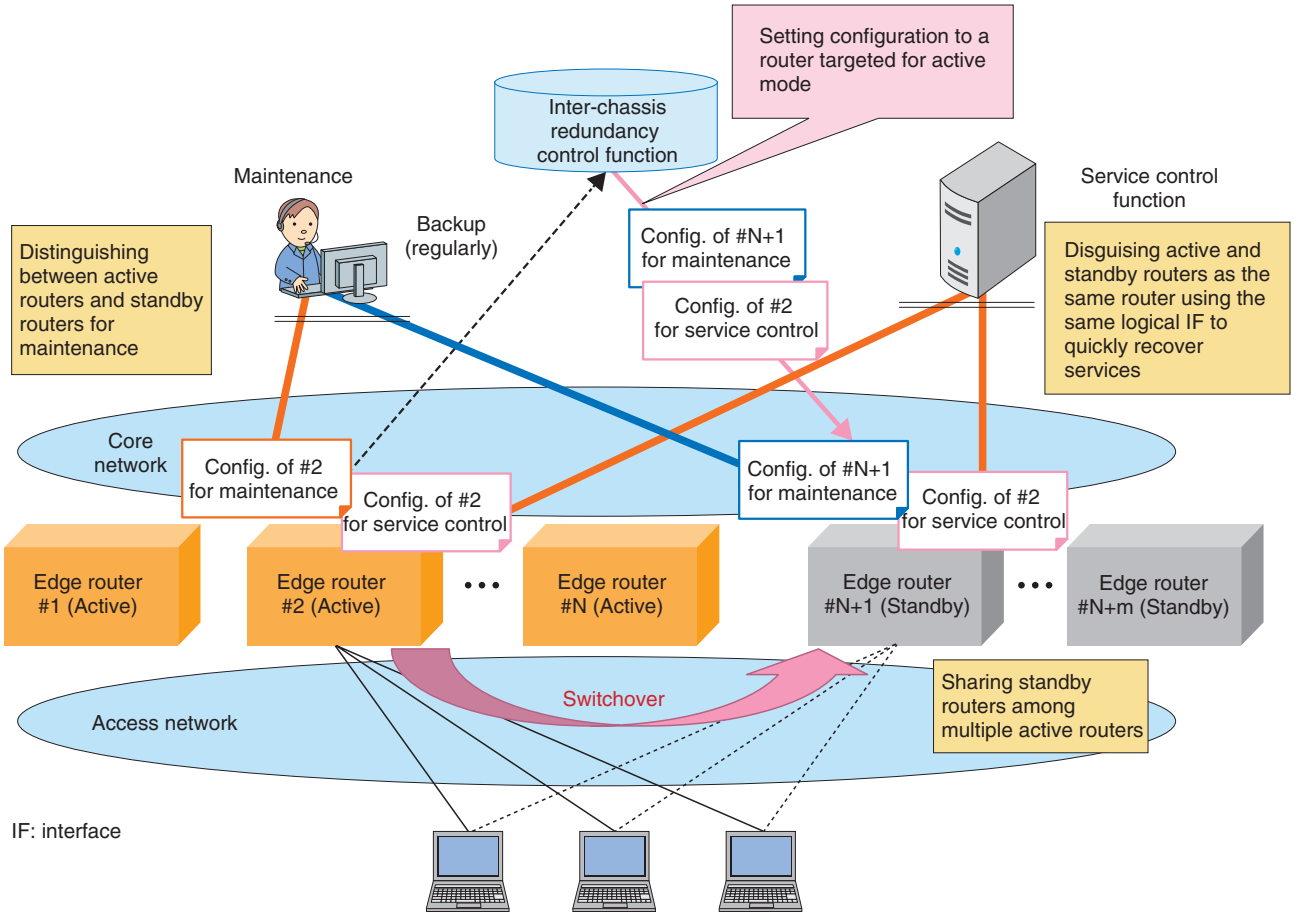

Fig. 1. Inter-chassis redundancy with shared standby routers.

greatly reduce system costs and power consumption per bit or per user. Furthermore, when fewer edge routers are required in a network, we can expect a decrease in the amount of maintenance work that depends on the amount of equipment, for example, file updates and replacement of broken modules.

2.2 Inter-chassis redundancy

Meanwhile, the effect of a system down failure such as a double failure of hardware modules becomes significant since systems can accommodate more subscribers than ever before. The edge routers in the system being developed have redundant module structures and redundancy in line interfaces. Moreover, this system has an inter-chassis redundancy function to achieve higher reliability. In the inter-chassis redundancy scheme as illustrated in **Fig. 1**, standby routers are prepared as a substitute for an active router; they provide services in the event that the active router goes down. To achieve high reliability and low cost, this scheme can adopt the N+m redundant architecture in which N active routers share m standby routers, which reduces the standby router costs.

An inter-chassis redundancy control function implemented outside of the edge routers orders the edge routers to perform a switchover. The configurations of all active routers which include the information about system settings and per user settings are retained in the inter-chassis redundancy control function. In the event of a switchover, the control function sets the configuration of the active router in the standby router that is targeted for the active mode. Since the information for maintenance or system management is related to each apparatus, it is preferable to use the information that was originally assigned to the standby router. In contrast, the information for providing services such as the interfaces to the service control servers is the information that was assigned to the original active router. This enables

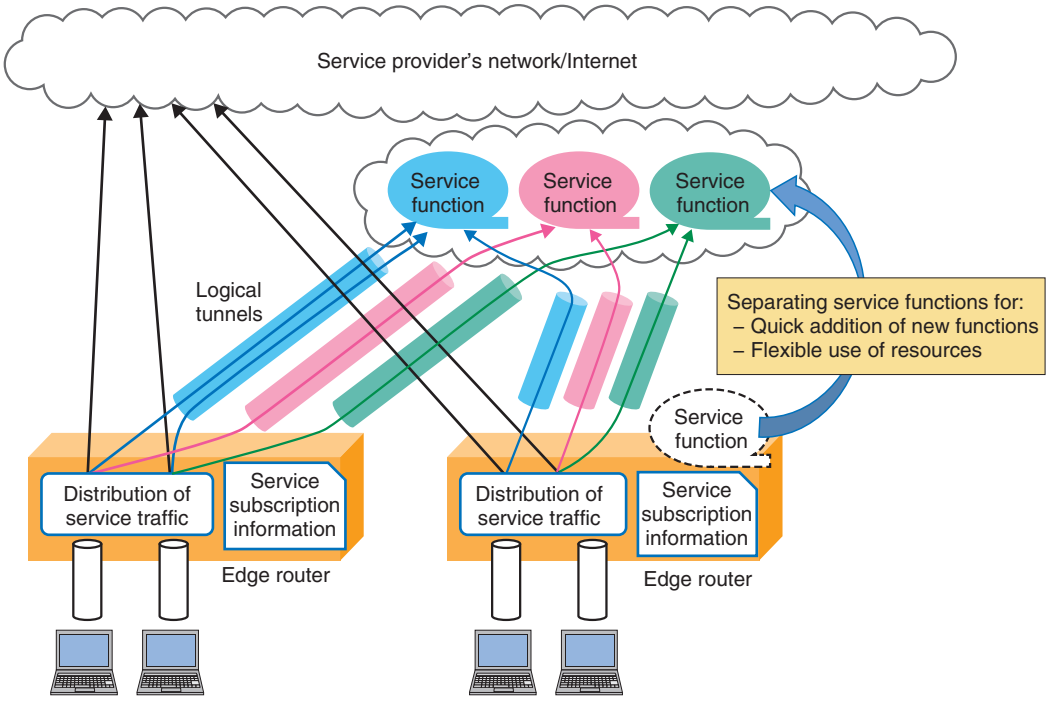

Fig. 2. Distribution of traffic to service functions.

services to be restored quickly from a system down fault.

3. Flexible addition of service functions

3.1 Separation of service function from router function

In the existing service edge router, a specific packet transfer function of each service such as the IP (Internet protocol) telephone service is implemented in a router chassis. This makes it possible to reduce the number of chassis as well as the capital expenditure. However, this implementation results in a complex packet process function in the edge router. Therefore, the number of development tasks required for deploying new service functions increases since sufficient verification is necessary to avoid degradation of other services. Furthermore, operation and maintenance work such as file updates for some services might affect the other services.

We aim to introduce an isolated architecture in which service functions are separately deployed from an edge router chassis in order to enable new functions to be added easily and quickly. This isolated architecture may be especially effective in cases where rapid introduction of new functions is important and where a centralized deployment is efficient, for example, when service demand is low or highly varied. Using network functions virtualization (NFV)[*2] technology to implement service functions makes it possible to reduce costs for equipment by using low-priced general-purpose servers and sharing resources among services.

We plan to gradually implement an isolated deployment and virtualization of service functions. Several factors should be considered in order to determine the appropriate deployment of service functions, for example, improvement of packet processing performance in NFV and the required quality level of services. For instance, more service functions can be virtualized as the packet processing speed in virtualized functions increases and delay-sensitive services are deployed in local datacenters.

3.2 Distribution of service traffic to appropriate service functions

To deploy service functions separately, the edge router classifies traffic according to its service and transfers the classified traffic to the appropriate service functions, as shown in **Fig. 2**. The edge router

*2 NFV: The deployment of network functions as software running in a virtual machine environment on a general-purpose server.

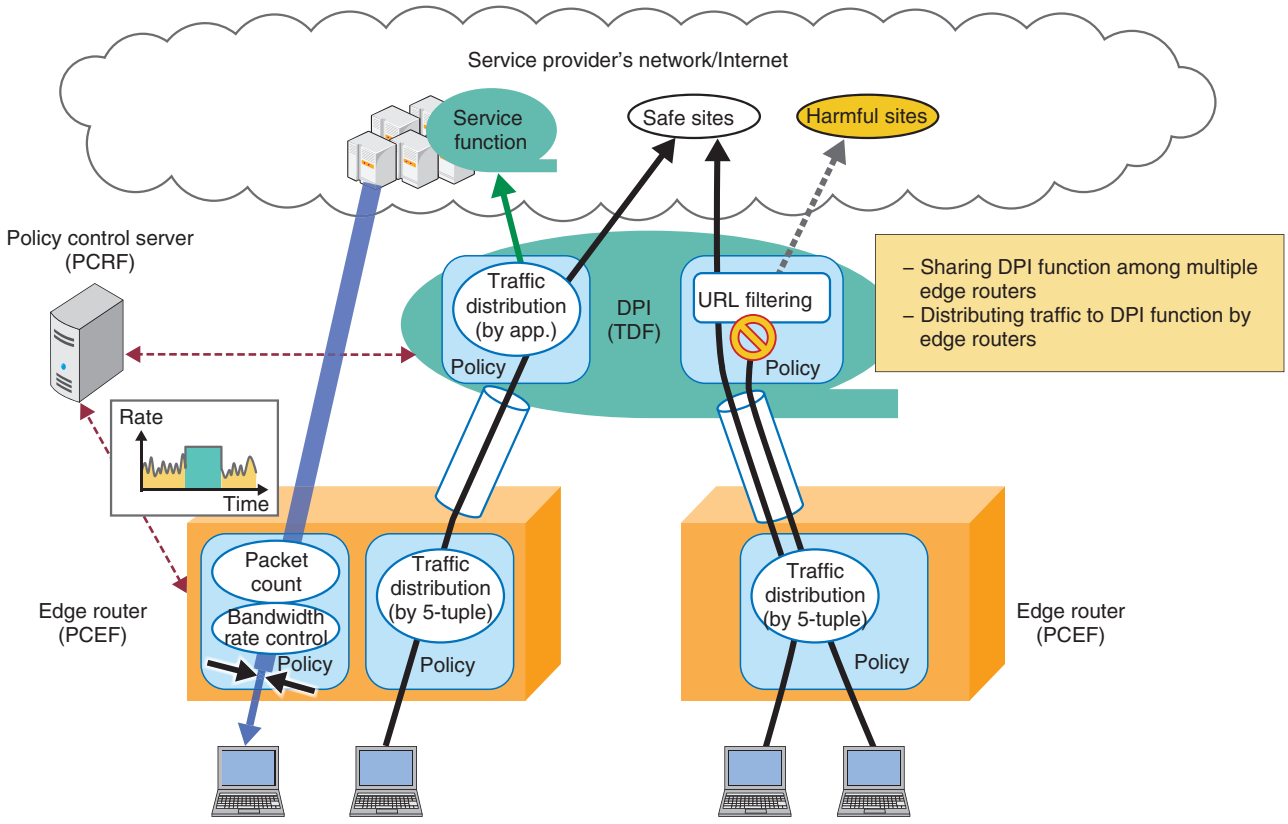

Fig. 3. Policy control and traffic distribution functions.

determines a service function in which an incoming packet is routed according to the service subscription of the user and the layer 3 and layer 4 (L3/L4) information in the packet. Then the edge router transfers the packet to the service function appropriate to each packet using logical tunnels that enable transit regardless of the destination address in the packet. In the future, we aim to achieve more flexible packet transit according to services using service chaining technology, which easily controls packets and enables them to be transferred through all of the necessary service functions.

4. Function to provide value-added services

4.1 Policy control by the edge router and deep packet inspection

To provide value-added services flexibly, this system has a policy control function that can control traffic according to individual user needs and a traffic distribution function that uses high-layer information such as the kind of application, as shown in **Fig. 3**. Examples of use cases include bandwidth rate control depending on the amount of transferred packets, URL (Uniform Resource Locator) filtering to prevent access to harmful sites, and packet transfer to an apparatus that has a value-added function such as an optimizer to convert the bandwidth of video traffic. To provide such service processes, this system has an application based control function that uses deep packet inspection (DPI)[*3] in addition to the L3/L4 based control in the edge router. The edge router and DPI have the capabilities to measure the volume of traffic, filter packets, limit bandwidth, and distribute traffic to service functions according to a policy rule predefined for each user. In the future, we aim to support dynamic setting of policy rules to change the

*3 DPI: Packet analysis and examination function using higher-layer information in a packet payload.

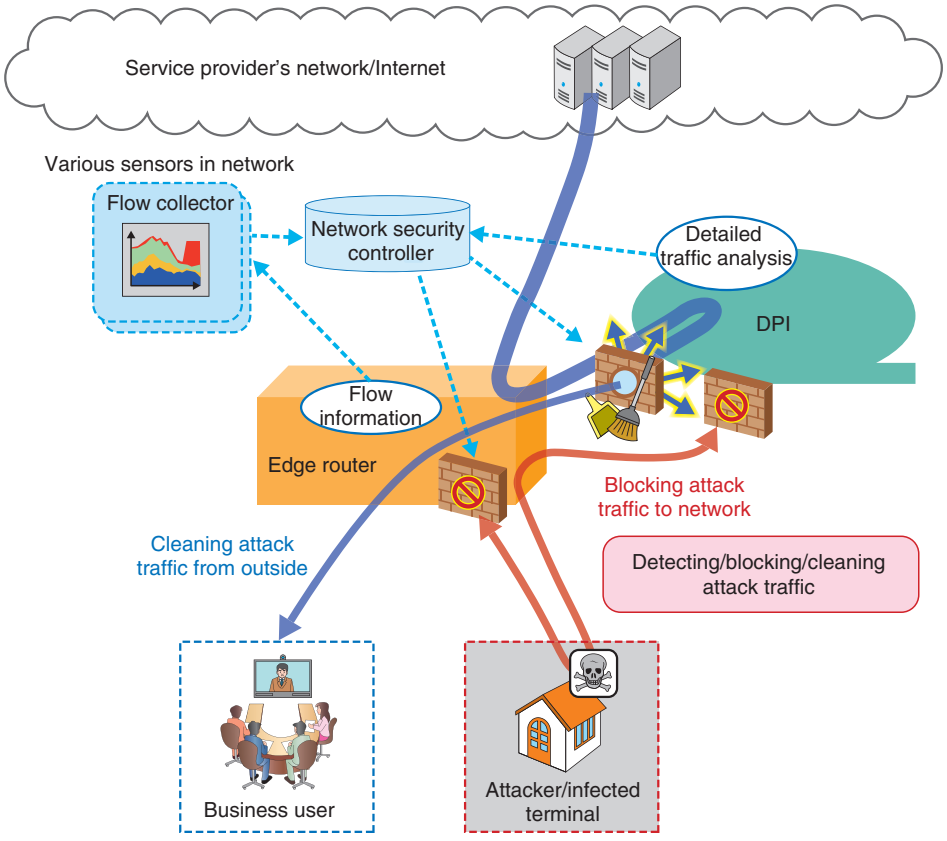

Fig. 4. Network security using edge router and DPI.

service control depending on the state of use.

4.2 Efficient use of DPI function

The cost per data transfer amount tends to be high in the DPI function since this function performs a complex process, that is, analyzing the payloads of packets. Placing DPI inline requires a very high performance DPI process in order to handle all transferred packets, which of course increases costs. This problem can be solved by sharing the DPI function among multiple edge router functions when only part of the traffic is the object of a DPI process such as an optional value-added service or an analysis of specified traffic. The edge router function distinguishes the packets to be processed in DPI and distributes them to the DPI function through logical tunnels. With this scheme, the cost of the DPI function can be reduced since the required throughput of the DPI function is only for processing selected traffic.

5. Extension to provide additional value

NTT Network Service Systems Laboratories is studying an extension to provide more value-added network services by combining the above-mentioned functions, that is, flexible distribution of service traffic and application based classification and control using the DPI function, with other external network functions.

5.1 Network security

One research subject is network security (**Fig. 4**). The edge router filters packets to prevent unnecessary access to network equipment, giving it a network security capability. However, it is important to improve network security further as we get closer to the year 2020 since security threats are increasing year by year. We are studying features of the edge router system to be utilized in conjunction with various security devices, while still accommodating users. Specifically, those features involve sending traffic measurement data to an analyzer in order to

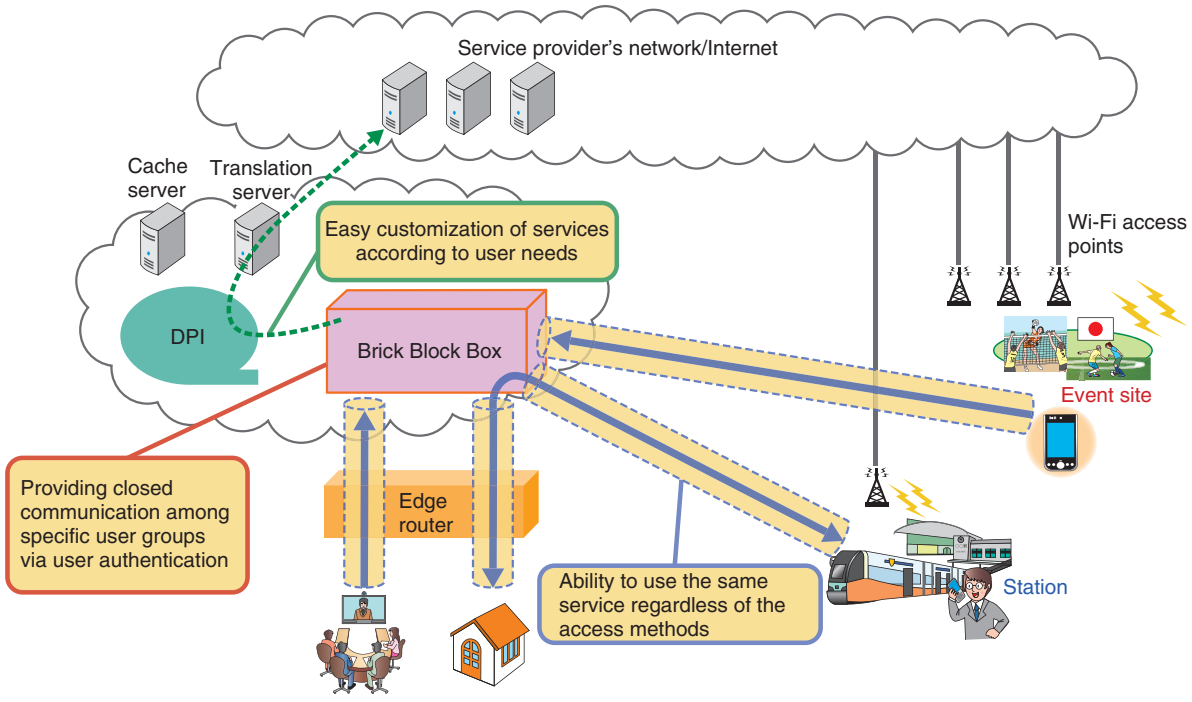

Fig. 5. Flexible service gateway technology (Brick Block Box).

detect security attacks and threats, distributing traffic suspected of being attack traffic to security devices by order of a security controller, and also blocking attack traffic by order of a security controller. We aim to contribute to improving network security measures in order to respond to new security threats efficiently and flexibly.

5.2 Service gateway for temporary demand for a service

We are researching a flexible service gateway named the Brick Block Box that can cope with temporary demand for services during events or with the various needs of corporations. We use vCPE (virtual customer premises equipment) technology, in which a communication device originally located in a user home is virtualized, to implement the Brick Block Box, which is deployed on a general-purpose server in the cloud. The Brick Block Box has location-free connectivity using secure tunnels and does not depend on a particular kind of access technology. It also features closed communication within a user group and access control so that only members of a group can access service functions in order to provide services that can easily be customized, as shown in **Fig. 5**.

6. Future prospects

To achieve a network that can respond flexibly and efficiently to the needs of collaboration partners, NTT Network Service Systems Laboratories is developing the edge router introduced in this article. This edge router can flexibly distribute traffic to separately deployed service functions and perform flexible policy control per user or per application. Our aim is to provide more added value; therefore, we plan to enhance functions in order to achieve a more secure network and provide flexible services in combination with the service gateway. We are also researching ways to modularize and virtualize the edge function in the NetroSphere concept and working on developing a more flexible, highly reliable, and efficient future network.

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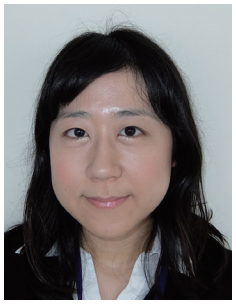

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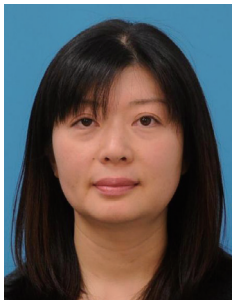

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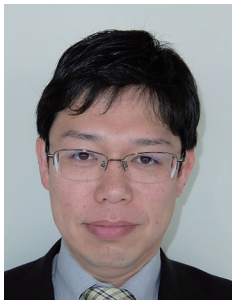

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Standardization Activities at W3C TPAC 2015

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Abstract

The World Wide Web Consortium Technical Plenary / Advisory Committee Meetings Week 2015 (W3C TPAC 2015) was held from October 26 to 30, 2015 in Sapporo, Japan, marking the first TPAC meeting held in this country. This article reports on W3C TPAC 2015 with a focus on NTT Group standardization activities in TPAC.

Keywords: W3C TPAC, digital signage, blockchain, vertical writing mode

1. Introduction

The World Wide Web Consortium (W3C) is an international industry-academia joint consortium whose members aim to standardize and promote web technologies. It holds an annual meeting in the form of the Technical Plenary / Advisory Committee Meetings Week (TPAC), which includes both a plenary session and standardization meetings by Working Groups (WGs) over a one-week period. TPAC 2015 brought together 580 participants from 14 countries at the Sapporo Convention Center in the largest-ever TPAC meeting. Various events were also held in addition to the usual technical meetings. One such event was a special panel discussion featuring Sir Tim Berners-Lee, inventor of the World Wide Web and founder of W3C, Dr. Vinton Cerf, a Transmission Control Protocol (TCP)/Internet Protocol (IP) designer known as one of the fathers of the Internet, and Professor Jun Murai of Keio University, who is referred to as the Internet Samurai. Demonstrations related to digital signage, television (TV), the Web of Things[*1], and automotive topics were also presented by more than 25 member companies in a specially established demonstration area.

2. Standardization activities at TPAC

The W3C WGs normally hold discussions via mailing lists and pursue their work individually. TPAC enables these WGs to come together for face-to-face meetings [1]. Furthermore, as in TPAC meetings in recent years, breakout sessions were held in an unconference style on the day of the plenary session so that participants themselves could propose discussion themes and participate in any other sessions they found interesting. The discussion themes proposed were quite diverse, including those issues currently faced by W3C and technical areas that W3C should address in the future. At TPAC 2015, up to 13 sessions were held simultaneously in each of four time periods (each lasting 60 or 90 minutes), resulting in a total of 50 sessions.

The following sections introduce the areas in which NTT has been making large contributions to standardization, namely, digital signage, blockchain application technology, and vertical writing mode.

*1 Web of Things: A term expressing the approach or architecture to developing services and applications using the Internet of Things through the use of web technology.

Table 1. WGs related to API proposals for digital signage.

API	Related WG
Autopilot API	
Power Management API (reboot and sleep for browser or terminal)	None
Web NTP Client API (time synchronization)	Collaboration with Multi-device Timing Community Group (under study)
System Context (system information acquisition and control)	None
System Events (system event acquisition)	SysApps WG in relation to service workers
Rich presentation API	
Multiple Resources for Video (multi-source support)	HTML WG (further study of requirements needed)
Multicast Video Playback (multicast support)	
Access Control of External Storage (external storage support)	None (further study of requirements needed)
Double Buffering API (content preload)	SysApps WG in relation to service workers

3. Digital signage

The Web-based Signage Business Group (BG) was established in April 2012 based on a proposal from Japan. Its role is to promote the standardization of digital signage in W3C. This BG was formed to study the feasibility of general digital signage that would use web technology to control various types of displays connected to the Internet, or in other words, web-based signage. Discussions to date have resulted in the creation of a document providing use cases and requirements and profile documents (core, basic media, storage, etc.) for configuring a signage player on a web browser using HTML5[*2].

More recently, the establishment of a new WG for discussing problems and promoting standardization toward a web-based digital signage service was proposed. This WG would be primarily concerned with application programming interfaces (APIs) essential to the operation of such a service. At TPAC 2015, NTT organized a breakout session that was attended by a wide range of participants and clarified discussion conditions with existing WGs on the API proposals listed in **Table 1** in relation to signage requirements, toward establishing this new WG. After the session, discussions on API selection were held at the BG meeting with the aim of recommending a new WG, and a general consensus on establishing a new WG was obtained in the BG.

Agreement was also reached at the BG meeting on promoting formal cooperation with the International Telecommunication Union-Telecommunication Standardization Sector (ITU-T) based on a liaison document issued from ITU-T Q14/16[*3] seeking collaboration and document provision from W3C. We expect coordinated standardization between W3C and ITU-T on web-based signage to progress as we move forward.

4. Blockchain application technology

NTT also held a breakout session on the concept of content distribution utilizing blockchain technology [2], which is currently being researched at NTT Service Evolution Laboratories. The purpose of this session was to foster discussions with experts involved in standardization on the affinity of blockchain technology with the web and to raise the presence of NTT in the field of blockchain application technology.

The blockchain technology discussed here is a core technology of Bitcoin[*4]. It enables the formation of a

*2 HTML5: The fifth major revision of hypertext markup language, the standard programming language for creating web pages and applications.

*3 ITU-T Q14/16: A Question established for studying digital signage systems and services at ITU-T.

*4 Bitcoin: A peer-to-peer (P2P) virtual currency based on open protocol. As a particular feature, it secures trust without the existence of a centralized administering authority by having Bitcoin participants perform a competitive verification procedure whenever new currency is issued.

publicly open and highly trusted ledger (blockchain) that records all transactions. In parallel with the growing interest in Bitcoin, the robust and general-purpose characteristics of blockchain technology have led to discussions on its application to fields other than virtual currencies. NTT Service Evolution Laboratories aims to invigorate the content distribution in the web by applying blockchain technology and clarifying the right of content ownership and the issuing of user licenses. The main point of this research and development effort is to establish a method that firmly ties content itself to rights information on the blockchain since the latter manages only rights information.

In the discussions at this breakout session, we received support from many of the participants for our concept to apply blockchain technology to enable a highly trusted exchange of rights even on the Open Internet, which was close to the Open Web[*5] concept advocated by W3C. However, applications of blockchain technology are so novel that they have not yet found widespread acceptance. At the conclusion of this session, a proposal was made to continue discussions on a voluntary basis within a Community Group, for example.

5. Vertical writing mode

The day before TPAC 2015 got underway, a Japanese Industry Meetup event was held between members of the Cascading Style Sheet (CSS)[*6] WG and representatives of Japanese publishing, e-books, and other related industries as a standardization activity concerning Japanese text layout on the web. The participants at this event discussed text composition in the Japanese writing system such as vertical writing mode, horizontal-in-vertical setting, ruby, sidelines, and line breaking rules. The content of these discussions was also reflected in the TPAC 2015 meetings. As a result, W3C members from around the world gained a better understanding of the importance and necessity of the vertical writing mode and other aspects of Japanese text layout on the web.

6. Support of TPAC 2015 meetings

As a Gold Sponsor, the NTT Group supported TPAC 2015, and in order to contribute to the smooth operation of the meetings, it installed digital signage for guidance within the venue and provided a network infrastructure for participants.

6.1 Digital information signage

NTT Service Evolution Laboratories in cooperation with related companies offered and voluntarily constructed a digital information signage system to provide guidance and information to participants at the venue. Past TPAC meetings had no digital information signage, so this was the first attempt at providing such a service.

This digital information signage consisted of two types of displays—a landscape type oriented in the horizontal direction like a standard monitor, and a portrait type in which the monitor's screen is rotated 90 degrees. The displays were installed in five locations within the venue. The role of the portrait signage was to provide meeting-related information such as schedules, rooms, and sponsors, while that of the landscape signage was to provide information related to the surrounding area such as weather reports, subway service details, and Sapporo sightseeing information and promotional videos.

For both the landscape and portrait displays, this digital information signage was constructed as web-based signage that uses a web browser equipped with a TV receiver as a signage player while keeping in mind future standardization trends. Some portions of the content were presented as vertical text, as shown in **Fig. 1**, which is an example of a vertical writing mode other than that used in books and documents.

Additionally, in the presentation of video content, we succeeded in delivering full high-definition (HD) video by employing a multicast technique using a virtual network to minimize the load on the actual network. The delivery of full HD video did not seem to hamper participant use of the network and is therefore expected to achieve high viewer satisfaction. Despite the fact that digital information signage had not previously been provided at a TPAC venue, it was well received within the venue and was put to good use as an information provision service for participants. We therefore feel that it was fully accepted and able to contribute to the success of TPAC 2015.

In addition to the above support, the NTT Strategic Business Development Division prepared a participant-oriented application (app) for meeting support that was also used by participants at TPAC 2015 (**Fig. 2**). This app included functions enabling users to check the meeting schedule, find venue access and

*5 Open Web: The idea that specifications of standard technologies for configuring the web should be open to the public and that anyone should be able to use them royalty-free.

*6 CSS: A language for expressing the style of a web page.

Fig. 1. Digital information signage for guidance.

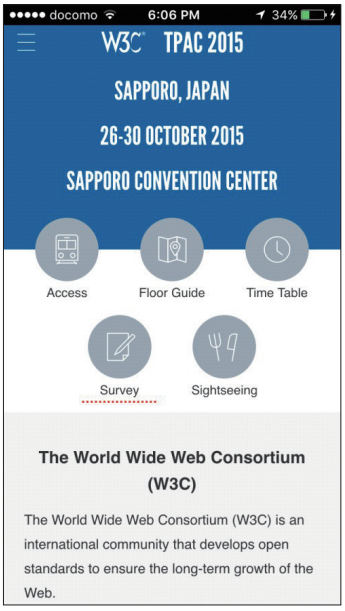

Fig. 2. App for participants.

venue floor maps, retrieve information using a beacon[*7], and get sightseeing information for post-meeting activities. An examination of the usage data revealed that this app was used in the morning to check access to the venue and that day's schedule and in the evening to plan activities for the following day by checking sightseeing information and other details. In the future, we would like to make this app even more convenient by linking it with other services and adding more post-meeting support functions with an eye to promoting excursions in the surrounding area.

6.2 Venue network infrastructure

As a TPAC 2015 network sponsor, NTT Communications provided network connections including the Internet connection at the venue, and as a Network Operation Center (NOC) member, it constructed and operated a Wi-Fi environment within the venue.

At this TPAC, digital information signage and exhibition booths of member companies were installed for the first time, which involved various network requirements. Here, to provide a problem-free infrastructure for meetings and exhibits, a 1-Gbit/s dedicated line was used for the main line, and three FLET'S lines were prepared as backup and demonstration lines. The final number of activated access points exceeded 90. As a result, NTT Communications was able to provide a stable network during TPAC 2015. A questionnaire given at the end of this TPAC indicated that it received a high evaluation of

*7 Beacon: A mechanism for receiving radio signals emitted by Bluetooth™ using a receiver on the mobile-terminal side to obtain location information.

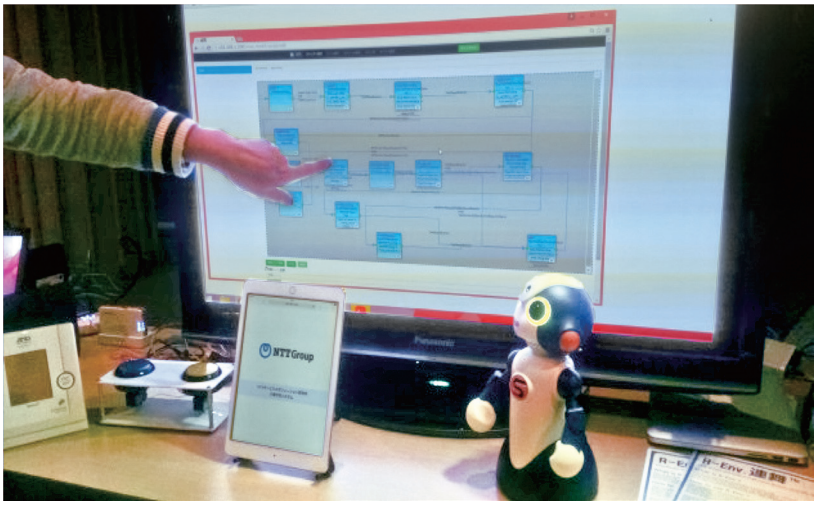

Fig. 3. R-env cloud-based visual programming environment.

8.26 points out of 9 for its network infrastructure.

7. Developer meetup in Sapporo

A Developer Meetup in Sapporo was also held as a parallel event to TPAC 2015 in the evening on the first day of meetings at the same facility. This event was planned and carried out by NTT Communications in cooperation with W3C to provide a discussion forum for W3C members and related individuals coming for TPAC from around the world and for web developers in the Sapporo area. It included talks on the latest web developments by six Japanese and overseas web engineers with real-time English/Japanese interpretation provided by a volunteer staff member. In addition, exhibition booths set up in cooperation with companies and municipalities in the Sapporo area were bustling with activity as many participants came to visit.

NTT Service Evolution Laboratories provided an exhibition on R-env™ [3], a cloud-based integrated development environment for creating interactive robot services. The aim of this exhibit was to promote the use of R-env and to obtain feedback from web engineers on the technology. Specifically, R-env has a cloud-based visual programming environment on a web browser for developing and executing applications that combine multiple devices including robots, sensors, and gadgets (**Fig. 3**). Participants in the meetup event were given demonstrations on creating an application linking multiple devices as well as an explanation and demonstration of a method for adding a new device to R-env. In this latter method, a device can be registered with R-env by simply using the protocol of the JSON[*8] data-interchange format over WebSocket[*9]. Many web engineers wanted to try using R-env and expressed the hope that it would become open source software. The evaluations of the participants were taken into account, and the plan is to create more opportunities to enable even more web engineers to try out R-env. NTT Communications, meanwhile, presented two demonstrations on WebRTC[*10] and received many useful comments from participants.

References

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*8 JSON: A type of data description format.
*9 WebSocket: An API that performs full-duplex communication with a server from JavaScript to exchange messages.
*10 WebRTC: An API that achieves P2P communication of video, voice, and data between browsers.

Kiyoshi Tanaka
Senior Research Engineer, Supervisor, Natural Communication Project, NTT Service Evolution Laboratories.

He received a B.E., M.E., and Ph.D. in communication engineering from Osaka University in 1992, 1994, and 2005. He joined NTT in 1994 and since then has been engaged in researching video-on-demand systems and metadata-related interactive video systems and services, especially those related to IPTV and digital signage services. His current interests include standardization of IPTV and digital signage. He is a member of the W3C Web-based Signage BG, Web and TV Interest Group (IG), the Institute of Electronics, Information and Communication Engineers (IEICE), and the Human Interface Society in Japan.

Shigeru Fujimura
Research Engineer, Natural Communication Project, NTT Service Evolution Laboratories.

He received an M.S. in information science and technology from the University of Tokyo in 2005 and joined NTT the same year. Since then, he has been engaged in research on web mining and web engineering, especially on effective methods for implementing web applications. He is a member of the W3C Web and TV IG.

Shinji Fukatsu
Senior Research Engineer, Natural Communication Project, NTT Service Evolution Laboratories.

He received a B.E., M.E., and Ph.D. in engineering from Osaka University in 1997, 1999, and 2002. He joined NTT Cyber Solutions Laboratories in 2002. His research interests include human interfaces, virtual reality, web technologies, metadata, and IPTV services. He is a member of IEICE.

Tetsuro Tokunaga
Research Engineer, Natural Communication Project, NTT Service Evolution Laboratories.

He received a Bachelor of Liberal Arts and Master of Informatics from Yokohama National University, Kanagawa, in 2002 and 2004. He joined NTT in 2004 and has been studying web technology. His current research interests include mastering web technology to achieve human-centered services. He was a co-developer on a team that participated in 2003 in the youth division in the Exploratory IT Human Resources Project (The MITOH Program) initiated by the Information-technology Promotion Agency of Japan. He is a member of the Information Processing Society of Japan and the Database Society of Japan.

Fumihisa Hamamura
Associate Manager, NTT Strategic Business Development Division.

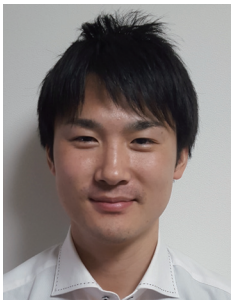
He received a B.A. in environmental information from Keio University, Kanagawa, in 2005 and joined the NTT Group the same year. He has recently been engaged in business development and is currently working on new business development in the MICE (meetings, incentives, conferences, and exhibitions) market and the sports tech and sports tourism markets.

Saki Homma
Research Engineer, Department of Technology Development, NTT Communications Corporation.

She received an M.S. in information science and technology from the University of Tokyo in 2011 and joined NTT Communications the same year. In 2011–2012, she was engaged in developing a big data analysis engine. Since 2013, she has been researching leading-edge web technology related to real-time communication.

Ryosuke Aoki
Researcher, Networked Robot and Gadget Project, NTT Service Evolution Laboratories.

He received a B.E. in engineering and an M.S. and Ph.D. in information sciences from Tohoku University, Miyagi, in 2005, 2007, and 2014. Since joining NTT in 2007, he has been conducting research in the areas of human computer interaction, multimodal interaction, motor learning, and service design.



Takahiro Matsumoto
Researcher, Networked Robot and Gadget Project, NTT Service Evolution Laboratories.

He received an M.S. in information and computer science from Keio University, Kanagawa, in 2012 and joined NTT the same year. Since then, he has been engaged in research on human-robot interaction. He is a member of IEICE Information and Systems Society Technical Committee on Cloud Network Robotics.

External Awards

Achievement Award
Winner: Shuto Yamamoto, NTT Network Innovation Laboratories
Date: February 19, 2016
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE)

For the research and development of ultra-high-capacity multilayer-integrated transport system.

Interaction 2016 Best Paper Award
Winner: Naomi Yamashita, NTT Communication Science Laboratories; Hideaki Kuzuoka, University of Tsukuba; Keiji Hirata, Future University Hakodate; Takashi Kudo, Osaka University; Eiji Aramaki, Kyoto University; and Kazuki Hattori, University of Tsukuba
Date: March 2, 2016
Organization: The Information Processing Society of Japan (IPSJ) Interaction 2016 executive committee

For "Mimamo-Mate: A Web Application for Family Caregivers to Track Their Caregiving Activities."
Published as: N. Yamashita, H. Kuzuoka, K. Hirata, T. Kudo, E. Aramaki, and K. Hattori, "Mimamo-Mate: A Web Application for Family Caregivers to Track Their Caregiving Activities," Proc. of IPSJ Interaction 2016, Tokyo, Japan, Mar. 2016.

2015 Temperature Award for the Best Puzzle
Winner: Hsin-Ni Ho, NTT Communication Science Laboratories
Date: March 11, 2016
Organization: Editorial board of Temperature

For "Red... How does it feel?"

Young Researcher's Award
Winner: Farhan Mahmood, NTT Network Technology Laboratories
Date: March 17, 2016
Organization: IEICE

For "Design of DC-AMN with Considering Longitudinal Conversion Loss."
Published as: F. Mahmood, K. Okamoto, H. Tatemichi, K. Takaya, and N. Kuwabara, "Design of DC-AMN with Considering Longitudinal Conversion Loss," Proc. of the 2015 IEICE Society Conference, B-4-34, Sendai, Miyagi, Japan, Sept. 2015 (in Japanese).

Young Researcher's Award
Winner: Minoru Inomata, NTT Access Network Service Systems Laboratories
Date: March 17, 2016
Organization: IEICE

For "Prediction Method for Propagation Loss Characteristics in NLOS Street Microcell Environment."
Published as: M. Inomata, N. Ohmaki, W. Yamada, M. Sasaki, T. Sugiyama, M. Mizoguchi, K. Kitao, and T. Imai, "Prediction Method for Propagation Loss Characteristics in NLOS Street Microcell Environment," Proc. of the 2015 IEICE General Conference, B-1-28, Kusatsu, Shiga, Japan, Mar. 2015 (in Japanese).

Young Researcher's Award
Winner: Minoru Inomata, NTT Access Network Service Systems Laboratories
Date: March 17, 2016
Organization: IEICE

For "Outdoor to Indoor Path Loss Characteristics for 8 to 37 GHz Band."
Published as: M. Inomata, W. Yamada, M. Sasaki, and T. Onizawa, "Outdoor to Indoor Path Loss Characteristics for 8 to 37 GHz Band," Proc. of the 2015 IEICE Society Conference, BS-1-8, Sendai, Miyagi, Japan, Sept. 2015 (in Japanese).

Young Researcher's Award
Winner: Naotaka Shibata, NTT Access Network Service Systems Laboratories
Date: March 17, 2016
Organization: IEICE

For "Performance Evaluation of Mobile Fronthaul Transmission Employing Ethernet-based TDM-PON."
Published as: N. Shibata, T. Tashiro, S. Kuwano, J. Terada, and A. Otaka, "Performance Evaluation of Mobile Fronthaul Transmission Employing Ethernet-based TDM-PON," Proc. of the 2015 IEICE General Conference, B-8-15, Kusatsu, Shiga, Japan, Mar. 2015 (in Japanese).

Young Researcher's Award
Winner: Hiroshi Takahashi, NTT Access Network Service Systems Laboratories
Date: March 17, 2016
Organization: IEICE

For "Splice Loss Measurement Using End-reflection Assisted Brillouin Analysis."
Published as: H. Takahashi, K. Toge, F. Ito, and C. Kito, "Splice Loss Measurement Using End-reflection Assisted Brillouin Analysis," IEICE Tech. Rep., Vol. 113, No. 265, OFT2013-22-37, pp. 39–42, Oct. 2013 (in Japanese).

Young Researcher's Award
Winner: Hiroshi Takahashi, NTT Access Network Service Systems Laboratories
Date: March 17, 2016
Organization: IEICE

For "Brillouin-based PON Monitoring Using Frequency-swept Pump Pulse."
Published as: H. Takahashi, C. Kito, K. Toge, and T. Manabe, "Brillouin-based PON Monitoring Using Frequency-swept Pump Pulse," Proc. of the 2015 IEICE Society Conference, B-13-17, Sendai, Miyagi, Japan, Sept. 2015 (in Japanese).

Young Researcher's Award
Winner: Takayoshi Mori, NTT Access Network Service Systems Laboratories
Date: March 17, 2016
Organization: IEICE

For "Compensation of Inter-channel Signal Quality Difference in Mode-division-multiplexed Transmission."
Published as: T. Mori, T. Sakamoto, M. Wada, T. Yamamoto, F.

Yamamoto, and K. Nakajima, "Compensation of Inter-channel Signal Quality Difference in Mode-division-multiplexed Transmission," IEICE Tech. Rep., Vol. 115, No. 201, OCS2015-33, pp. 13–18, Aug. 2015 (in Japanese).

Young Researcher's Award

Winner: Takayoshi Mori, NTT Access Network Service Systems Laboratories
Date: March 17, 2016
Organization: IEICE

For "Experimental Evaluation of Inter-modal Fiber Nonlinearity in MDM Transmission."
Published as: T. Mori, T. Sakamoto, M. Wada, A. Urushibara, T. Yamamoto, and F. Yamamoto, "Experimental Evaluation of Inter-modal Fiber Nonlinearity in MDM Transmission," Proc. of the 2015 IEICE Society Conference, B-13-28, Sendai, Miyagi, Japan, Sept. 2015 (in Japanese).

Young Researcher's Award

Winner: Yui Yoshida, NTT Network Innovation Laboratories
Date: March 17, 2016
Organization: IEICE

For "An Efficiency Evaluation of Dispersed Storage Systems Based on Irregular Flat XOR Codes."
Published as: Y. Yoshida, T. Nakachi, D. Shirai, and T. Fujii, "An Efficiency Evaluation of Dispersed Storage Systems Based on Irregular Flat XOR Codes," Proc. of the 2015 IEICE Society Conference, A-20-6, Sendai, Miyagi, Japan, Sept. 2015 (in Japanese).

Young Researcher's Award

Winner: Hideya So, NTT Network Innovation Laboratories
Date: March 17, 2016
Organization: IEICE

For "Suppression Design of Undesired Reflections from Frequency-selective Surfaces for Multiband Antenna Employing FSSs" and "A Proposal on Undesired Radiation Suppression Technique Using Adaptive Control of Transmission Plate for Distributed Array Antenna Systems in Mobile Environment."
Published as: H. So, A. Ando, T. Sugiyama, and K. Cho, "Suppression Design of Undesired Reflections from Frequency-selective Surfaces for Multiband Antenna Employing FSSs," Proc. of the 2015 IEICE General Conference, B-1-149, Kusatsu, Shiga, Japan, Mar. 2015 (in Japanese); H. So, K. Suzaki, D. Goto, Y. Suzuki, and F. Yamashita, "A Proposal on Undesired Radiation Suppression Technique Using Adaptive Control of Transmission Plate for Distributed Array Antenna Systems in Mobile Environment," Proc. of the 2015 IEICE Society Conference, B-3-18, Sendai, Miyagi, Japan, Sept. 2015 (in Japanese).

Young Researcher's Award

Winner: Yasuhiro Mochida, NTT Network Innovation Laboratories
Date: March 17, 2016
Organization: IEICE

For "A Proposal of UI Construction Using WebSocket for REMOCOP."
Published as: Y. Mochida, D. Shirai, and T. Fujii, "A Proposal of UI Construction Using WebSocket for REMOCOP," Proc. of the 2015 IEICE Society Conference, B-11-13, Sendai, Miyagi, Japan, Sept. 2015 (in Japanese).

Young Researcher's Award

Winner: Mitsuteru Yoshida, NTT Network Innovation Laboratories
Date: March 17, 2016
Organization: IEICE

For "Blind Chromatic Dispersion Estimation Using Spectral Symmetry of Real-valued Signals."
Published as: M. Yoshida, K. Yonenaga, and A. Hirano, "Blind Chromatic Dispersion Estimation Using Spectral Symmetry of Real-valued Signals," Proc. of the 2015 IEICE Society Conference, B-10-23, Sendai, Miyagi, Japan, Sept. 2015 (in Japanese).

Maejima Hisoka Award

Winner: Kazuhide Nakajima, NTT Access Network Service Systems Laboratories; Shigeru Tomita, NTT Advanced Technology Corporation; and Izumi Sankawa, NTT Electronics Corporation
Date: March 18, 2016
Organization: Tsushinbunka Association

For the research and development of hole-assisted optical fibers.

SUEMATSU-Yasuharu Award

Winner: Yoshihide Tonomura, NTT Service Evolution Laboratories
Date: June 2, 2016 (presentation ceremony)
Organization: IEICE

For the research and development of high-efficiency forward error correction (FEC) codes and the contribution to ISO/IEC MPEG/MMT standardization.
Published as: Y. Tonomura, D. Shirai, T. Nakachi, T. Fujii, and H. Kiya, "Layered Low-density Generator Matrix Codes for Super High Definition Scalable Video Coding System," IEICE Trans. Fundamentals, Vol. E92-A, No. 3, pp. 798–807, 2009.

Papers Published in Technical Journals and Conference Proceedings

Performance Evaluation of SSB Transmission of DFTs-OFDM Using Multi-level BPSK through Nonlinear HPA

M. Umehira, S. Nihei, H. Fusayasu, T. Miyajima, S. Takeda, J. Mashino, and T. Sugiyama

Proc. of VTC2015-Spring (the 2015 IEEE 81st Vehicular Technology Conference), Glasgow, UK, May 2015.

This paper describes performance evaluation results of single side band (SSB) transmission of discrete Fourier transform spreading orthogonal frequency division multiplexing (DFTs-OFDM) using multi-level binary phase shift keying (BPSK) through a nonlinear HPA (high power amplifier). SSB-DFTs-OFDM is generated by eliminating the USB (upper side band) or LSB (lower side band) in the frequency domain after DFT spreading of multi-level BPSK signals. Thus, a Hilbert transformer is not necessary to generate SSB signals. The simulation results show that SSB-DFTs-OFDM achieves almost the same peak-to-average power ratio (PAPR) and adjacent channel power leakage (ACLP) as conventional DFTs-OFDM and lower PAPR and ACLP than OFDM.

Study on Multiple Stream Transmission by Using Multiple Polarizations

M. Arai, T. Seki, and N. Shinohara

Proc. of the 45th European Microwave Conference, pp. 1359–1362, Paris, France, September 2015.

In this paper, we propose a new method for achieving multiple stream transmission by using multiple polarizations. Using polarization switching sequences corresponding to streams enables interferences to be canceled and multiple streams to be made because the polarizations are symmetrical regardless of antenna spacing. Therefore, the method is effective when antenna spacing is small. Numerical analysis revealed that the channel capacity per unit area achieved with our method increases in proportion to the number of streams.

Cavity-less On-chip Optomechanics Using Excitonic Transitions in Semiconductor Heterostructures

H. Okamoto, T. Watanabe, R. Ohta, K. Onomitsu, H. Gotoh, T. Sogawa, and H. Yamaguchi

Nature Communication, Vol. 6, Article no. 8478, October 2015.

The hybridization of semiconductor optoelectronic devices and nanomechanical resonators provides a new class of optomechanical systems in which mechanical motion can be coupled to light without any optical cavities. Such cavity-less optomechanical systems interconnect photons, phonons, and electrons (holes) in a highly integrable platform, opening up the development of functional integrated nanomechanical devices. Here we report on a semiconductor modulation-doped heterostructure-cantilever hybrid system, which realizes efficient cavity-less optomechanical transduction through excitons. The opto-piezoelectric back-action from the bound electron-hole pairs enables us to probe excitonic transition simply with a sub-nanowatt power of light, realizing high-sensitivity optomechanical spectroscopy. Detuning the photon energy from the exciton resonance results in self-feedback cooling and amplification of the thermomechanical motion. This cavity-less on-chip coupling enables highly tunable and addressable control of nanomechanical resonators, allowing high-speed programmable manipulation of nanomechanical devices and sensor arrays.

Selective-layer-free Blood Ionogram Using a 0D Nanotransistor Biosensor

R. Sivakumarasamy, K. Nishiguchi, A. Fujiwara, and N. Clément

Proc. of the 28th International Microprocesses and Nanotechnology Conference (MNC 2015), 11D-2-4, Toyama, Japan, November 2015.

We show that a 0D nanotransistor in liquid has unique properties that enable ion selectivity without the need for ion-selective layers. We performed a blood ionogram for various ions with a 1.5 mm × 1.5 mm silicon chip.

Electron Emission Using Multilayered-graphene/SiO_2/Si Heterodevice Driven by Low-voltage Supply in Low Vacuum

D. Yoshizumi, K. Nishiguchi, Y. Sekine, K. Furukawa, A. Fujiwara, and M. Nagase

Proc. of MNC 2015, 13P-11-104L, Toyama, Japan, November 2015.

In this study, taking advantage of this low electron scattering rate, we demonstrate a new application: a multilayered-graphene/SiO_2/Si heterodevice for electron emission. Since electrons gain energy during their tunneling event through the heterostructure, electrons are emitted from the device with a low-voltage supply in low vacuum.

Scalable and Locality-aware Distributed Topic-based Pub/Sub Messaging for IoT

Y. Teranishi, R. Banno, and T. Akiyama

Proc. of IEEE GLOBECOM 2015, San Diego, CA, USA, December 2015.

Topic-based pub/sub (TBPS) messaging plays an important role in building event-driven Internet of Things (IoT) applications. In IoT applications, scalability and locality-awareness are important properties that help to achieve low-latency message delivery and efficient usage of network resources. However, none of the existing distributed TBPS methods can simultaneously achieve a sufficient level of both properties. This paper proposes a new TBPS overlay method called 'Skip Graph-based TBPS with Locality-Awareness' (STLA), which extends existing Skip Graph-based TBPS messaging by adding locality-awareness. STLA determines the order of the keys on a Skip Graph overlay network according to the network hierarchy structure using 'locality-aware topic keys' (LATK). Using 'split-forward broadcasting' (SFB) with LATK, the locality-awareness can be dramatically improved.

Perceptual Illusions for Multisensory Displays

T. Amemiya

Proc. of IDW 2015 (the 22nd International Display Workshops),

pp. 1276–1279, Ohtsu, Shiga, Japan, December 2015.

Human perceptual properties have been applied for designing multisensory display technologies. This paper overviews the sensory-illusion-based approach we have used to create a force display that elicits illusory continuous force sensation by presenting asymmetric vibrations and a self-motion display based on a cross-modal effect between visual and tactile motion.

Orthogonalized Directional MIMO Transmission Using Higher Order Mode Microstrip Antennas

M. Arai, T. Seki, K. Hiraga, K. Sakamoto, H. Toshinaga, and T. Nakagawa

IEICE Transactions on Communications, Vol. E99-B, No. 1, pp. 48–57, January 2016.

We propose a spatial division method using orthogonal directivities formed by using higher order modes of rectangular microstrip antennas. Each of them is formed by one antenna element so that channels are orthogonalized only by antennas. We verify antenna radiation characteristics by using higher order mode microstrip antennas and confirm that orthogonal directivities are obtained with them. Measurement of two-stream transmission reveals that the method achieves almost the same channel capacity as that of an eigenmode-beamforming method because of the high multiplexing gain it achieves.

A DNA Aptamer Recognising a Malaria Protein Biomarker Can Function as Part of a DNA Origami Assembly

M. Godonoga, T.-Y. Lin, A. Oshima, K. Sumitomo, M. S. L. Tang, Y.-W. Cheung, A. B. Kinghorn, R. M. Dirkzwager, C. Zhou, A. Kuzuya, J. A. Tanner, and J. G. Heddle

Scientific Reports, Vol. 6, No. 21266, February 2016.

DNA aptamers have potential for disease diagnosis and as therapeutics, particularly when interfaced with programmable molecular technology. Here we have combined DNA aptamers specific for the malaria biomarker *Plasmodium falciparum* lactate dehydrogenase (*Pf*LDH) with a DNA origami scaffold. Twelve aptamers that recognise *Pf*LDH were integrated into a rectangular DNA origami, and atomic force microscopy demonstrated that the incorporated aptamers preserve their ability to specifically bind the target protein. Captured *Pf*LDH retained enzymatic activity, and protein-aptamer binding was observed dynamically using high-speed AFM. This work demonstrates the ability of DNA aptamers to recognise a malaria biomarker whilst being integrated within a supramolecular DNA scaffold, opening new possibilities for malaria diagnostic approaches based on DNA nanotechnology.

Sequence Alignment as a Set Partitioning Problem

M. Nishino, J. Suzuki, S. Umetani, T. Hirao, and M. Nagata

Journal of Natural Language Processing, Vol. 23, No. 2, pp. 173–194, March 2016 (in Japanese).

Sequence alignment, which involves aligning elements of two given sequences, occurs in many natural language processing (NLP) tasks such as sentence alignment. Previous approaches for solving sequence alignment problems in NLP can be categorized into two groups. The first group assumes monotonicity of alignments; the second group does not assume monotonicity or consider the continuity of alignments. However, for example, in aligning sentences of parallel legal documents, it is desirable to use a sentence alignment method that does not assume monotonicity but can consider continuity. Herein, we present a method to align sequences where block-wise changes in the order of sequence elements exist. Our method formalizes a sequence alignment problem as a set partitioning problem, which is a type of combinatorial optimization problem, and solves the problem to obtain an alignment. We also propose an efficient algorithm to solve the optimization problem by applying column generation.

Dense Space Division Multiplexed Transmission over Multicore and Multimode Fiber for Long-haul Transport Systems

T. Mizuno, H. Takara, K. Shibahara, A. Sano, and Y. Miyamoto

Journal of Lightwave Technology, Vol. 34, No. 6, pp. 1484–1493, March 2016.

In this paper, we review recent progress on space division multiplexed (SDM) transmission and our proposal of dense SDM (DSDM) with more than 30 spatial channels toward capacities beyond petabit/s. Furthermore, we discuss the requirements for realizing long-haul DSDM transport systems using multicore and/or multimode fiber, including power and space efficient amplification schemes, the use of fibers with large effective areas and transmission lines with low intercore crosstalk, low differential mode delay (DMD), and low mode dependent loss (MDL). Graded index heterogeneous 12-core × 3-mode fiber with low crosstalk, low DMD and low MDL, parallel multiple-input and multiple-output signal processing, low mode-dependent gain Erbium-doped fiber amplifiers, and MDL equalization technologies are significant in terms of extending the reach of multicore and multimode transmission. We review our long-distance transmission experiment on polarization-division multiplexed 16-quadrature amplitude modulation signaling over 12-core × 3-mode fiber.

New Indoor Accelerated Weathering Condition for Approximating Molecular Weight Distribution of Outdoor-exposed LDPE

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LDPE (low-density polyethylene) photodegraded through various accelerated weathering tests has molecular weight distribution curves unlike that attained through outdoor exposure. The authors therefore developed new weathering test conditions based on the existing accelerated weathering test using a xenon arc lamp. Samples of LDPE were photodegraded using various accelerated weathering test conditions and outdoor exposure. The physical properties and chemical structures of the photodegraded samples were studied through a tensile test, infrared spectroscopy, and gel chromatography. The authors found that the molecular weight distribution curve of a sample photodegraded using a xenon lamp at a higher BPT (black panel temperature) (73 °C) was more similar to that of an outdoor-exposed sample than that of a sample photodegraded at the standard BPT (63 °C). It is considered that a higher temperature accelerates radical recombination, consequently recreating molecular enlargement similar to the outdoor-exposed sample. Multiple regression analysis using newly introduced Mp (peak-top molecular weight) and Mw (weight-average molecular weight) as explanatory variables was conducted, which successfully enabled the authors to provide a simple explanation for the decrease in polymer tensile strength.

32-core Dense SDM Unidirectional Transmission of PDM-16QAM Signals Over 1600 km Using Crosstalk-managed Single-mode Heterogeneous Multicore Transmission Line

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We demonstrate 32-core dense space-division multiplexed (SDM) unidirectional transmission of PDM-16QAM (polarization-division multiplexed 16-quadrature amplitude modulation) 20-WDM (wavelength-division multiplexed) signals over 1644.8 km employing a low-crosstalk single-mode heterogeneous 32-core fiber in a partial recirculating-loop system.

A Sparsity Managed Adaptive MIMO Equalization for Few-mode Fiber Transmission with Various Differential Mode Delays

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It is often observed that various differential mode delays (DMDs) coexist in single multi-core fiber and/or few-mode fiber transmission. From a multi-input and multi-output (MIMO) equalization perspective, this indicates that the optimum equalization tap length for each multi-core and/or multi-mode signal varies according to its DMD. Correspondingly, complex calculation to find each optimum tap length is necessary to obtain satisfactory performance. This paper presents a new adaptive MIMO equalization method to deal with various DMDs while avoiding such complex calculation. The method uses the same tap length for all multi-core and/or multi-mode signals according to the maximum DMD to reduce the calculation cost.