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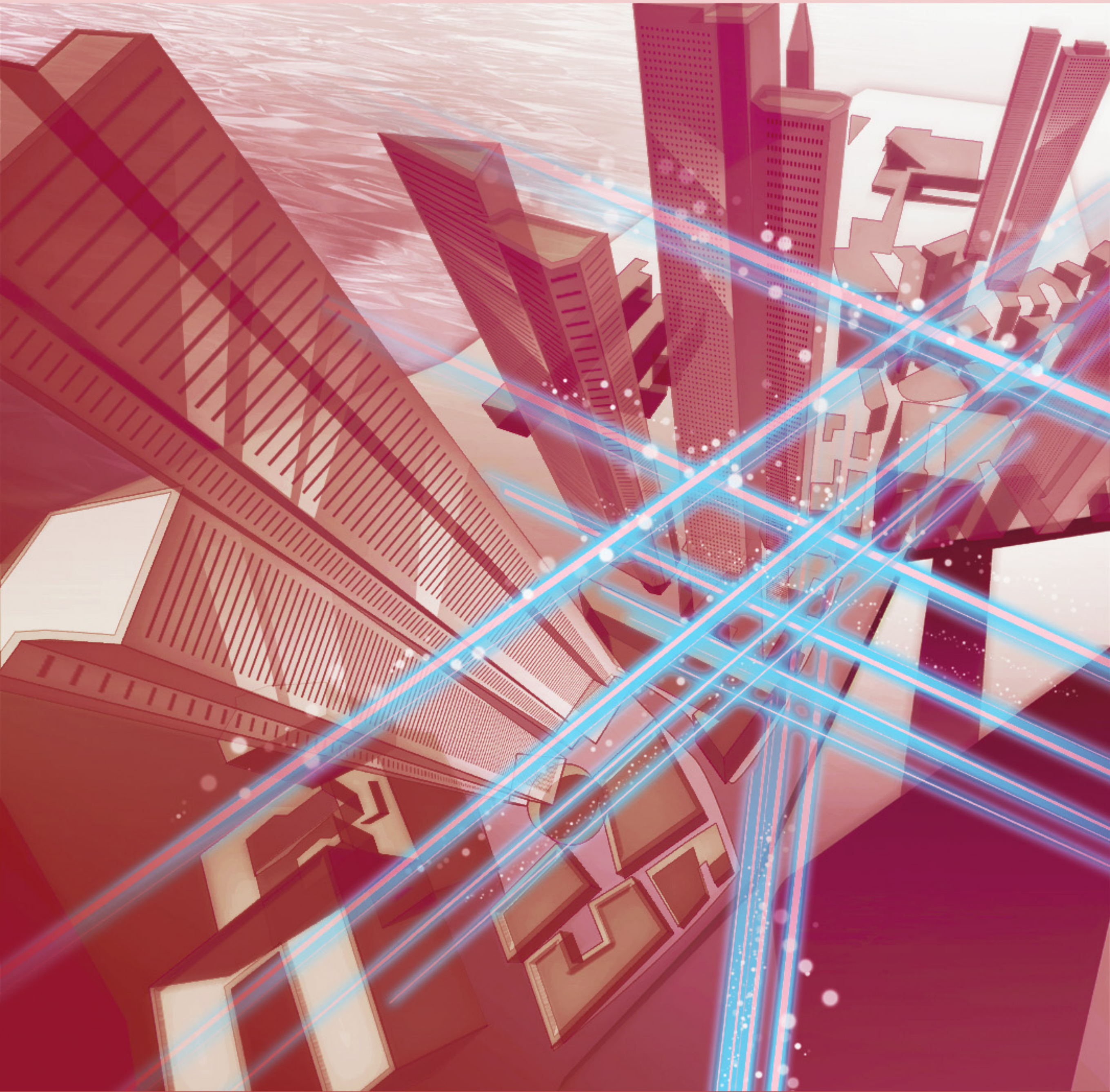

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Front-line Researchers

Feature Articles: Digital Transformation of Urban Areas Focusing on Mobility

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Set a Goal Differing from Those of Other People and Achieve It Using a Pivot Strategy

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Overview

As optical communications continue to spread, the results of research on the physical properties of light, electricity, and electrons to achieve high speed and low power consumption of such communications are being put to practical use. New physical phenomena have been discovered and explained by the interaction of the physical properties of mechanical vibration and those of light, electricity, and electrons. We asked Hiroshi Yamaguchi, a senior distinguished researcher at NTT Basic Research Laboratories, who has produced several world-first results in regard to applied technologies in the relatively new research field of nanomechanics, about his research activities and his attitude as a researcher.

Keywords: nanomechanics, MEMS, phononic crystal

Fabricating new micromechanical devices to discover new physical phenomena

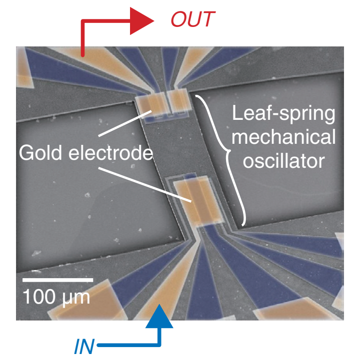
—Please start with the research you are currently conducting.

I and my co-researchers are fabricating micron-scale mechanical devices using semiconductor heterostructures and using its mechanical properties to develop novel devices used in integrated circuits (ICs). More specifically, we fabricate a mechanical device with an ultrafine structure (for example, a device with a leaf-spring structure) by using high-purity semiconductor crystals. We then experimentally use that device to discover and examine new physical phenomena caused by fusing the physical properties of light, electricity, and mechanical vibration, and develop novel devices used in ICs by exploiting those phenomena.

When an electric voltage is applied to an object, mechanical expansion and contraction occurs, which is called the piezoelectric effect. If a semiconductor material is used for fabricating a mechanical device, this effect can be combined with the opto-electrical properties of semiconductors, making it possible to switch between three types of signals: light, electricity, and mechanical vibration. Adding a new degree of freedom, namely, mechanical vibration, to the interaction between light and electricity will reveal new physical phenomena, which will open up applications for ultrasensitive electrical, optical, and molecular sensors and new signal-processing technologies.

Moreover, by fusing these physical phenomena with semiconductor quantum structures such as quantum wells and quantum dots (in which the quantum-mechanical properties of electrons appear), it will be possible to fabricate new hybrid quantum devices.

We are investigating new applied technologies by using microelectromechanical systems (MEMS)*1 and nanoelectromechanical systems (NEMS). MEMS and NEMS are attracting attention from both academic and practical viewpoints as microstructure devices that cause mechanical vibration. We have fabricated functional mechanical devices such as (i) an ultrasonic laser called *sound amplification by stimulated emission of radiation* (SASER), which can output extremely high-precision and high-quality ultrasonic vibrations by applying a principle similar to that of lasers to a mechanical oscillator (**Fig. 1**), (ii) an ultrasensitive sensor that can detect slight changes in weight and charge from minute movements of mechanical elements (**Fig. 2**), and (iii) signal-processing devices (such as memories and processors) that use elastic vibration.



The orange components, namely, the gold electrodes, are used for signal input/output. The blue areas show the conductive semiconductor layers. The leaf-spring mechanical oscillator (in the center) vibrates in the out-of-plane direction. In the experiment, when vibration with low-frequency accuracy was input from the bottom electrode, a signal with extremely high-frequency accuracy (i.e., frequency fluctuation of only 80 mHz) was output from the upper electrode.

Fig. 1. Electron microscope image of SASER.

—I heard that you are making globally important accomplishments. Could you introduce them to us?

Artificial crystals called phononic crystals—to which the concept of photonic crystals*2 is applied to control phonons (namely, media for transmitting sound, vibration, and heat via elastic vibrations of substances)—are attracting attention as a new category of functional materials that can control the sound, vibration, and heat that phonons can propagate. A phononic crystal has an artificial structure in which different elastic bodies are periodically arranged on a micron scale (**Fig. 3**). Since it has been difficult to electrically and externally control the operation of conventional phononic crystals, their application as active devices has been limited. We have successfully demonstrated—the world's first—in electrically controlling the propagation of phonons by using a semiconductor MEMS resonator (which can electrically control mechanical vibrations) as the basic device of a phononic crystal. This achievement was published in the scientific journal *Nature Nanotechnology* in 2014 [1, 2]. In 2018, using a phononic crystal that can manipulate the flow of ultrasonic vibration, we demonstrated the amplification of ultrasonic signals by waveform compression. This achievement was published in the online version of the scientific journal *Nature Communications* [3, 4]. Semiconductor devices that use ultrasonic signals are widely used in mobile terminals and other electronic equipment. If advanced control of those signals is enabled, new and various applied technologies would spread. Furthermore, we have recently been developing more-advanced ultrasonic-vibration control technologies such as the generation of chaos*3 and solitons*4 by exploiting the nonlinearity associated with mechanical resonators. We have also successfully fabricated a phononic-crystal waveguide that operates with high-frequency (gigahertz) vibration due to the miniaturization and high speed of mechanical resonators.

*1 MEMS: A type of miniature machine that has both mechanical and electrical functions. MEMS technology integrates mechanical structures of several millimeters to several microns on a chip by using microfabrication technology used for making semiconductor ICs.

*2 Photonic crystal: A material with a structure consisting of different refractive media that are periodically arranged on the order of the wavelength of light.

*3 Chaos: Common physical phenomena observed in many systems, such as the growth of populations of living species, turbulence of water, electric circuits, and laser light. It is a complex behavior that seems to be random at first glance but has a reproducibility in that it shows the same behavior under the same initial conditions.

*4 Soliton: A solitary wave that maintains its waveform while it propagates or a solitary wave that its waveform repeatedly compresses and expands periodically during propagation. The former is called a fundamental soliton, and the latter is a higher-order soliton.

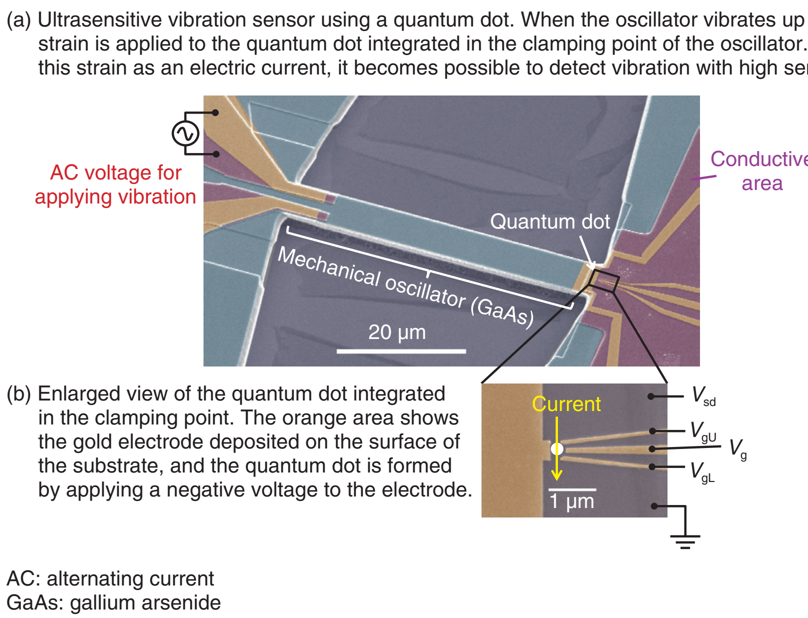
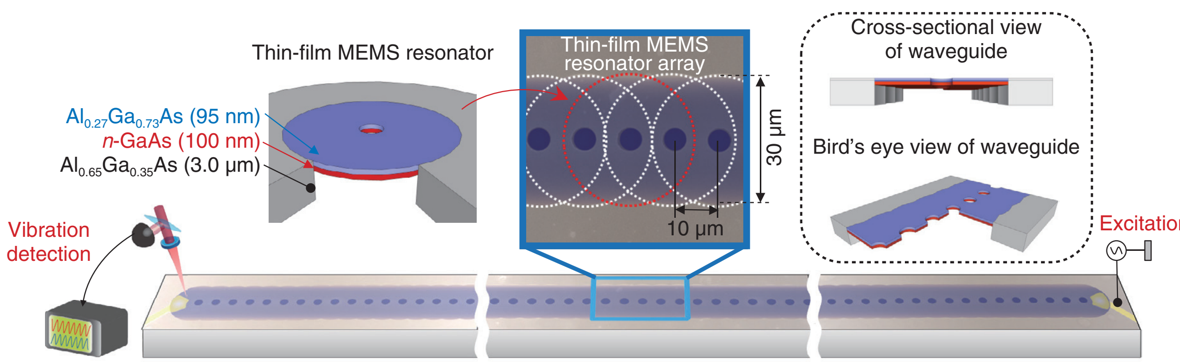


Fig. 2. Ultrasensitive sensor.



Using compound semiconductors enables electrical excitation and vibration detection.

Fig. 3. Phononic crystal waveguide incorporating one-dimensional array of 100 MEMS resonators with a circular thin-film vibrating section.

New properties that emerge due to nonlinearity, such as the generation of chaos and solitons, have the potential to greatly expand the functionality of mechanical devices. For example, a soliton is known to be generated in an optical fiber and is attracting attention as a special wave the shape of which is not changed by propagation. If such ultrasonic signals (i.e., that special wave) can be generated using mechanical devices, it will be possible to develop semiconductor devices that can process signals with high efficiency. Regarding the application of chaos by using mechanical devices, the possibility of efficient machine learning has recently attracted attention, and a method of controlling that chaos is being actively researched. It is expected that these methods can be widely used in applications requiring low power consumption, miniaturization, and integration, such as mobile communication systems (mobile phones, etc.) and Internet-of-Things technologies.

In the future, we would like to focus on overcoming the low speed, which is the most significant weakness of mechanical devices, and expanding our demonstration experiments using compound semiconductors to other materials with superior properties. Unless you are an expert in the properties of matter and applied physics, it may be difficult to understand the importance of changing materials and the bottlenecks to implementation. Even a slight change in materials will completely change the fabrication method and the effects of mechanical devices. However, it takes some time to produce the best results with different materials. Since we are in charge of basic research, it will take a long time; and we would like to persistently research technologies using new materials over the next three to five years.

Extend the antenna high and wide to obtain and disseminate information

—How do you feel about producing several world firsts in a row?

To announce a world first is to present something that has not been asserted by any one; therefore, it requires a certain amount of preparedness. Such an announcement may be interpreted wrongly, and many counterarguments are expected. Regardless, it is important to make a decision to publish it without hesitation. Of course, it is also necessary to prepare for responding to counterarguments to some extent. In 2013, we presented our research on the creation of phonon lasers that use the diverse dynamics of phonons. MEMS made from compound semiconductors exhibit nonlinearity in their vibration response. We found that this nonlinear phenomenon can be used to induce interactions between different vibration modes, enabling the output of high-quality ultrasonic vibrations.

This principle is similar to that concerning a laser of light, so we called it a "phonon laser" and announced it. However, there were various opinions about whether our achievement could be regarded as a "laser." Announcement of world-first achievements invites controversy, including such counterarguments, so it takes courage to deliberately plunge yourself into that controversy. However, if you are always afraid, you won't be able to announce your results, so you have to make a decision at some point. In fact, this presentation of the phonon laser was subsequently selected by the American Physical Society as one of the eleven best papers of "2013 Highlights of the Year" and introduced as one of the achievements getting the most responses from all disciplines across a wide range of physics. In that sense, I think it was a result that was widely accepted by many researchers at academic societies. The more new results you obtain, the more important it is to have the courage to present your ideas, even if you hear different opinions.

—What has been the most-important point when doing research?

As a researcher, I have always set goals that differ from those of others. Setting the same goals makes it easier to explain the purpose of research; however, differences from other researchers can be found only in regard to the research methodologies, and the choice of research itself is narrowed. In the research fields in which those goals are gaining attention, major research institutes around the world devote a great deal of their funds and compete by mobilizing excellent researchers. Students from prestigious international universities are outstanding in terms of motivation, knowledge, and abilities, and such students are working together and competing with the same goal in mind. It is true that Japanese students are also outstanding, and the students I teach are doing their best, but I have to say that it is difficult to compete with other students in international universities.

In such a situation, our policy is to compete by including the goal setting in the purpose of research. I think that selecting nanomechanics, which almost no one was working on at the time we started research, and targeting signal processing using ultrasonic signals is an example of setting goals that differ from those of other researchers. At first, no one else looked at that topic, but after a while, many related studies citing our paper emerged. It is precisely because we tried to create new goals that we were able to lead in new research fields.

When setting goals, I think it is better not to collect too much information. To be precise, when collecting information, I try to collect information in a manner that is not narrow and deep in one's own field but broad and shallow covering other fields. For example, when working on nanomechanics, I use the perspective of optical technology. Regarding the term "nonlinearity" that came up in the previous question, since research on nonlinearity in optical technology is progressing considerably, I ponder whether nonlinearity can be applied to nanomechanics or whether transistors, which have been studied for a long time in the field of semiconductors, can be applied to nanomechanics. In this manner, it is important to take inspiration from broader fields and use it when setting goals.

It is indeed important to step into a field different from your own. At that time, however, it is necessary to firmly identify your specialty and keep your foot there then take a step into another research field. If the direction of the goal of the research field matches your specialty, you go in that direction, but if the directions do not match, you pivot into another field. By repeating this process, you will gradually lay the groundwork for setting new goals. This approach is similar to *pivoting* in basketball. By using such a *pivot strategy*, you can proceed with research in a new direction while making the most of your specialty.

The role of an academic society is vital in not only collecting information by extending our "antenna" high and wide but also disseminating information (transmitting radio waves). For researchers in my age group, the number of jobs outside my research group, such as external committees and international conferences, increases, and during my busiest time, I was on business trips for more than one-third of the year. When doing such work, I often listened to talks in research fields that differed from my own. At first, those speeches had little to do with me, so I didn't concentrate on listening to them. However, as I took the opportunity to listen, I realized that many parts of those talks could be useful for my research. I learned from such opportunities that listening to researchers in other fields is paramount to developing new research in my field.

Researchers from other organizations are both competitors and collaborators. If you hide all your new ideas and research results just because they are your competitors, your arguments will get nowhere. If you don't speak, your ideas won't be stolen; however, by speaking, not just listening, you can build and maintain relationships of trust with your competitors. I think that kind of communication is important. Of course, your research results must be valuable and meaningful to the other party. I want us to build good cooperative relationships in which we can grow and increase our accomplishments, exchange information with other parties, and aim for our next accomplishments.

Researcher = Geek × Olympic athlete?

—Please tell us about the most-memorable events in your research life.

It was when I was researching optomechanics. I am also a visiting professor at Tohoku University. Once, at the university, a student in my laboratory who was involved in research said, "Professor Yamaguchi, I can't measure it." When I asked, "What is it that you can't measure it? Are you doing something wrong?", the student said, "When I try to measure it, the element trembles of its own accord." So I said, "That can't be happening. Try again. Something must be wrong." When the student re-measured it, a large vibration was indeed generated, and the target could not be measured. However, it could be measured when the conditions were slightly changed. By investigating this phenomenon, we discovered an operating principle of a completely new device related to light, electrons, and mechanical vibration, and published a paper about this principle in *Physical Review Letters*, one of the most-prestigious journals of the American Physical Society. We couldn't have written that paper if I had overlooked this phenomenon as some error made by a student with poor laboratory skills. It was an event that made me realize that it is really important to have an attitude of valuing even the slightest change, even one by chance. When I thought about it later, the personality of the student who honestly reported the phenomenon to me led to success. If a student who had a different personality had discovered the phenomenon and tried to do something about it alone, the phenomenon might not have been reported. In other words, we should emphasize diversity in regard to the nature and personality of researchers. In many cases, we can only progress by working with researchers with different characters and perspectives.

I think researchers are "geeks," very unique people. The average person may wonder, "Why is something so difficult so much fun?" For people like us who are absorbed in physics, however, we enjoy delving deeper into difficult research. In a sense, we research in a world of geeks. On the contrary, I think that researchers also have a characteristic similar to that of an Olympic athlete. Unsatisfied with becoming the top in their respective countries, they are competing for the top on the world stage. Olympic athletes may also be geeks in the sense that they are pursuing their sport. In any case, people are happy to be able to pursue what they like. However, researchers face a lot of hardship and are constantly under pressure since compromises are unacceptable, and matters must be investigated thoroughly. We are competing with researchers from all over the world aiming for the top, and some young researchers may feel crushed by that competition.

—Please say a few words to junior researchers.

There will always be times when you feel like you're about to get crushed or you don't get the results you expected. As you gain experience, you'll gradually get used to such times. When I joined the company, I sometimes didn't see the fun in the research theme assigned to me. Therefore, I talked to my boss about my distress that things weren't going well, and although I got involved in another research, the results of that research were unsatisfactory. At that time, I realized that I had focused too much on showing my own characteristics in the research theme that I wasn't confident with. Throughout this experience, I was blessed with a very caring boss, and I began to tackle themes that seemed uninteresting head-on. Then, I gradually felt that those themes were interesting. The Japanese proverb, "Three years on a cold stone will make the stone warm" means that perseverance and patience will bring good results, and now I know it really does. Therefore, I think it's better to move on a track laid for at least three years even if its direction seems different from that in which you are willing to go. I understand that researchers tend to avoid choosing themes that other people can do since they value being unique. However, once you've gained experience, you'll be able to conduct your own research; that said, just start from the theme you are given. Over time, your unique ability will surely emerge.

Moreover, those who manage basic research teams may feel pressure to be leaders; regardless, I think it's important to leave outstanding researchers alone. That is, managers should let researchers do what they want to do and dedicate themselves to supporting those researchers. Managers may feel anxious if they do not give direct guidance to researchers; however, I think we should foster the independence of our young researchers. It might be necessary for young researchers to try to free themselves from the customs of Japanese society that they have been brought up on, i.e., being provided every possible support. You may be concerned about the future, but today's research environment in Japan has a higher degree of freedom than in the past, and I think you will get many opportunities to play an active role. Let's enjoy our research together.

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■ Interviewee profile
Hiroshi Yamaguchi

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He received a B.S. and M.S. in physics and a Ph.D. in engineering from Osaka University in 1984, 1986, and 1993. He joined NTT Basic Research Laboratories in 1986. His current interest is in micro/nanomechanical devices using semiconductor heterostructures. He has been a guest professor at Tohoku University, Miyagi, since 2006. He is a fellow of the Institute of Physics and the Japan Society of Applied Physics and a member of the Physical Society of Japan, the American Physical Society, and the Institute of Electrical and Electronics Engineers.

Optimization of Entire Urban Areas Using IOWN

Shin Mitsuhashi, Noriyuki Miwa, Satoshi Fukada, and Kota Hidaka

Abstract

NTT is advancing the Innovative Optical and Wireless Network (IOWN), NTT's vision of creating a *smart world* using innovative technologies. The aim is to accelerate digital transformation in collaboration with its partners and solve social problems. This article introduces NTT's activities to optimize urban areas with a focus on mobility and how it can be used to address current social problems. Essentially, this will be done by achieving both individual/local and group/global optimization on the basis of various types of information using IOWN and other technologies and assets of the NTT Group.

Keywords: IOWN, smart cities, digital transformation

1. Activities of Japan and NTT to address current social problems

Economic development and technical innovation have led to the advent of many different services, which have enriched our lives, and people's priorities and values have become diverse. The aging population, which has resulted from improvements in quality of life and medical care, and global economic and political changes are making social problems more complex. The current social system is not conducive to achieving both economic development and resolving social problems.

In light of these circumstances, the government of Japan has proposed, in the 5th Science and Technology Basic Plan, Society 5.0 [1]. This is the government's vision of the type of society that should be aimed at in the coming years. Society 5.0 is a human-centered society that balances economic development with the resolution of social problems using systems that closely integrate cyberspace and the physical space.

In Society 5.0, a huge amount of information sent from sensors in the physical space is accumulated in cyberspace. In cyberspace, artificial intelligence (AI), which exceeds human capacity, analyzes the accumulated information. The analysis results are fed back to people in the physical space in a variety of ways, including by robots, bringing hitherto unknown value to industry and society.

To solve the diverse social problems mentioned above, i.e., achieving both individual/local and group/global optimization based on various types of information and creating a better society more receptive to diversity, NTT has announced its vision of the Innovative Optical and Wireless Network (IOWN) [2]. IOWN is a network and information processing infrastructure, including terminals, that exploits innovative technologies centering on photonics to provide high-speed, high-capacity communication and massive computing resources, both of which surpass the limits of the conventional infrastructure. NTT aims to define its specifications in 2024 and start commercial use in 2030 (**Fig. 1**).

2. Social problems related to urban areas and mobility

Urban areas are characterized by population concentration, which gives rise to long-standing and unresolved social problems, ranging from traffic problems, such as commuter rush hours, to environmental and energy problems. In contrast, rural areas are characterized by a decline in the productive

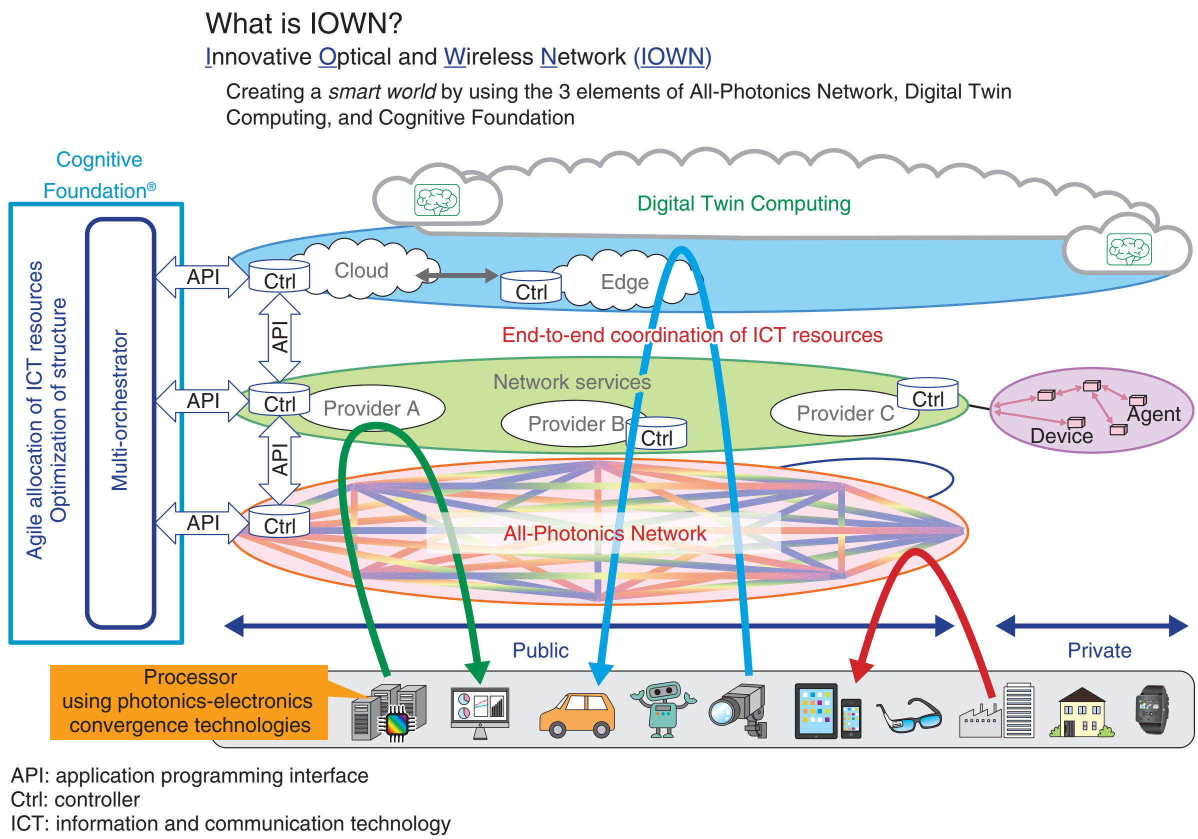

Fig. 1. Overview of IOWN.

population owing to a sinking birthrate, increase in the aging population, and decrease in the working-age population, making it difficult to maintain public and other services.

It is difficult in rural areas to maintain transport systems, such as trains, buses and taxis, at the same level as in urban areas. Therefore, it is important to provide diverse and sustainable mobility services capable of supporting the lifestyles and workstyles of people in these areas by considering a variety of mobility means in an integrated manner, including future use of automated driving.

3. Considerations in solving mobility problems

Conventionally, both economic growth and population growth have been taken for granted, and means of transport and mobility services have been designed and provided in a manner that achieves efficiency from a macroscopic viewpoint.

However, services needed in the coming years are those that use various mobility means adapted to users' purposes, usage situations, and health conditions. The aim is to solve diverse social problems while encompassing diverse values and needs of an individual/local in a timely manner. As well as mobility optimization for individuals, as mentioned above, it is also important to design and operate infrastructures and services from the perspective of group/global optimization to ensure that services are sustainable. For example, maintenance costs should be reduced by minimizing the requirements for human labor and energy resources in real time.

If we are to provide the aforementioned services, it is necessary to integrate cyberspace and the physical space to collect massive amounts of data about people, things, and events, such as geographical space information, mobility information, and information on people's behavior, tastes and history of their actions on the Internet, which have conventionally been managed and used separately for individual purposes. Such data should be integrated at high speed and used in cyberspace so that both individually/locally and statistically/globally optimal solutions

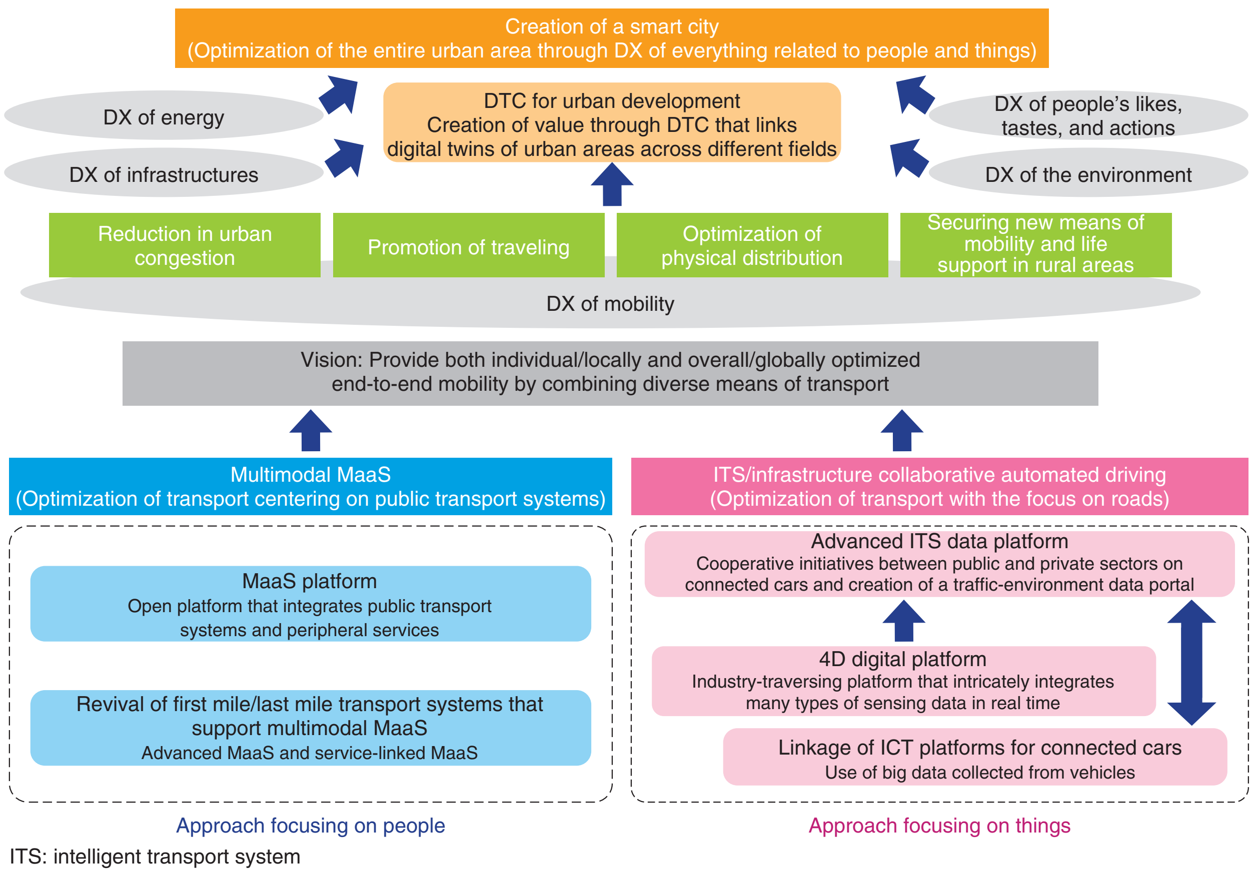

Fig. 2. Activities for optimizing entire urban area with a focus on mobility.

can be achieved and used for controlling devices and encouraging people to change their behavior.

Using the All-Photonics Network (APN) [3], Digital Twin Computing (DTC) [4], and other technologies under IOWN, NTT aims to achieve real-time collection and feedback of diverse data and implement services that help solve social problems while minimizing large-scale and complex computation in cyberspace and demands on energy and time.

4. Current activities of the NTT Group on optimizing mobility and urban areas

The NTT Group advocates a vision whereby both individually/locally and statistically/globally optimized end-to-end mobility are provided by combining different forms of transport. Through digital transformation (DX) of mobility, the group aims to solve a broad spectrum of social problems and create new value. It further seeks to optimize entire urban areas and achieve a smart city through DX of a wide range of business fields, including mobility.

The following Feature Articles in this issue introduce the NTT Group's activities for DX of mobility and urban areas, as shown in **Fig. 2**, as well as prospects for the age of IOWN.

(1) Open MaaS platform that supports multimodal MaaS

The first article [5] discusses future public transport systems from the perspectives of solving social problems, such as the declining birthrate, aging population, and global environmental problems. It also presents the NTT Group's activities for an open mobility as a service (MaaS) platform that supports multimodal MaaS, which integrates public transport systems and peripheral services.

(2) Activities on multimodal MaaS to solve the first mile/last mile problem

The second article [6] introduces NTT DOCOMO's activities involving AI and cross-industrial collaboration to achieve sustainable communities and smart cities and revive public first mile/last mile transport systems, the shortage of which is seriously impacting transport systems for both residents and tourists.

(3) Use of the 4D digital platform™ for mobility

The third article [7] presents activities for achieving smooth transport using a four-dimensional (4D) digital platform. The 4D digital platform collects many types of sensing data about people, things, and events in real time, integrates four dimensions of information (latitude, longitude, altitude, and time) with a high degree of precision, and provides data useful for predicting the future of various industrial infrastructures.

(4) Technical developments and verification of connected cars

The fourth article [8] describes NTT's collaboration with Toyota Motor Corporation regarding connected cars. Using big data collected from vehicles, NTT and Toyota are jointly developing technologies needed for the provision of new mobility services.

(5) Cooperative initiatives between public and private sectors on connected cars and creation of a traffic-environment data portal

The fifth article [9] introduces NTT DATA's activities on a traffic-environment-information portal and data-platform architecture, which are being studied to create a social infrastructure that facilitates collaboration among different traffic infrastructures needed in the coming age of automated driving.

(6) Data-driven and optimized smart cities using urban DTC

The sixth article [10] presents activities on DTC for urban development. It is intended to provide new value using a number of digital twins created by sensing environments, things, and people with sensor devices, such as cameras and smartphones, to predict the future in accordance with services provided in urban areas and link them across different fields. The goal is to optimize entire urban areas.

5. Future prospects

This article introduced current activities intended to optimize mobility and entire urban areas as well as prospects for the coming IOWN era. Remarkable advances in information and communication technology (ICT) as well as the technologies and assets of NTT and its partners are making it possible to create services that span diverse technical fields. However, before implementing these services, it is necessary to study their implications from several perspectives: protection of personal information and security; assignment of responsibility for future prediction made by and behavioral changes induced by computing systems that integrate cyberspace and the physical space; legal systems; social receptivity; and economic effects. NTT will carefully take these disparate challenges into account and work together with its partners to contribute to a better society using ICT.

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Open MaaS Platform that Supports Multimodal MaaS

Yoshihide Sato, Shinya Ooi, and Kuniaki Suseki

Abstract

The concept of integrating various transport systems is called mobility as a service (MaaS), and one early example started in Finland. This article describes a vision of a public transport-based MaaS platform and NTT's activities on the platform. Focusing on the mobility of people, the platform integrates several public transport systems and peripheral services to generate traffic flows that are locally and globally optimized end-to-end. The aim is to make a one-stop mobility service possible.

Keywords: MaaS platform, public transport, cloud-based certification

1. MaaS levels

There are four levels of mobility as a service (MaaS), as shown in **Fig. 1** [1]. At Level 0, there is no integration. At Level 1, information about transport systems is integrated so that users can access information across different transport services. Examples are train route search services that are widely used today. It is at Level 2 or above that booking and payment are integrated. At Level 2, users can book and pay for railway and bus services that are provided by different operators as if they were a single service. At Level 3, transport services provision (bundling/subscription, contracts, etc.) is integrated. It becomes possible to provide a service by which the user can select transport systems appropriate for the particular situation with the same ticket or a subscription service that allows the user to use different transport systems up to a certain amount per day or per month. Level 4 is the ultimate MaaS level at which transport services are integrated with the policies of municipalities and the national government to optimize mobility.

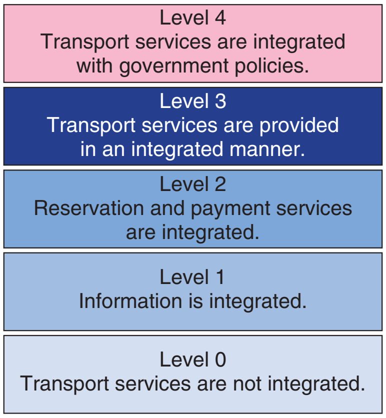

Fig. 1. Levels of MaaS.

2. World of MaaS in which public transport systems and various services are linked

As the level of MaaS goes up, mobility is made increasingly convenient for individuals. In achieving Level 4, it is important to look at mobility from a broader perspective and to pay attention to easing congestion and supporting movements of mobility-impaired people. For example, if the mobility demand in crowded urban areas can be leveled off temporally and spatially, congestion in transport systems and crowding at destinations can be reduced, leading to comfortable mobility experiences for individual travelers. For this purpose, it is important not only to integrate transport services but also to link mobility with various services that travelers will use at destinations.

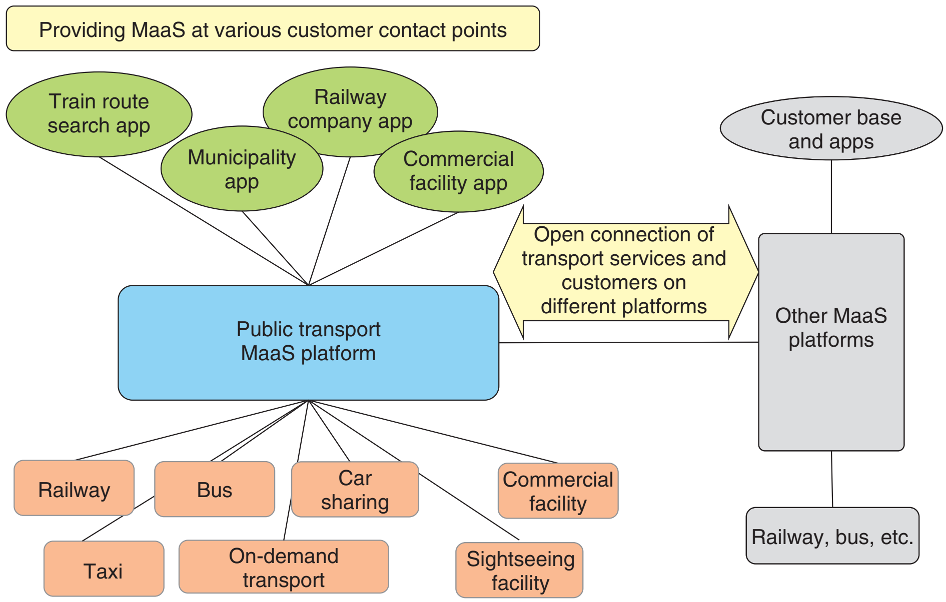

Fig. 2. World of MaaS in which transport and services are linked, and public transport MaaS platform.

For example, travelers may be encouraged to stay at their destinations longer for shopping or entertainment to level off transport demand.

The overall picture of the envisioned MaaS is shown in **Fig. 2**. By providing, at various customer contact points, public transport systems and services on the public transport MaaS platform, it is possible to increase opportunities to sell mobility and other services. If multiple MaaS platforms exist, they can be connected so that the user will not have to install several MaaS apps for different transport systems.

3. Cloud-based authentication using transport-service IC cards

An important function of a public transport MaaS platform is authentication of users. Assigning the authentication function to the platform makes it easy to integrate authentication services for existing public transport systems and services and enables flexible service design. NTT DATA is conducting a demonstration experiment of cloud-based authentication using transport-service integrated circuit (IC) cards (i.e. smart cards) in collaboration with East Japan Railway Company (JR East) and JR East Mechatronics.

How cloud-based authentication using transport-service IC cards works is shown in **Fig. 3**. When the user holds a transport-service IC card, such as Suica®*, on a dedicated card reader, the user identifier (ID) is authenticated by the cloud. By referring to the user's ticket information that is linked to the user ID on the platform, it is possible to determine whether this user can use a particular public transport system or whether the user can receive a particular item, service, or discount.

To examine what value can be created with MaaS, we at Mobility Innovation Consortium [2] hosted by JR East conducted the following demonstration experiments using cloud-based authentications of transport-service IC cards in collaboration with transport system operators.

(1) Demonstration experiment of congestion reduction and excursion promotion in Yokohama City, Kanagawa Prefecture (November 2019)

To reduce congestion in the surrounding area after a sports event has finished, information that forecasts congestion on the routes from the event site to nearby transport systems was transmitted to participants. Temporal dispersion of transport system usage and spatial dispersion of passengers on transport systems and at stations were examined. Using flow-of-people data assimilation technology developed by NTT Service Evolution Laboratories, the system reproduced the flow of people on a simulator based on real-time local people-count data, historical data, and external

* Suica is a registered trademark of East Japan Railway Company.

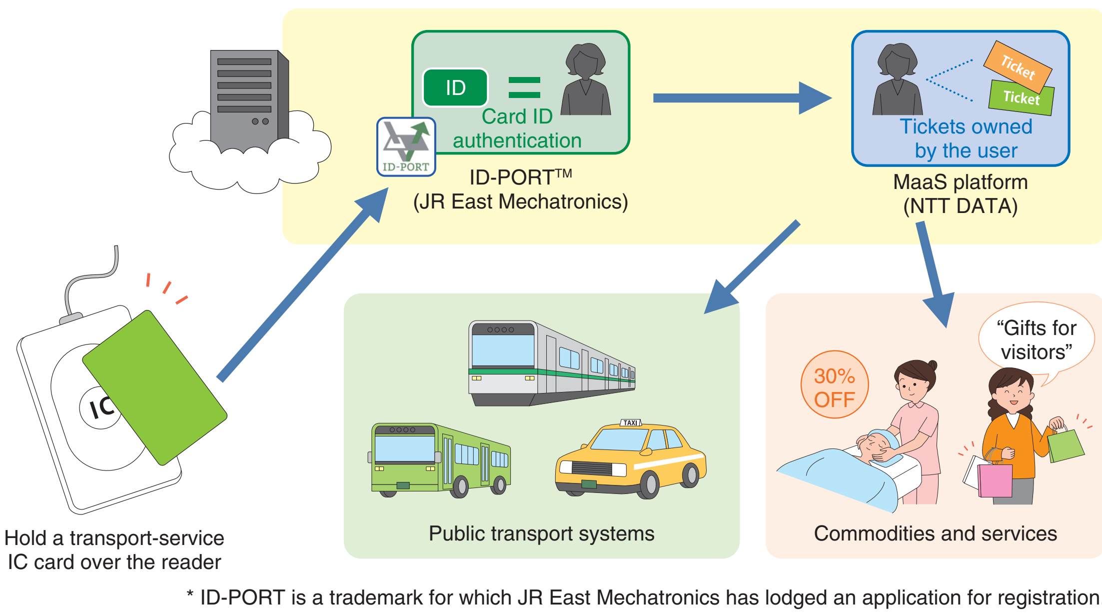

Fig. 3. Cloud-based authentication using a transport-service IC card.

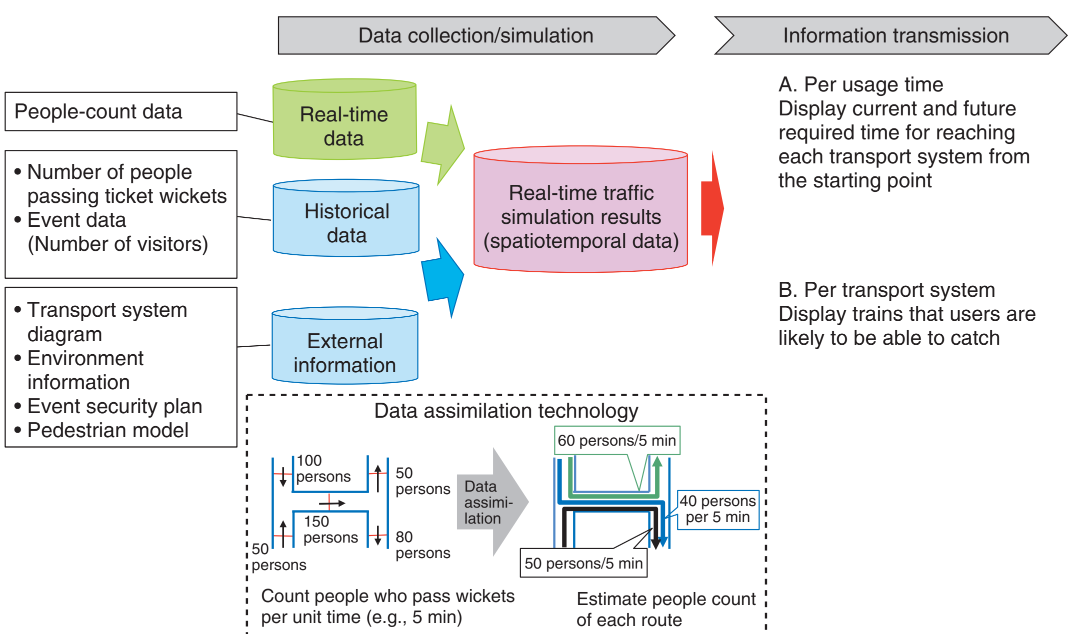

Fig. 4. Demonstration experiment of congestion reduction in Yokohama City.

information. The system generated information about the time required for people to reach transport systems at present and in the future and transmitted this congestion forecast information to participants (**Fig. 4**).

The transmitted information also included an attractive message inviting the participants to receive an incentive item and the privilege to ride on NTT DOCOMO's AI Bus [3] by choosing to take a train at the designated station using a dedicated transport-service IC card and to take a 10-minute ride to the

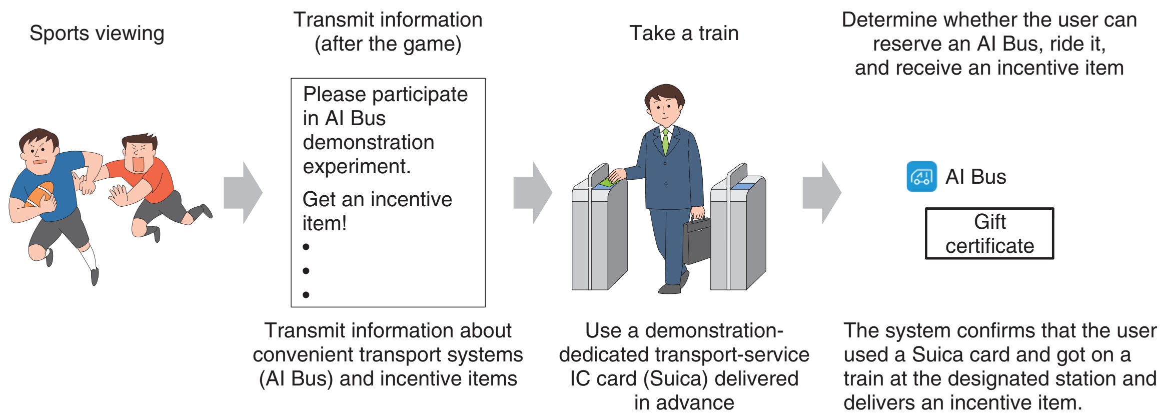

Fig. 5. Demonstration experiment of excursion promotion in Yokohama City.

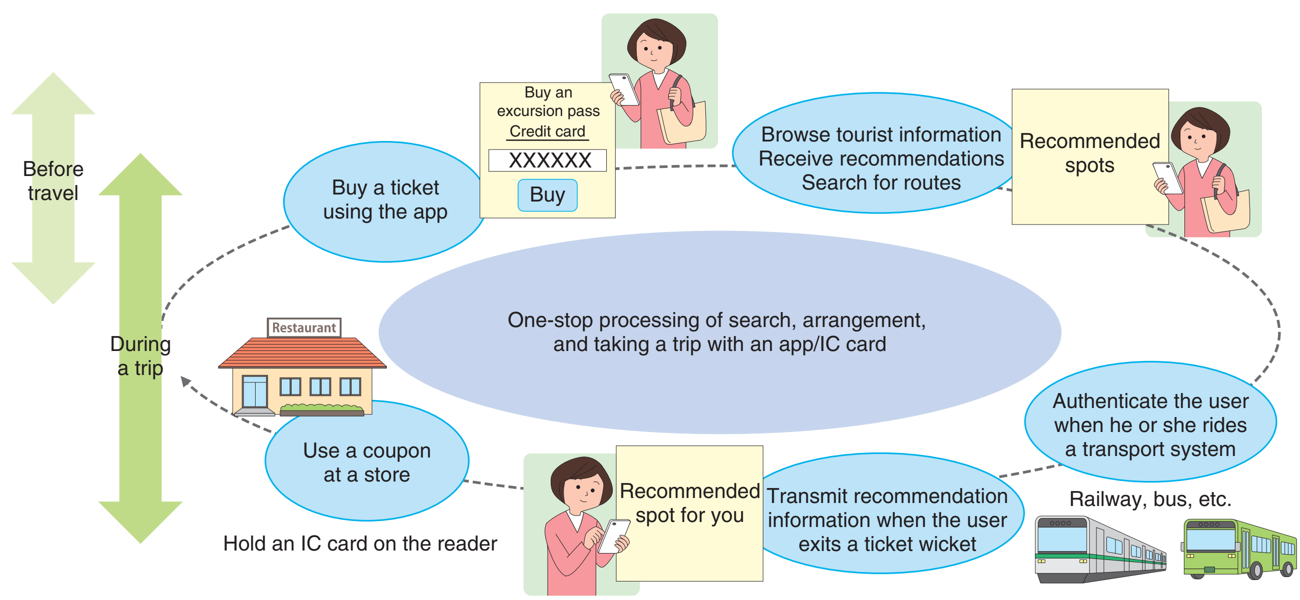

Fig. 6. Demonstration experiment of a multimodal sightseeing MaaS in Maebashi City.

Yokohama Rinkai area. This was an attempt to examine how providing incentive information can prompt participants to travel over a wider area or to different destinations (**Fig. 5**).

(2) Demonstration experiment of a multimodal sightseeing MaaS in Maebashi City, Gunma Prefecture (January 2020)

In this experiment, participants experienced the following service. A smartphone app was linked to the user's transport-service IC card in advance. With the app, a user can buy an integrated ticket that enables him or her to ride multiple public transport systems and receive discounts at stores. When a participant exited a ticket wicket, he or she received information about stores near the station and discount information, which were suggested by NTT COMWARE's LIKEUP™ [4] based on the user's attributes, location, and time. Therefore, seamless integration of mobility and consumption was examined (**Fig. 6**).

4. Future prospects of activities for non-urban areas

With a view to making a public transport MaaS platform accessible throughout Japan, we are also directing our efforts towards solving traffic problems in non-urban areas. We established the Kasama City Smart City Consortium [5] in Kasama City, Ibaraki Prefecture to make it a smart city by resolving its traffic problems. Looking forward, we are seeking to link various provincial transport systems, such as on-demand transport systems and excursion buses, on a public transport MaaS platform so that transport systems that are convenient to both residents and tourists can be maintained and reinforced.

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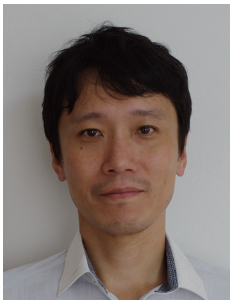

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Activities on Multimodal MaaS to Solve the First Mile/Last Mile Problem—NTT DOCOMO's Next-generation Mobility Service

Motoharu Miyake and Noritoshi Nishida

Abstract

This article introduces NTT DOCOMO's activities that use artificial intelligence and cross-industrial collaboration to achieve sustainable communities and smart cities and solve the first mile/last mile (FM/LM) problem—the shortage of the FM/LM connection to public transportation—that is seriously affecting both resident and tourist transport services.

Keywords: next-generation mobility service, AI Taxi, AI Bus

1. Introduction

With the emergence of CASE (connected, autonomous, shared, and electric), the automobile industry is undergoing major transformation, the kind that is said to occur only once every hundred years. This transformation along with the entry of companies from outside the industry is compelling automakers to make vigorous effort to create businesses for next-generation mobility services [1].

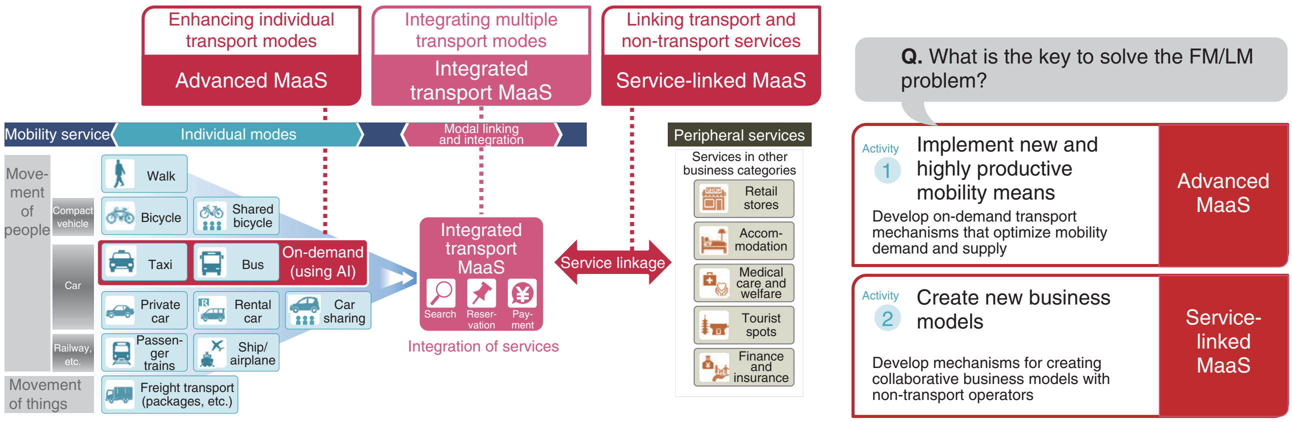
As part of this effort, a concept of next-generation mobility, called mobility as a service (MaaS), was proposed in Europe. It is intended to solve mobility-related problems, such as traffic congestion and carbon dioxide emissions, through a shift from mobility centering on use of private vehicles to use of a wide range of public mobility means, such as railway, bus, taxi, bicycle sharing, and car sharing. Many activities have already started, such as attempts to improve convenience by providing services that seamlessly integrate all travel processes, from reservation to fare payment. In Japan, there is an urgent need to solve the first mile/last mile (FM/LM) problem—the shortage of the FM/LM connection to public transportation—that is seriously affecting both resident and tourist transport services.

NTT DOCOMO initiated its promotion of a bicycle-sharing business in 2010 and has been providing the bicycle-sharing service DOCOMO BIKE SHARE since 2015. NTT DOCOMO has been approaching MaaS from three angles, as shown in **Fig. 1**: advanced MaaS, integrated transport MaaS, and service-linked MaaS (mobility × service). Given the urgency of tackling the FM/LM problem, NTT DOCOMO has given priority to studying the use of artificial intelligence (AI) to optimize vehicle assignment in an on-demand transport system, as part of advanced MaaS.

This article introduces AI Taxi [2] and AI Bus [3] as examples of advanced MaaS and describes NTT DOCOMO's efforts to reinforce the mobility business by linking mobility and services using AI Bus as an example of service-linked MaaS.

2. Advanced MaaS: AI Taxi

We developed a technology for forecasting taxi demand in each area of a city from historical taxi-operation data and statistical data on the locations of crowds. A taxi service using this technology has been in commercial service since February 2018 under the



Source: NTT DOCOMO revisions to materials from Ministry of Land, Infrastructure, Transport and Tourism, Japan, "Working Group for New Mobility Services in Cities and Regional Areas"

Fig. 1. NTT DOCOMO's approach to MaaS—Initiatives toward solving mobility problems.

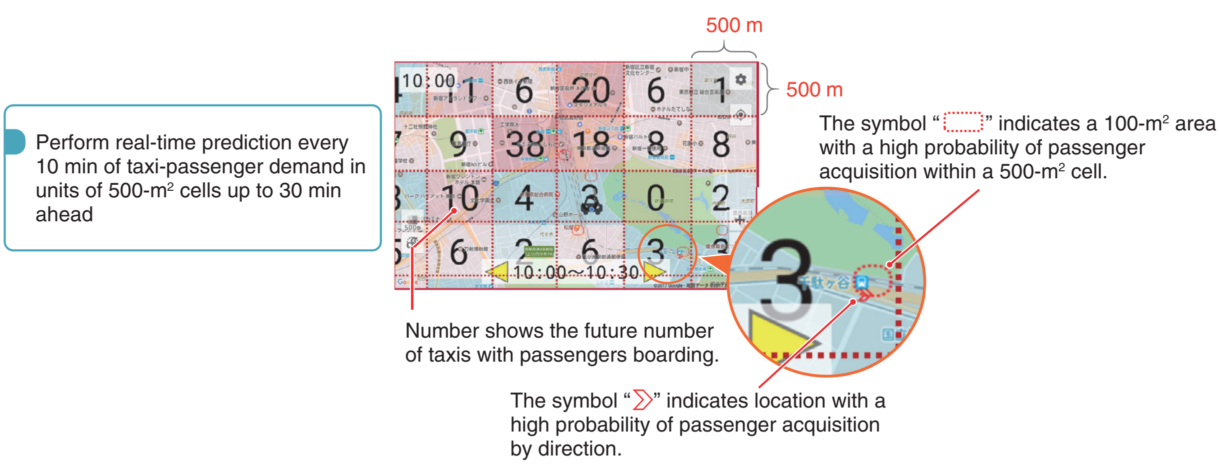


Fig. 2. AI Taxi service scheme.

name of "AI Taxi."

2.1 Demand forecast based on demographic data

In addition to using historical taxi-operation data and weather data, AI Taxi forecasts taxi demand using demographic data obtained from Near-Future People Flow Prediction, a technology based on the NTT Group's AI technology "corevo®", that identifies the distribution and flow of people all around the country. Taxi demand up to 30 minutes later in each grid area of 500 square meters is forecast. The forecast data are sent to taxi drivers every 10 minutes so that many taxis can be assigned to high demand areas (**Fig. 2**). Even when there is an unexpected delay in train operation or a special event, taxi demand can be forecast accurately, something which was previously difficult to achieve based on taxi drivers' experience and intuition alone. Even novice drivers with little familiarity with the area can efficiently find passengers and increase the boarding ratio because they can check changing demand in real time. Taxi users can also benefit from having a shortened waiting time.

2.2 Use of a hybrid model

Some correlations are known to exist between a change in population in an area and taxi demand. For example, (i) taxi demand depends on the type of area. It increases when the number of people begins to

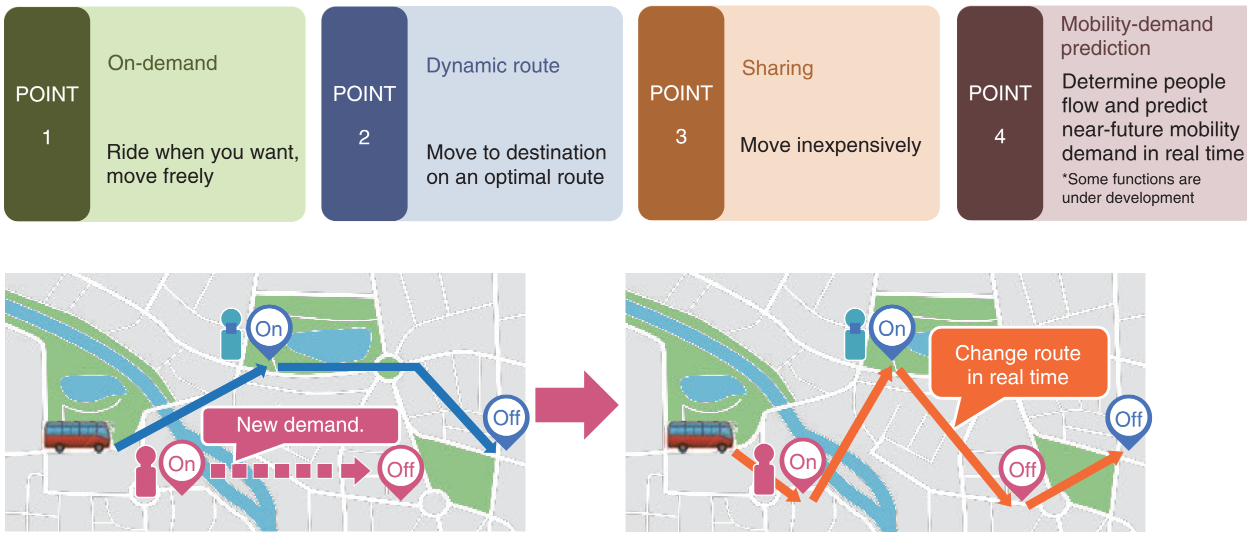


Fig. 3. AI Bus initiatives.

grow in an office district and when it begins to decrease in a shopping and entertainment district. (ii) Taxi demand depends on the type of event, which in turn determines the attributes of people who gather for the event. In a multipurpose stadium, taxi demand increases to a greater extent when people come to watch a baseball game than when people come to watch a girl band perform.

Since correlations between taxi demand and other factors, such as area type or event type, are varied, AI Taxi adopts a hybrid model, in which the results from a multivariate autoregressive model[*1], which is a time-series prediction model, and the results from deep learning[*2] are compared, and the one with a higher level of accuracy is selected.

3. Advanced MaaS: AI Bus

An on-demand transport system, AI Bus, has been in commercial service since April 2019. It improves operational efficiency for transport system operators and mobility convenience for users.

3.1 Efficient on-demand bus assignment using AI

AI Bus is an on-demand transport system that enables users to go to their desired destinations at the time they want. Users reserve a bus ride via a smartphone app, web browser, or call center, specifying their desired boarding time, destination, and the number of accompanying passengers. The system recalculates the running route of each bus in response to new reservations, which can arise at any time, and notifies drivers of the latest bus-operation plan. In this recalculation, the AI assigns buses and selects routes that are optimal for the current demand under the condition that prospective passengers who have already made reservations will not experience an unduly long waiting time (**Fig. 3**).

Since the bus-operation plan selects only those routes that connect the points where passengers board or alight, the travel time is shorter than in a conventional fixed-time, fixed-route bus service. Furthermore, since AI Bus allows multiple users to share a ride, the user can travel at lower cost than taking a taxi.

3.2 Function to recommend a potential service area based on demand forecast

As with AI Taxi, AI Bus forecasts demand in each area based on historical bus-operation data and demographic data and diverts buses to high-demand areas under the condition mentioned above (**Fig. 4**). It has an additional function to reduce passengers' waiting time and improve operational efficiency by notifying drivers of the place where they are to wait when the bus is empty. The collection of learning data is required to enable this function. However, it is difficult

*1 Multivariate autoregressive model: An autoregressive model with an extension to incorporate multivariate data. It is also called a vector autoregression model.

*2 Deep learning: A machine-learning method using a multi-layer neural network.

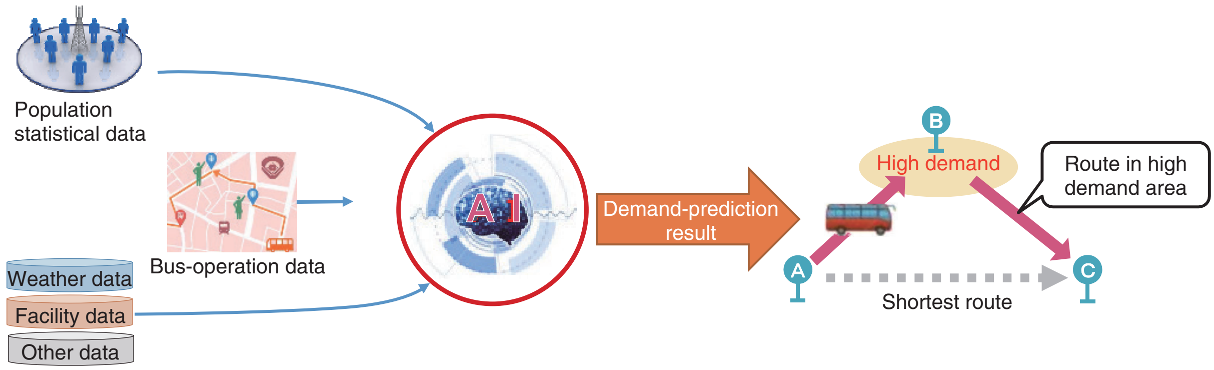


Fig. 4. Recommendation of driving routes/waiting spots based on passenger-demand prediction.

to accumulate learning data because the number of buses involved is small in comparison to the number of taxis. To solve this problem, AI Bus uses XGBoost (eXtreme Gradient Boosting)*3 for ensemble learning*4 so that a demand-forecast model can be developed quickly.

4. Service-linked MaaS: creating mobility × service business using AI Bus

Two activities on advanced MaaS have been described above. Besides cost optimization, another key to maintaining and reinforcing on-demand bus services is to develop new revenue sources. As an example of service-linked MaaS, a mobility × service business is created by linking AI Bus to the businesses of other companies.

4.1 Linkage of AI Bus to stores

Most transport systems do not carry passengers to their final destinations but to nearby stations or bus stops. Therefore, it has been difficult to link a mobility service with passenger activities. With AI Bus, however, users can select their destinations using a smartphone app or web browser, then be transported there, so it is possible to directly provide passengers with a smooth excursion and information about nearby facilities.

A demonstration experiment is being conducted to assist stores in attracting customers. The demonstration system provides a store-management portal, which carries information about stores and other facilities and distributes coupons in real time. The system also visualizes future mobility demand using Near-Future People Flow Prediction so that store owners can find out the number and attributes of prospective visitors and how these prospective visitors have browsed information about their stores (**Fig. 5**).

4.2 Linkage between AI Bus and services of other companies

The reservation function of AI Bus is provided through an application programming interface so that the mobility service can be linked to, and enrich, services provided by companies in other business categories, such as retail, accommodation, medical care and welfare, sightseeing spots, finance, and insurance. From services provided by other companies, users can reserve on-demand bus rides and specify the boarding time, boarding and alighting points, and number of accompanying passengers.

For example, if AI Bus is linked to a medical care system of a hospital, users can reserve a ride on an on-demand bus after settling accounts for examination at the hospital, so they can take a bus at the most convenient time and return home. AI Bus can also be linked to a hospital's reservation management system so that users are reminded of the need to go to the hospital one day before their next examination and can also reserve a ride on an on-demand bus for the examination day.

5. Conclusion

This article introduced AI Taxi and AI Bus, which are advanced MaaS platforms being developed by

*3 XGBoost: A type of ensemble learning that has been attracting attention in recent years.

*4 Ensemble learning: A method that builds different models and, in making predictions, integrates the prediction results of these models. This method is expected to improve predictive ability for unknown data.

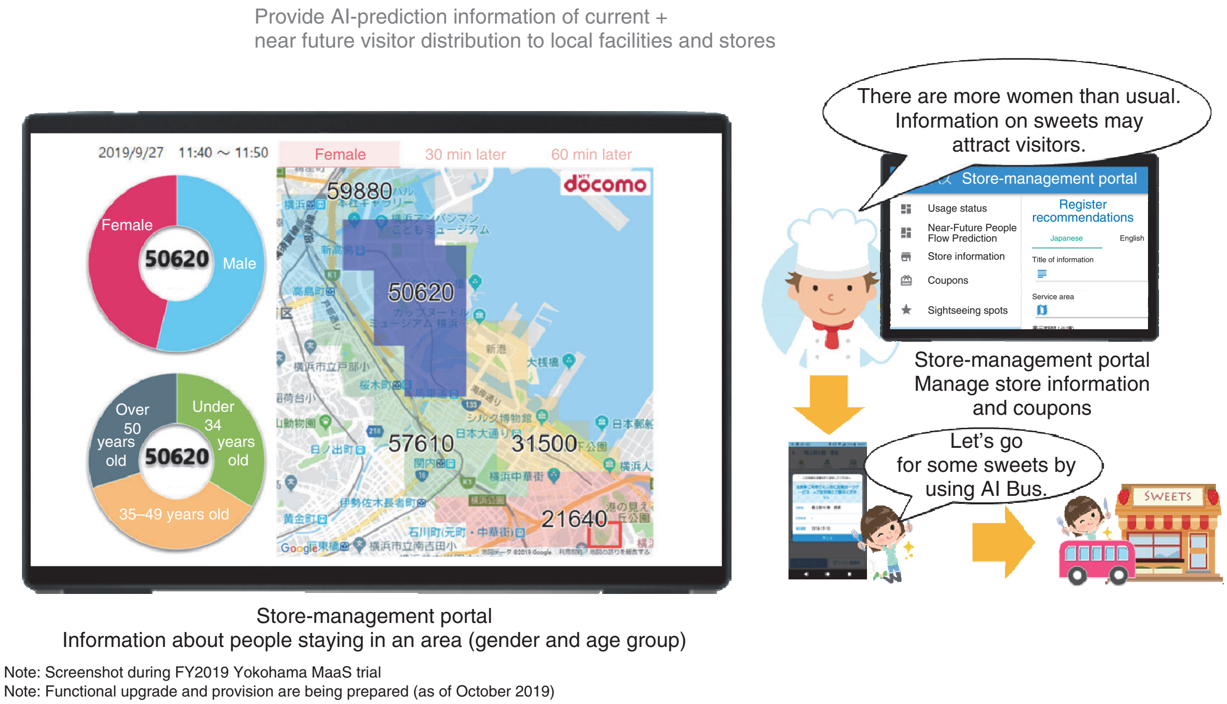


Fig. 5. Customer-management support tool for stores and facilities.

NTT DOCOMO. It also gave examples of service-linked MaaS, which is intended to reinforce business through mobility × service linkage made possible by AI Bus. Looking forward, we will contribute to solving social problems, such as the need to revitalize local economies, by refining mobility services and adding value using the latest AI technologies and expanding MaaS service areas through intensified cooperation with municipalities and transport system operators.

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Use of 4D Digital Platform™ for Mobility

Noriyuki Miwa, Satoshi Fukada, Seiji Yoshida, and Daisuke Tokunaga

Abstract

While the evolution of various forms of mobility, such as cars, have enriched our lives, there are concerns over deepening social problems related to road transport. This article focuses on the 4D digital platform™, which integrates many types of sensing data in real time to enable various predictions, and introduces our current effort and future prospects for solving social problems and creating value related to road transport centering on mobility, particularly regarding a cooperative connected-car platform.

Keywords: 4D digital platform, connected car, ITS

1. NTT's vision and activities in the mobility area

The evolution of various forms of mobility, such as cars, have enriched our lives. However, changes in social structures, such as declining birthrate, aging population, and population concentration in urban areas, have given rise to concerns over the following deepening social problems related to road transport:

- Increase in the number of traffic accidents involving the elderly
- Discontinuation of, or reduction in, public transport services in rural areas due to depopulation, and increase in the number of mobility-impaired people due to the elderly surrendering their driver's licenses voluntarily
- Traffic congestion in urban areas and resulting economic loss and environmental problems
- Increase in physical distribution due to e-commerce and resulting labor shortage in the logistics industry

Against the background of these social problems, automakers are conducting research and development (R&D) and demonstration experiments in collaboration with other industries to upgrade connected-car services and implement multimodal mobility as a service (MaaS). The Japanese government is also promoting R&D on common issues (cooperative domains) that need to be tackled through industry-academia-government collaboration. Advances in connected cars and autonomous driving have made communication networks an essential infrastructure for them.

The NTT Group is working to solve social problems and create new value through digital transformation of mobility. This article focuses on the four-dimensional (4D) digital platform™, which the NTT Group is now developing as a platform that can handle various types of data in an integrated manner, and describes value that the platform can provide for smooth road-traffic flow from the perspective of mobility, in particular, in cooperative intelligent transport systems (ITSs).

2. Background of the 4D digital platform

The remarkable advancement in information technology (IT) has enabled the collection of a large volume of Internet of Things (IoT) data and their analysis. Accordingly, the Japanese government and various companies are engaged in R&D with the aim of developing systems that merge cyberspace and the physical space, such as those proposed for Society 5.0. However, in the linkage of statistical data sets or

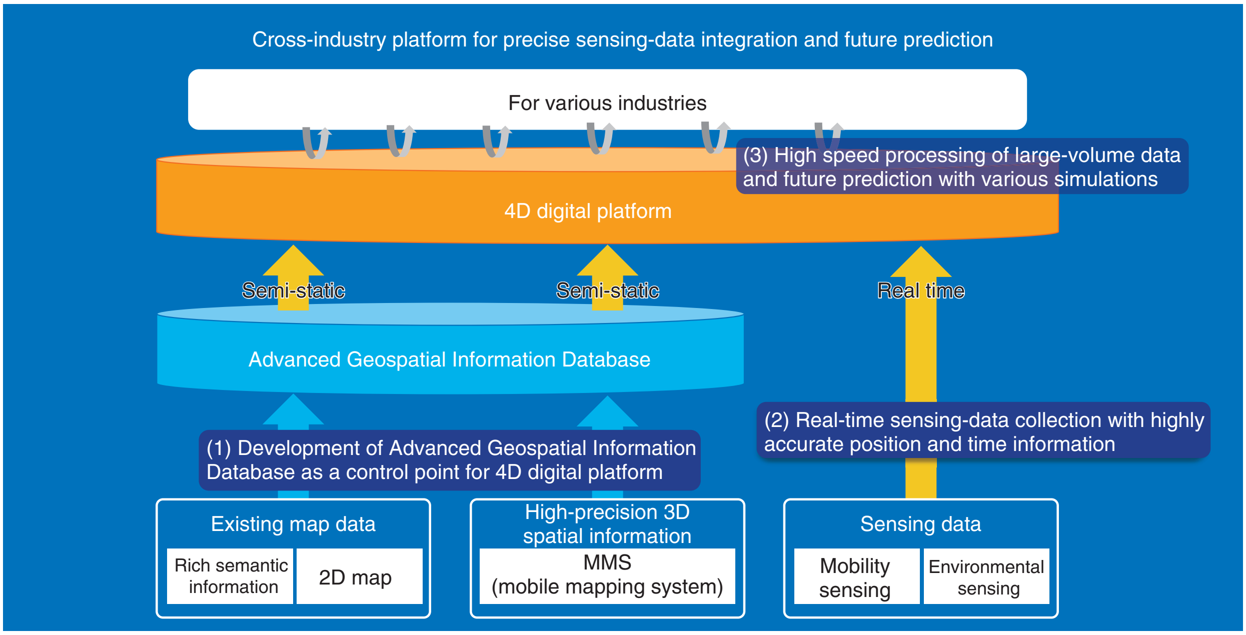

Fig. 1. Conceptual diagram of the 4D digital platform™.

the matching of misaligned position and time data, there are cases in which the accuracy of future predictions cannot be heightened.

To tackle this challenge, NTT has undertaken R&D of a 4D digital platform, making it possible to precisely integrate position and time information from sensing data in real time while also providing latitude, longitude, height, and time data useful for future predictions.

3. Overview and value creation with the 4D digital platform

As shown in **Fig. 1**, the 4D digital platform integrates sensing data in real time into the Advanced Geospatial Information Database with its highly precise and abundant semantic information and executes a variety of high-speed analyses. The following are three main features of the platform.

(1) Development of the Advanced Geospatial Information Database as a control point for the 4D digital platform

- Further improvement in the position accuracy for existing maps using the NTT Group's expertise in map data
- Development of high-definition 3D spatial information primarily for roads using a mobile mapping system (MMS) by applying infrastructure-management expertise

(2) Real-time sensing-data collection with highly accurate position and time information

- Technology, such as Smart Satellite Selection™ [1] (**Fig. 2**), that improves the accuracy of positioning and time synchronization in urban areas and real-time collection of accurate sensing data through high-speed, low-delay communications such as fifth-generation mobile communication systems (5G)
- Precise integration of sensing data into the Advanced Geospatial Information Database using mapping technology

(3) High-speed processing of large-volume data and future prediction through various simulations

- High-speed search and analysis of large-volume data sent simultaneously from moving objects by using the real-time spatio-temporal data management technology Axispot™ [2] (**Fig. 3**)
- Optimization simulation, future prediction, and behavior modification using artificial intelligence (AI) technologies

By combining the collection of high-precision sensing data and high-speed processing of large-volume data using this platform, we demonstrated the obtaining of precise and high-speed vehicle positions in real space that could not be achieved with conventional technologies.

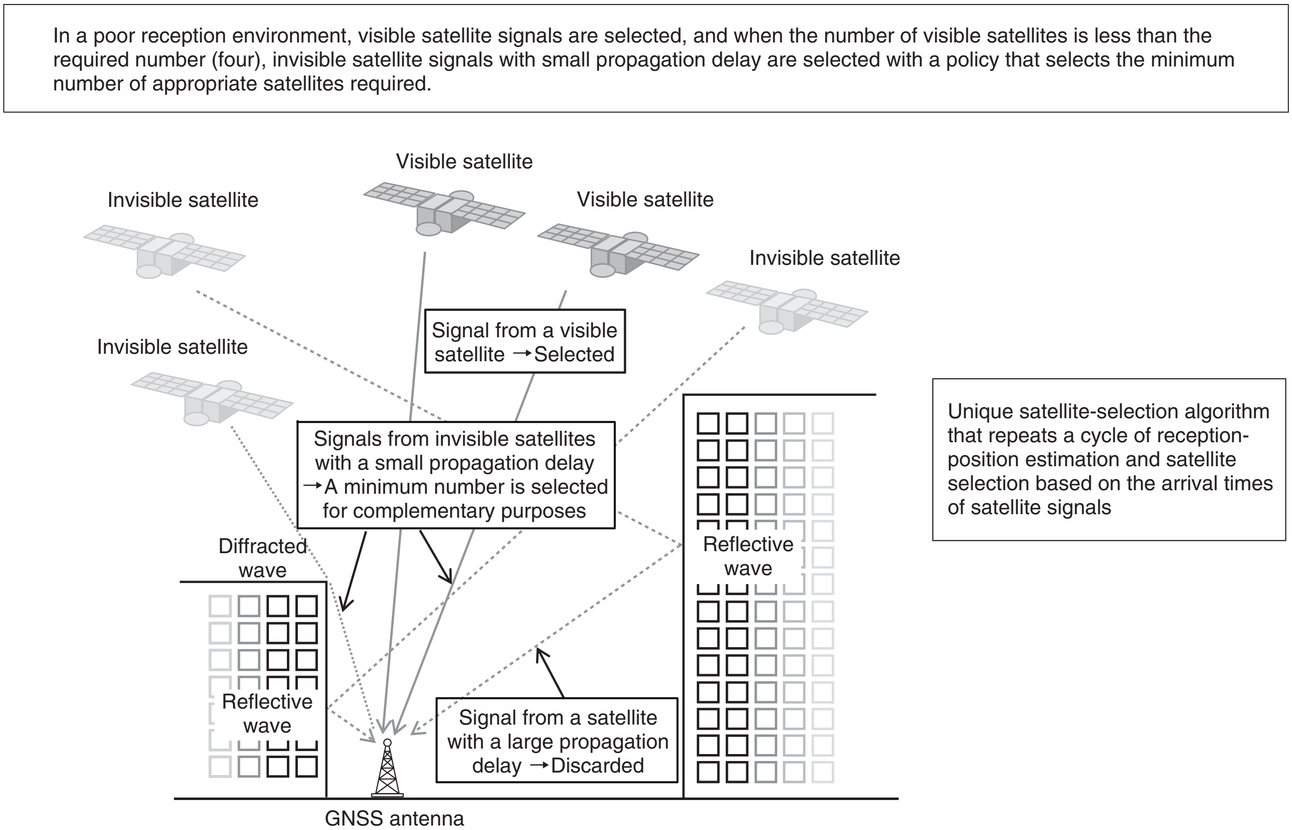

Fig. 2. Smart Satellite Selection™.

Figure 4 shows a demonstration of vehicle-position tracking on a per-lane basis by combining the aforementioned Axispot with Smart Satellite Selection to improve positioning and time synchronization accuracy in urban areas. In this demonstration, using the area near Kichijoji Station, Tokyo, as an example, plotting of vehicle position by satellite positioning and a search of the number of vehicles per lane were carried out.

With conventional technology (left in Fig. 4), satellite-positioning errors occurred in front of Kichijoji Station, which is surrounded by high-rise buildings, and the locations of vehicles plotted on the map were off the road. Furthermore, since it takes a long time to conduct a rectangular search for vehicles that match the lane shape, the number of vehicles could not be measured in time, and the final search result (number of vehicles by lane) was not correct.

In contrast, when the technologies of the 4D digital platform were applied (right in Fig. 4), the vehicle positions were correctly plotted on the map by high-precision satellite positioning, and rectangular search was conducted at high speed, so the search results for each lane were correct.

By combining these functional groups and data, we believe they will be used in a variety of fields such as road-traffic rectification, optimal use of urban assets, and maintenance and management of social infrastructure, as shown in **Fig. 5**.

4. Use of the 4D digital platform in the mobility field

As described earlier, the Japanese government is aiming to upgrade mobility services using information and communication technology (ICT) to solve social problems using future autonomous driving and create a society in which everyone can enjoy a high quality of life. To this end, it is promoting R&D of common issues (cooperative domain) that need to be tackled through industry-academia-government collaboration.

The NTT Group aims to enhance the efficiency and safety of urban transport by gaining an overall picture

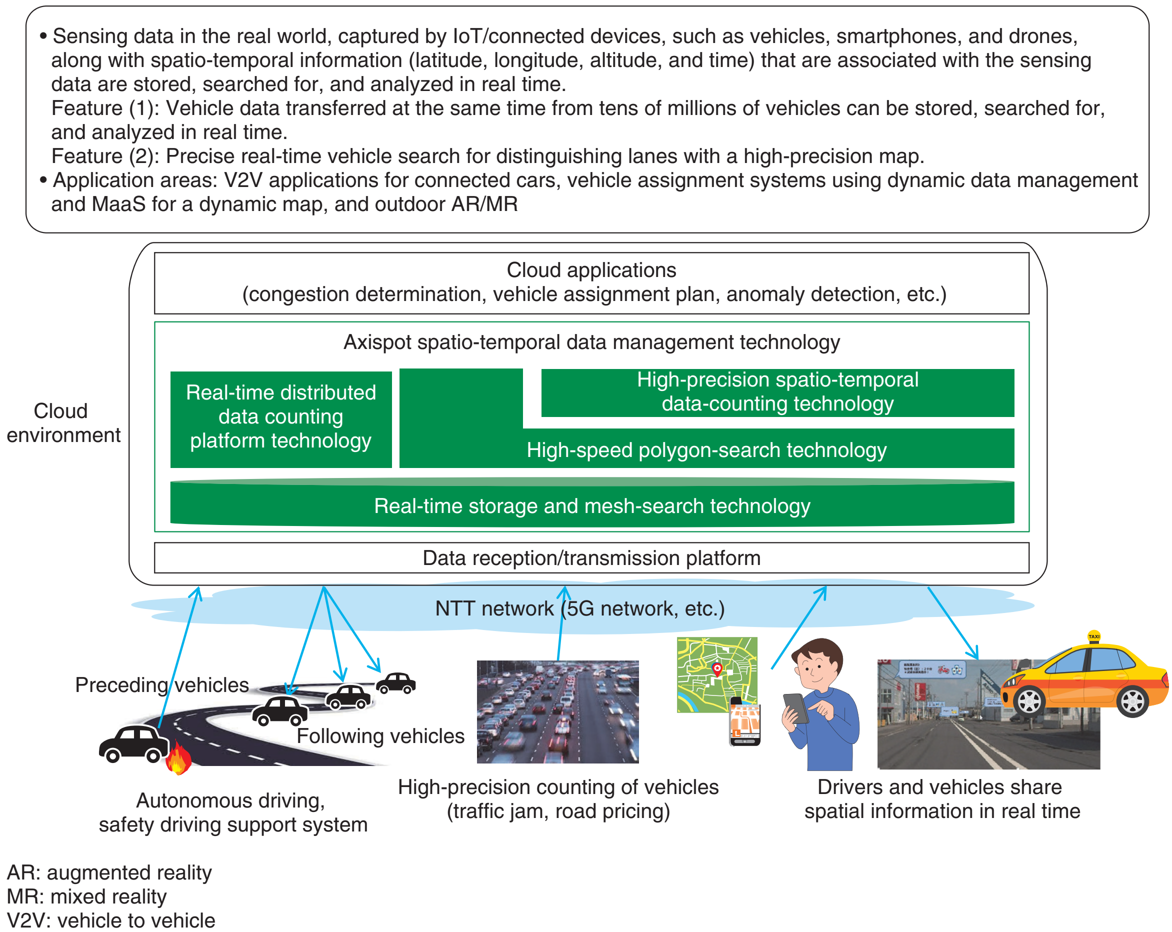

Fig. 3. Overview of the real-time spatio-temporal data management platform: Axispot™.

of traffic, which is considered difficult to achieve only with autonomous driving systems in individual vehicles. To this end, the NTT Group is aiming to contribute to the development of a cooperative connected-car platform, which handles vehicles and various data in an integrated manner using different types of communication (**Fig. 6**).

To achieve efficient and safe urban transport, it is necessary to build an efficient and high-speed network architecture, which is made possible by distributed processing platforms, and collect data on people, vehicles, and roads over a wide area using an overlay network. In the system layer, the 4D digital platform is used to store traffic-related sensing data in the Advanced Geospatial Information Database and correct (assimilate) the data so that traffic-related sensing data can be integrated with other types of sensing data and be searched for and extracted at high speed.

Data for which time and location are precisely aligned on the 4D digital platform will be used on the public-private partnership platform for ITS and mobility and on other industry platforms.

5. Use cases of 4D digital platform in the mobility field

The following describes what becomes technically feasible with the 4D digital platform when geographical traffic-related data are collected, aligned, and integrated on the platform. It also explains the R&D direction concerning the technologies used in these use cases.

(1) Reducing the number of traffic accidents

Dynamic dangers (objects fallen onto a road, pedestrian rushing into the road, and blind spots behind an idling car and at an intersection) can lead to serious accidents. One use case is to detect such dangers early, identify their positions quickly and

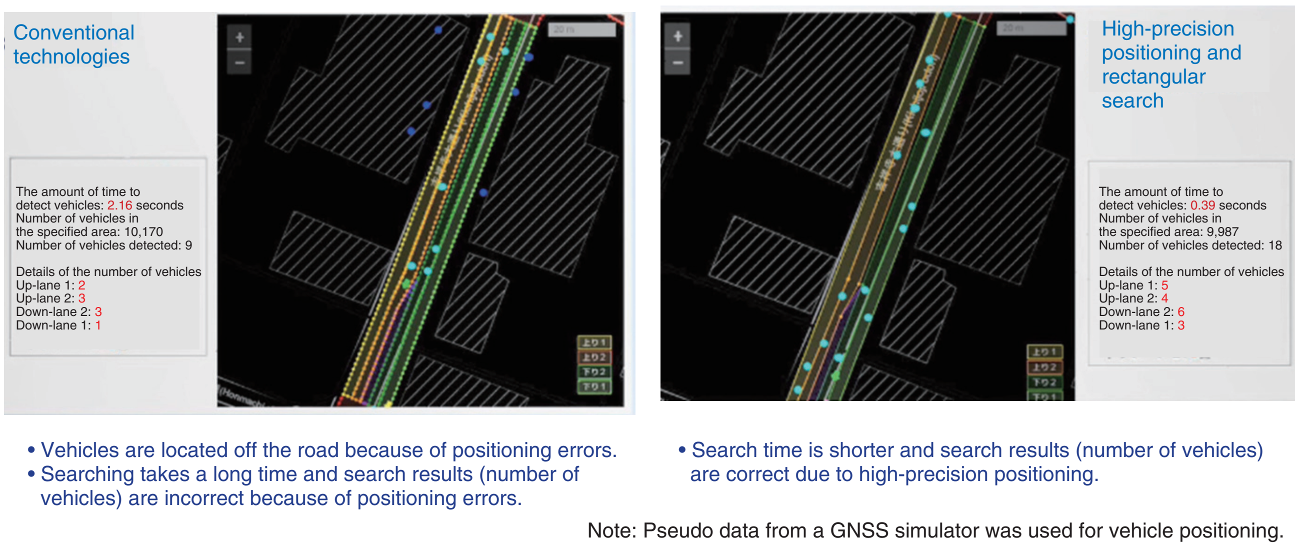

Fig. 4. Axispot × Smart Satellite Selection.

Fig. 5. Value proposition of the 4D digital platform.

accurately, and transmit information to nearby vehicles so that they can avoid accidents.

• From image data and vehicle-behavior data sent from vehicle-mounted cameras and roadside units, obstacles on the road are recognized in real time and their positions are accurately identified. Also, the area affected by the obstacles is estimated.

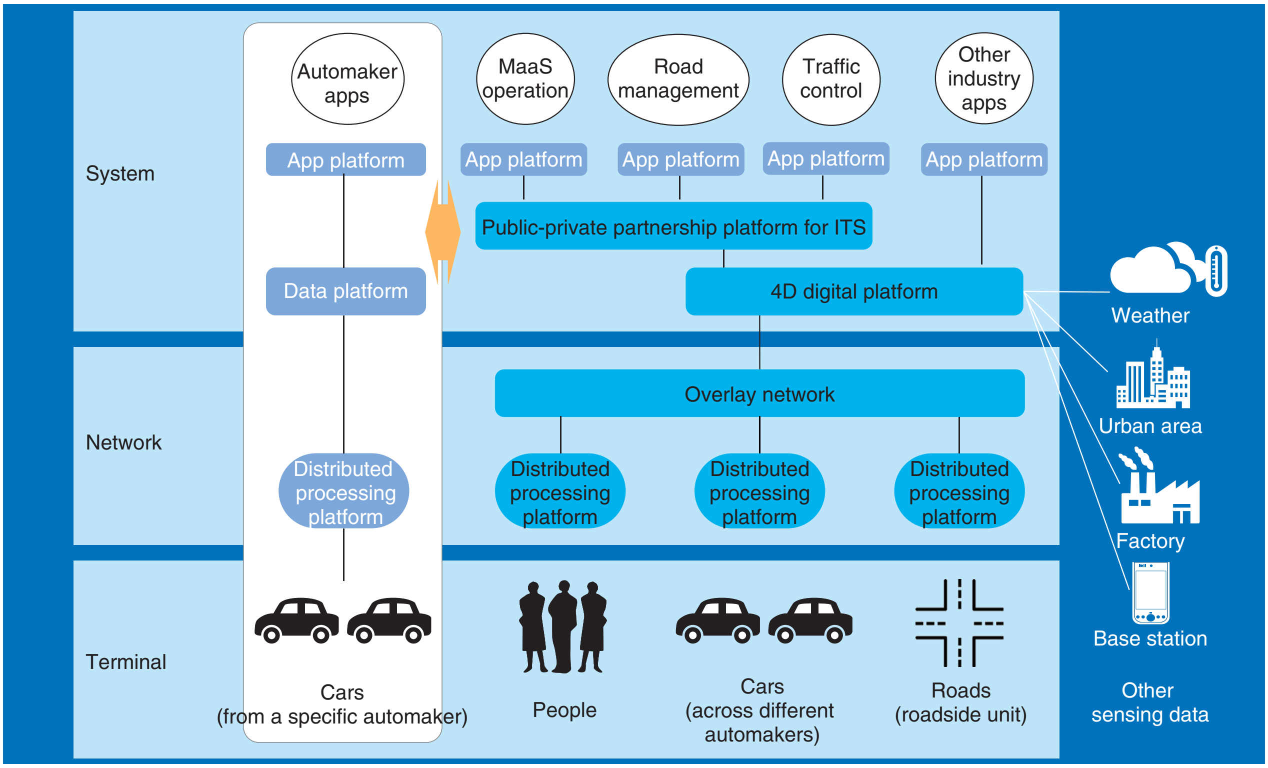

Fig. 6. Cooperative connected-car platform.

- Warnings are quickly sent out to vehicles so that they can avoid accidents.

(2) Reducing or resolving traffic congestion

Traffic congestion causes significant economic loss, particularly in urban areas. To mitigate traffic congestion, peak traffic volumes can be levelled off by controlling traffic signals to reflect the traffic volume and by configuring roads and lanes appropriately.

- Traffic volume is measured in real time using probe data and data from roadside units and by high-precision positioning.
- Traffic-congestion is predicted and congestion reduction using traffic-flow simulation that takes various environmental factors into account.
- Information for controlling traffic signals and for encouraging people to modify their behavior are transmitted.

6. Future prospects—ultimate level of mobility society through IOWN

With the Innovative Optical and Wireless Network (IOWN), which provides high-speed, low-latency, high-reliability networks and a high-speed processing platform, as well as the approaches and technologies described in this article, we believe it is possible to achieve the ultimate level of *harmonic mobility* with the highest level of safety and security and a society in which people, vehicles, and the infrastructure cooperate in a close-knit manner.

For example, overall optimized control along with autonomous driving control in individual vehicles will enable vehicles to cross without incident at a lightless intersection (**Fig. 7**). In the event of an accident or a disaster, vehicles can receive optimal guidance to minimize damage.

Achieving this comes with various challenges. We will pursue social implementation of the 4D digital platform by leveraging the characteristics of IOWN technologies as follows:

- Collect data using ultrahigh-speed low-latency communication and transmit calculation results to all vehicles
- Construct a network that spans the networks of multiple carriers using integrated ICT-resource allocation
- Calculate optimal solutions to enormous

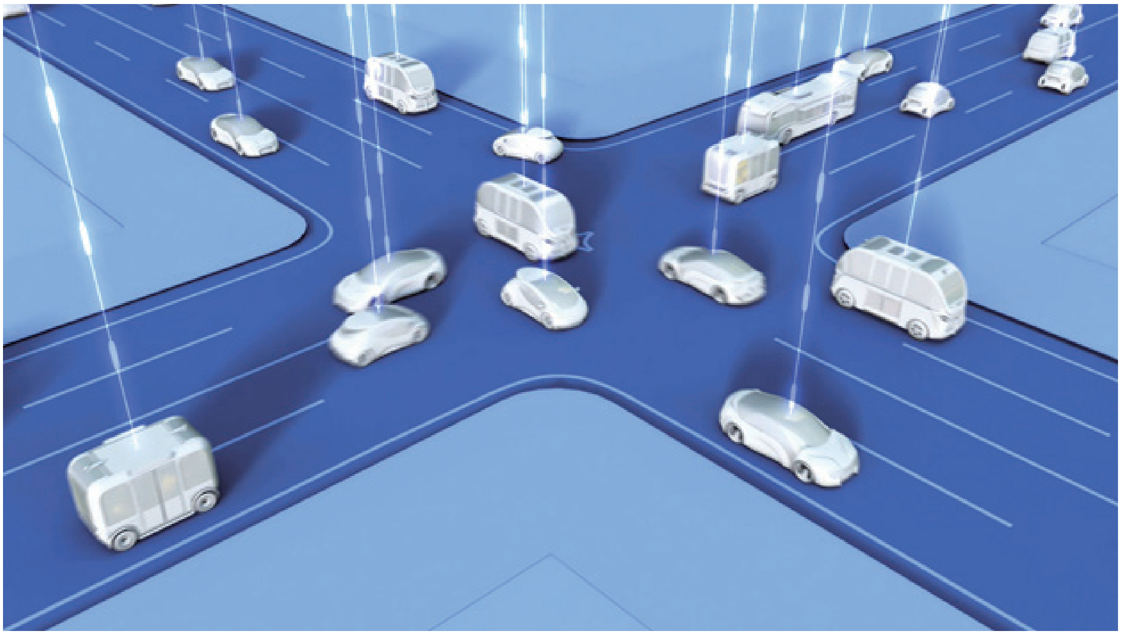

Fig. 7. Lightless-traffic-intersection management.

combinatorial problems using ultrahigh-speed information processing

- Collect and analyze accurate information about vehicles and surroundings in real time, including mapping of the vehicles and surroundings on advanced geospatial information constructed based on accurate positional reference points and generate precise predictions

7. Conclusion

The architecture for a cooperative-connected-car platform using the 4D digital platform and related technologies described in this article is extremely challenging. Various stakeholders, such as the government, automakers, map companies, and communications and IT companies, need to collaborate to study not only technical aspects but also business viability and social receptivity.

Since various unexpected events can occur in actual transport, we believe that all segments of society must work together to address mobility problems, including implementation of extremely sophisticated traffic control and traffic infrastructure, and conduct studies of legal systems and ethical issues.

With a view to providing platforms that support and services that enrich the lives of people, particularly concerning mobility, the NTT Group aims to make the most of its technologies, expertise, and assets toward this goal in collaboration with its partners.

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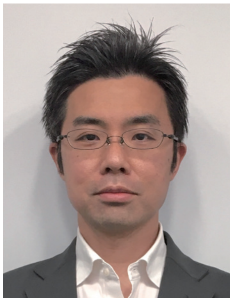

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Technical Developments and Verification of Connected Cars

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Abstract

Toyota Motor Corporation and NTT have agreed to collaborate on the technical development and verification of connected cars by combining Toyota's automobile-related technology and NTT's information and communication technology (ICT)-related technology. They have begun a demonstration experiment to check the current degree of completion of the required technical development. This article presents an overview of the ICT platform for connected cars and describes technical issues, technologies used to address these issues, and the demonstration experiment.

Keywords: connected cars, IoT, big data

1. Development of the ICT platform for connected cars

After the collaboration agreement was concluded [1], Toyota Motor Corporation and the NTT Group have been developing an information and communication technology (ICT) platform for connected cars by taking future automated driving into consideration. To achieve safe and secure automated driving, various data sent from vehicles must be collected and used in a cloud. The ICT platform is being developed as a means to achieve this.

2. ICT platform for connected cars

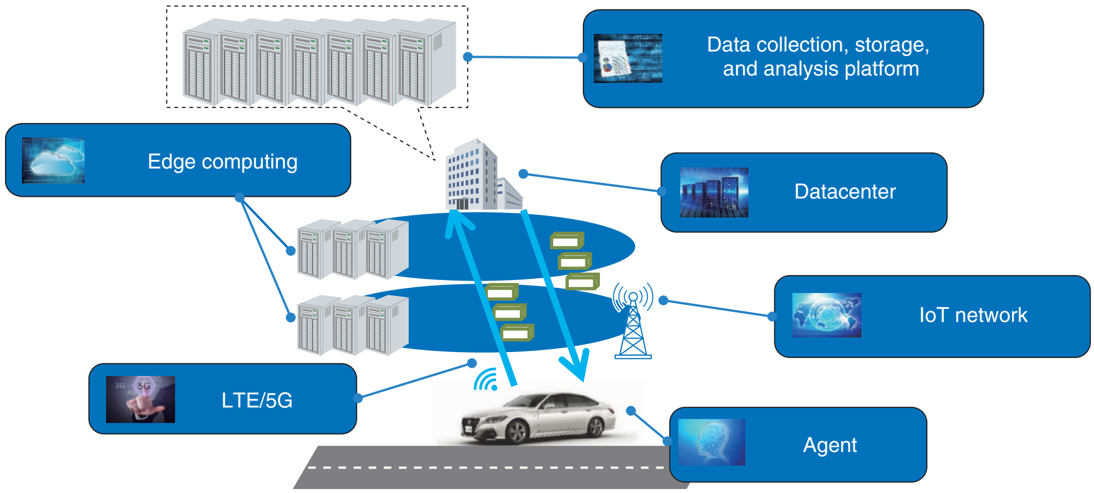
A connected car is a car that also functions as an ICT terminal. Since a vehicle holds many items of information, it is possible to understand the vehicle and its surroundings from the data it sends. If we are to solve social problems, such as traffic accidents and traffic jams, and upgrade mobility services, it is essential to use data collected from connected cars via a network.

Many key technologies are required to support connected cars: technology to collect and store a large volume of vehicle data sent by numerous vehicles; technologies to analyze the collected large volume of data in real time and reproduce the surroundings on a cloud; artificial intelligence (AI) algorithms to determine the behavior of vehicles; technology to collect and distribute a large volume of data; 5G (fifth-generation mobile communication system); edge computing; and communication technology to collect and distribute a large volume of data reliably and securely using Internet of Things (IoT) networks.

Specifically, a large volume of data from electronic control units (ECUs) installed in vehicles on roads and sensor data, including images from cameras, need be collected and stored in a cloud reliably and efficiently. From the collected data, the status of vehicles and their surroundings need be reproduced in cyberspace in real time. These processes make it possible to generate maps to be used in next-generation traffic systems and allow various services and automated driving. The ICT platform for connected cars will support the reproduction of the status of vehicles and their surroundings in cyberspace (**Fig. 1**).

3. Demonstration experiment

The development of the ICT platform for connected cars is being undertaken through short cycles of studying individual key technologies and a demonstration



LTE: Long Term Evolution

Fig. 1. ICT platform for connected cars.

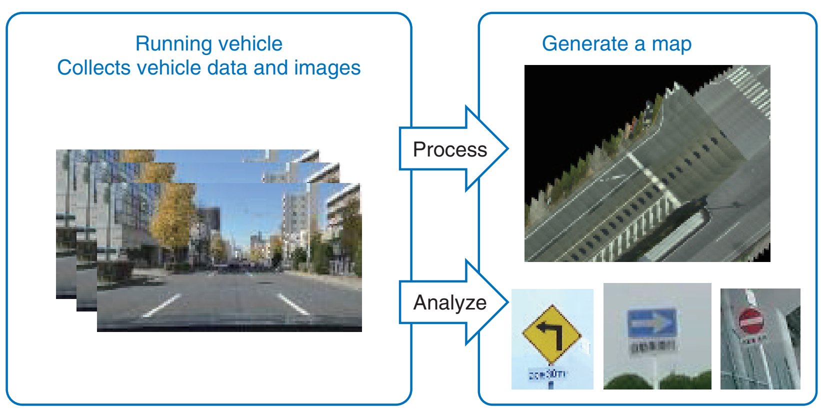


Fig. 2. Generation of a high-precision map.

experiment in which these technologies are combined and verified on an end-to-end connection, including terminals, a network, and datacenter. In the demonstration experiment, data from multiple experiment vehicles running on roads are collected via a network and stored in a cloud. The collected data are analyzed to confirm whether technical issues identified for use cases of connected cars and automated driving have been solved. In addition, vehicle data equivalent to millions of vehicles are generated to evaluate the feasibility of communication and datacenter technologies.

Specific uses cases being studied are: (1) generation of a high-precision map, (2) detection and notification of obstacles, and (3) traffic-jam detection in each lane. The extent to which the technical requirements of each use case are satisfied is being examined.

(1) Generation of a high-precision map

Whether video data captured with vehicle-mounted cameras can be sent to the cloud and whether information about vehicle positions and about the surroundings can be reproduced in cyberspace are being examined (**Fig. 2**). In particular, we are developing a technology for collecting video data and location information from vehicles and estimating the positions of road signs, road marks, and other structures from the collected video data captured with vehicle-mounted

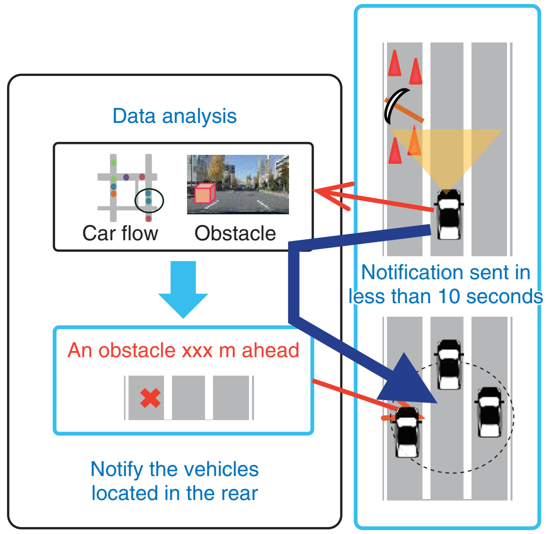


Fig. 3. Detection and notification of obstacles.

monocular cameras with a high degree of precision. Currently, changes in road surfaces are examined by driving a dedicated measurement vehicle over the road to be examined. This method is costly and cannot produce examination data in real time. Instead, our technology can be used to produce a high-precision map from image data captured with an ordinary vehicle-mounted camera.

(2) Detection and notification of obstacles

We are examining whether data sent by a vehicle can be shared with other vehicles in real time (**Fig. 3**). Specifically, when a vehicle-mounted monocular camera captures image data of an obstacle, the platform receives its data from the vehicle and estimates the position of the obstacle. The information about the obstacle is registered on a dynamic map. The platform quickly searches for vehicles that can be affected by the obstacle. Finally, the information about the obstacle is transmitted to these vehicles. We are developing a technology that accelerates the processing of these steps in less than 10 seconds.

(3) Traffic-jam detection in each lane

We are verifying whether the level of congestion in neighboring lanes can be reproduced from video data captured with a vehicle-mounted monocular camera. In particular, we are developing a technology for identifying the lane in which the vehicle runs and accurately estimating the level of congestion in neighboring lanes from the video data.

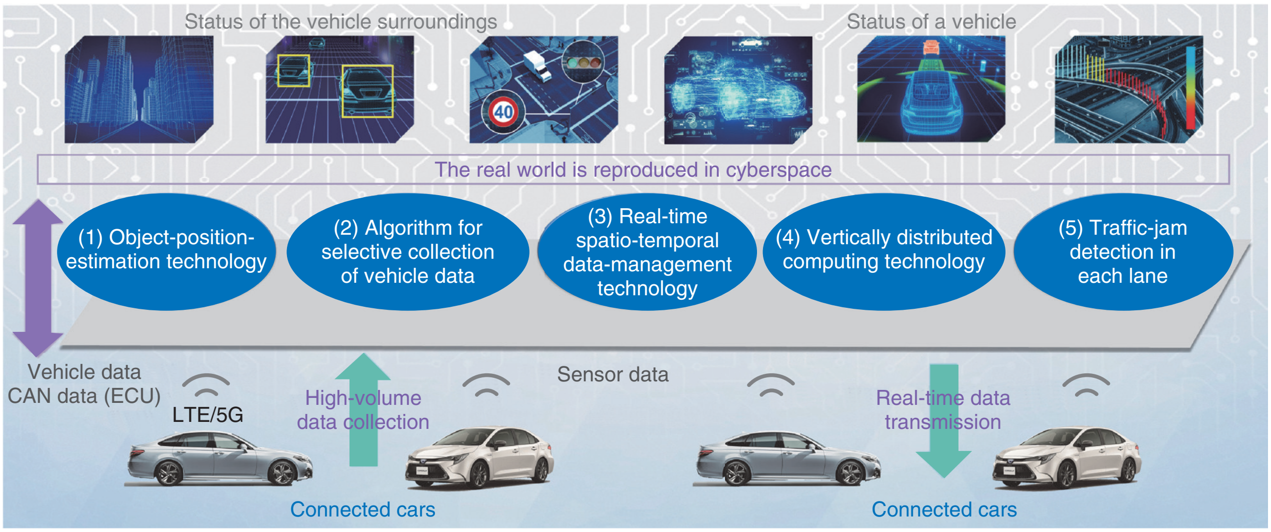
Technical targets have been defined for the key technologies being used in the demonstration experiment by assuming several use cases. The targets are the ability to connect tens of millions of vehicles to the system and perform the above steps within just a few seconds. This demonstration experiment began in 2018. It has been gradually expanded and will continue until the end of fiscal year 2020. We have already confirmed that 5 million vehicles can be connected to the system and that all the required steps can be performed in less than 20 seconds.

4. Main technologies that support the ICT platform

The ICT platform for connected cars involves a number of technical challenges. The main technologies being developed to meet these challenges are described below (**Fig. 4**).

(1) Object-position-estimation technology

This technology estimates the positions of display objects (road signs, signboards, etc.) in the road surroundings from vehicle status data and video data captured with vehicle-mounted cameras. It can even process data from low-end dashcams. It improves positional accuracy by selecting high-quality data from a large volume of data and using statistical methods. Accurate recognition of three-dimensional objects, such as road signs and traffic lights, on roads and high-precision estimation of the positions of these objects make it possible to map the objects on a map. This technology is expected to be used for generating maps for automated driving and automatically



CAN: Controller-Area Network

Fig. 4. Main technologies supporting the ICT platform.

updating them.

(2) Algorithm for selective collection of vehicle data

Data collected from connected cars are both voluminous and varied, ranging from vehicle data to video and sensor data. Since these data are collected consecutively from a large number of vehicles, the volume of collected data is enormous. This imposes a huge load on the network, and data processing capacity is stretched to the limit. To solve these problems, we developed a technology for selecting data collected from vehicles based on meta-information, such as location information, time information, sensor type, resolution, observational range, and observation impairment caused by the presence of surrounding vehicles. This technology makes it possible to efficiently collect data with minimum duplication of observational ranges and adjust the volume of collected data in accordance with the load on communication links and the analysis platform.

(3) Real-time spatio-temporal data-management technology

This technology enables a large volume of data to be stored instantaneously and searches a specified range (time and space) of data at high speed. It is a spatio-temporal database that manages time and location information generated by moving objects, such as vehicles and smartphones, as one-dimensional data using a unique method and enables the searching for those moving objects within a specified time and rectangular space range. It also searches within a space with a complex shape, such as a road or parking lot. Therefore, it enables the storing of sensor information generated by a large number of moving objects in real space, and time and space information associated with each item of sensor information, as well as searching for this information within a specified time and space range.

(4) Vertically distributed computing technology

This technology processes applications at high speed by offloading computation tasks done at datacenter servers to edge servers. Since the processing capacity of the system server is limited, it is sometimes not possible for the system to respond to all devices instantly. In reality, the required response time varies depending on the status of each vehicle (vehicle speed, moving direction, time of day, etc.). For this reason, vertically distributed computing technology dynamically distributes applications between edge servers and datacenter servers based on the status of vehicles. This technology can use limited server resources effectively while ensuring that the system responds instantly to those vehicles that require a quick response. This technology enables the system to serve a large number of vehicles and to collect and respond to a large volume of data. Thus, limited distributed computing resources can be used efficiently.

(5) Traffic-jam detection in each lane

This technology detects traffic jams in each lane from vehicle-status data and video data captured with vehicle-mounted cameras. It detects a queue of vehicles from the relative locations of vehicles moving along the surrounding lanes. It can also recognize the cause of a queue by identifying the first and last vehicles and combining this information with the surrounding facility information. Currently, information about traffic jams by road is provided by the Vehicle Information and Communication System (VICS) and smartphone map apps. When the above technology has been developed and in wide use, more valuable traffic-jam information will become available. As with the object-position-estimation technology described above, this technology can detect a traffic jam using video data captured with even low-end dashcams.

5. Conclusion

It is said that the automobile industry is facing a once-in-a-hundred-year transformation. The environment surrounding automobiles has been changing dramatically over the last few years. One of these changes is the spread of connected cars, resulting in the emergence of various services for drivers, fellow travelers, automakers, insurance companies, and service garages.

When it will become possible to process a large volume of data on vehicles quickly and at low cost, information that cannot be captured using current sensors will become available, and faster and more reliable services than today will be provided. These developments will not only enhance convenience and efficiency but also provide safety and security to the coming age of automated driving.

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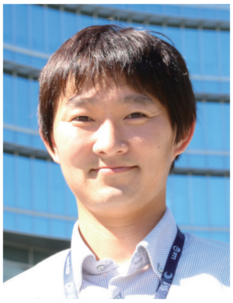

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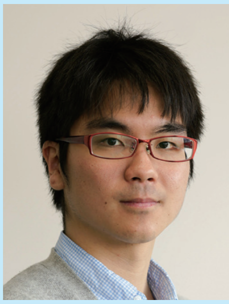
He received a B.A. in commerce from Waseda University, Tokyo, in 1995. After working on system development in the public sector at NTT DATA, he was seconded to the NTT DATA Institute of Management Consulting Inc. After returning to NTT DATA, he worked on sales reform and marketing in the Corporate Planning Department then engaged in business planning in the organization dedicated to business process outsourcing and robotic process automation. Currently, he is at NTT and engaged in the research and development of connected cars.

Young researcher's view

Research and Development of Digital Twin Computing Technology to Support Future Transport Systems

Masaru Takagi
Researcher, Unit-2, NTT Digital Twin Computing Research Center



My research team is developing technology for building a digital twin city using data collected from connected cars. Collection of LiDAR (light detection and ranging) and video data from connected cars allows continuous scanning of an entire city. A digital twin of a city can be built in virtual space by analyzing these data. Such a digital twin can be used for many purposes. In transport, it can be used to create a road-surface image map for autonomous driving cars and enable vehicles to share information about obstacles on the road. It can also be used in other applications such as detecting queues at restaurants located along a road, checking the damage after a disaster, and detecting anomalies in utility poles and cables.

The challenge is the sheer amount of sensing data. A single car equipped with multiple cameras and LiDAR sensors generates 10 MB of data every second. If 10 million cars are running throughout the country, the total amount of data generated per second reaches 100 TB. This is a huge amount, 10 times the amount of data carried by communications networks in Japan. It is extremely difficult to collect all such data due to the capacity limits of communication networks, computing resources, and storage systems. This situation can be mitigated because the urgency of collecting sensing data varies. Some need to be collected immediately for analysis, while other data can be collected after a delay. Some need to be collected only once a day, and some have no utility value whatsoever.

Therefore, we developed a technology that prioritizes data collection based on meta-information, such as location information, time information, sensor type, resolution, observational range, and observation impairment caused by the presence of surrounding vehicles. Although the amount of meta-information is huge, the high-speed spatiotemporal data management technology Axispot™ makes it possible to search meta-information at a practical processing speed. Our technology makes it possible to collect data efficiently with minimum duplication of observational ranges and adjust the volume of data to collect in accordance with the load on communication links and analysis platform.

In a demonstration experiment conducted in FY2019, this technology was implemented on an analysis platform, and vehicles running on public roads were connected to the platform. The function to selectively collect data based on the priority of the data was verified. In a demonstration experiment currently being conducted (FY2020), we are examining a function to dynamically switch the servers executing analysis on the basis of data priorities and processing load.

We are also making an ambitious effort to develop technology capable of predicting impending traffic status, to within just a few minutes to several hours from the present, with a high degree of precision. This technology is based on a multi-agent, microscopic traffic-flow simulator, which can reproduce the movement of each vehicle. We set the initial conditions by analyzing collected sensing data. We are aiming to improve reproduction precision by adjusting important parameters such as the stop-go indications of traffic signals. In the event of an unexpected incident, such as a traffic accident, this technology enables rapid assessment of the accident's impact on traffic flow, thereby helping to prevent secondary damage or traffic jams.

I believe that, as connected cars become widespread, there will be an increasing demand for the ability to use spatiotemporal data intuitively in real time. By fully exploiting virtual reality technology, I will develop an intuitive user interface that displays digital twins in an elegant and well-organized manner so that anyone will be able to easily use spatiotemporal data. I will promote data usage in a wide range of applications through this effort and will do my utmost to develop technologies that will close the digital divide.

■ **Profile**

Masaru Takagi received a B.E. in engineering and an M.E. and Ph.D. in information science and technology from the University of Tokyo in 2013, 2015, and 2018. He joined NTT Network Innovation Laboratories in 2018 and is engaged in a collaboration project with Toyota Motor Corporation. He developed the technology to efficiently collect the sensor data from connected cars using the edge computing platform (ICT platform). He is currently studying multi-agent mobility simulation as part of Digital Twin Computing technology. He received the Best Paper Nominee Award from the Association for Computing Machinery UbiComp 2014. He is a member of the Institute of Electronics, Information and Communication Engineers and Information Processing Society of Japan. He is interested in mobile terminals and owns more than 100 Android devices.

Cooperative Initiatives between Public and Private Sectors on Connected Cars and Creation of a Traffic-environment Data Portal

Naoki Iso, Ryuichi Inagawa, Ryo Takashima, Ayako Nakajima, Hisashi Kojima, Tatsuki Matsuda, Koichi Sato, and Ryosuke Noji

Abstract

NTT DATA is developing various services in the automotive field. Among its endeavors is an initiative that uses the government's promotional policies to build a social infrastructure through cooperation between the private and public sectors. This article presents NTT DATA's activities to create a traffic-environment data portal, which collects data on traffic environments and matches service providers with data providers. It also describes NTT DATA's activities and initiatives on the connected-car data platform conducted in collaboration with NTT Network Technology Laboratories and NTT Communications.

Keywords: traffic environment data, connected car, dynamic map

1. Importance of cooperative initiatives in the ever-advancing mobility society

Against the background of the need to solve various social problems and advances in technology, several mobility-related concepts and projects have been proposed and executed such as automated driving, mobility as a service (MaaS), and smart cities in which new value is created by putting those concepts into practice. Since the mobility-related market is expected to offer new business opportunities, it is a competitive area with both new and old information and communication technology providers pitted against each other, including automakers, information technology (IT)-platform providers, navigation-service providers, as well as related software/hardware vendors. These providers also need to cooperate to expand this market. Backed by the policies of the national government, local governmental organizations, such as municipalities, are also actively promoting smart cities that exploit the Internet of Things (IoT). Mobility is at the core of initiatives by which municipalities try to improve their regional transport systems.

Mobility is characterized by the existence of two different domains: a public domain involved in building social infrastructures, encompassing both institutional and hardware aspects, and a business domain of private companies providing advanced services. There are a number of initiatives in the public domain, such as technical development to reinforce Japan's competitive edge and vitalize the mobility market, and implementation of measures to enhance social receptivity to automated driving and other new services. In undertaking these initiatives, it is important to create a cooperation domain in which those involved in the development and provision of services can collaborate with the public sector so that the mobility of all segments of society can rapidly improve.

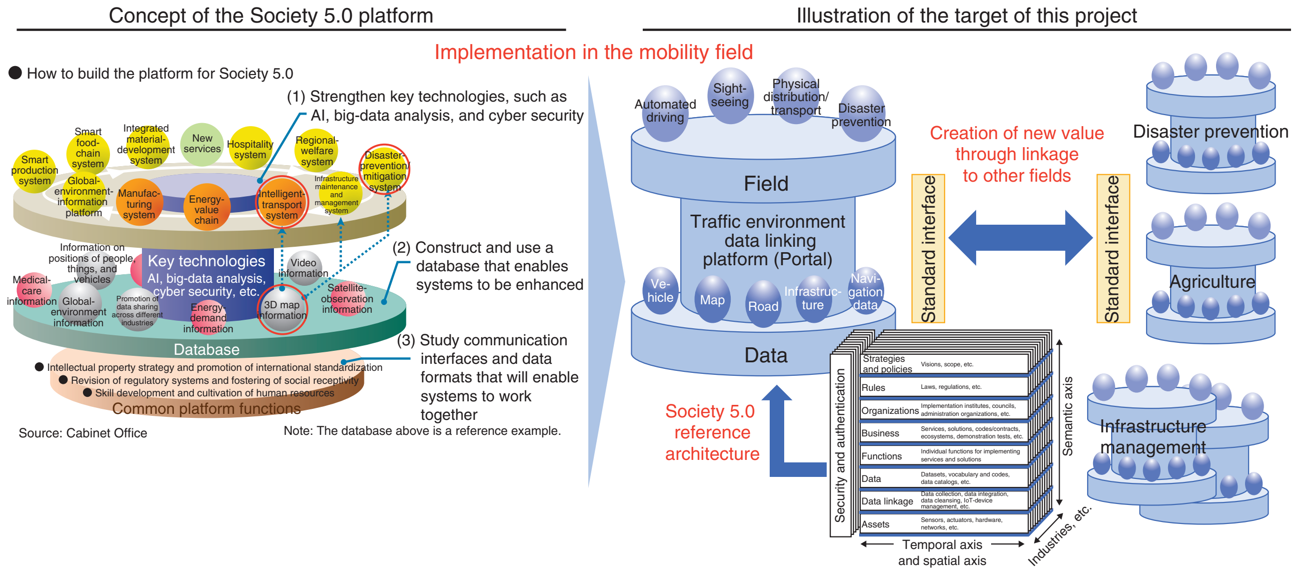


Fig. 1. Research on design and development of autonomous driving/drive-assistance architectures.

As well as being engaged in business areas that create new services, NTT DATA is working on initiatives that involve collaboration with the public sector and that are intended to enhance the overall quality of life throughout society. This article introduces some of NTT DATA's activities in two programs: the automated driving program, which is executed as part of the strategic innovation program (SIP) promoted by the Cabinet Office, Government of Japan, and a program entitled "Research for design and development of autonomous driving/drive assistance architectures," which was conducted by the Ministry of Internal Affairs and Communications in fiscal years 2018 and 2019.

2. Activities in the SIP automated driving system

The cross-ministerial SIP is "a new program in which the Council for Science, Technology and Innovation acts as the command organization and promotes scientific and technological innovations by managing the program across conventional ministerial and industrial boundaries." The program consists of two phases: the first phase (fiscal years 2014–2018) and the second phase (fiscal years 2018–2022). Various projects have been established to address the different challenges that automated driving presents. The first phase focused on autonomous cruising systems while the second phase is addressing automated driving (expansion of systems and services). In the first phase, we at NTT DATA worked on the multipurpose use of a high-precision three-dimensional (3D) road-surroundings map called a *dynamic map*. We conducted a demonstration experiment to investigate the possibility of using mobile-mapping-system data, which are created to produce a dynamic map for autonomous cruising, for the maintenance of communications and power facilities. The following describes the activities for the "Research for design and development of autonomous driving/drive assistance architectures" program. These activities are being undertaken in the second phase (**Fig. 1**).

A key to achieving Society 5.0, conceived by the government to solve social problems, is to link data individually held by the national government, municipalities, and private organizations to allow the use of data and provision of services across industrial and organizational boundaries. The goal is to dramatically increase the productivity of all activities through the highly integrated fusion of cyberspace and the physical space. Our study of the autonomous driving/drive assistance architecture is intended to enable the traffic-environment data used by vehicles and social infrastructures to be integrated and used in other fields. We are working on the three initiatives shown in Fig. 1.

The first initiative is to build and operate a portal site. This is the core of our activities. The dynamic-map and road-traffic data, which are produced for

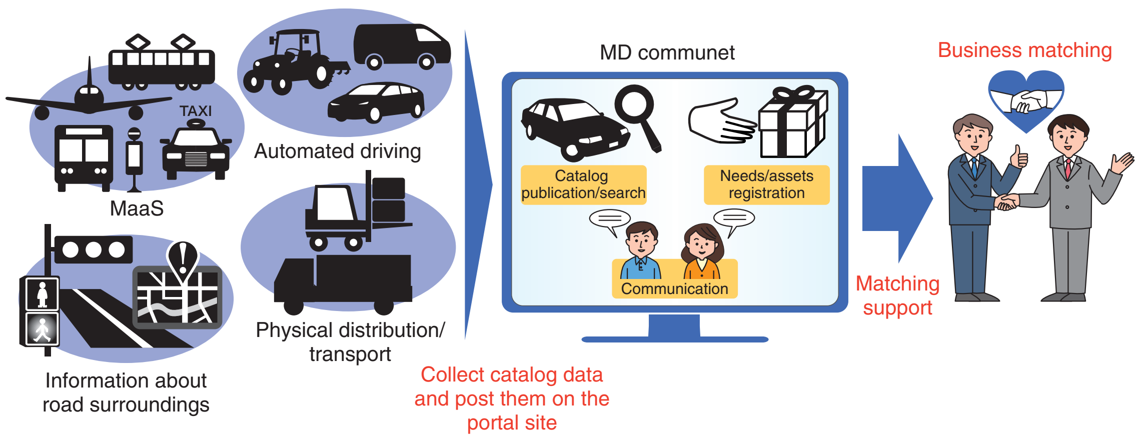


Fig. 2. Activities revolving around the traffic-environment data portal.

automated driving, and data sent from vehicle probes can also be used in other industries. Therefore, we are studying and promoting a mechanism with which these data can be shared securely and conveniently. We are also studying how the traffic-environment data can be integrated with SIP studies on other issues, such as disaster prevention and infrastructure management (**Fig. 2**).

The role of this portal is to serve as a business-matching site that functions as a data depository in the mobility field and helps create new businesses. The data are stored in the form of data catalogs. These data can be searched using a normal key search. They have also been analyzed and given semantic attributes using various methods so that data can be displayed in ways that will provide opportunities for encountering new data. For example, graphs created by automatic classification and the degree of proximity of similar data are displayed so that data users can discover or become aware of new data.

In addition to assisting business matching online, we are planning to provide such opportunities offline. For example, the portal site will provide a function that enables users to communicate with each other freely and carry information about offline events, both open and closed/semi-closed events, in which a limited scope of participants can hold business discussions. Therefore, we plan to launch a variety of activities that promote data utilization on the basis of our understanding of direct needs/assets of users, demand and supply of data, and trends in data usage.

We are also building a demonstration system to show how effective it is to combine different types of data. A wide variety of data are being collected in the Tokyo waterfront area, where a demonstration experiment of automated driving is being carried out, and in cities visited by many tourists such as Kyoto. Data can be used by different types of users for different purposes, such as sightseeing, disaster prevention, logistics, and commercial activities.

Our second initiative involves the construction of a demonstration system for a logistics service and a personal navigation service using automated-driving vehicles in the same Tokyo waterfront area (**Fig. 3**). Our third initiative is a demonstration experiment in an urban area (Kyoto City), in which service providers participate in a contest of app that uses data provided by both the public and private sectors.

Throughout the present fiscal year (2020), we will intensify our activities by making the portal site available to the public, publicizing our projects at various events, and extending invitations to a wide audience to participate in this portal.

3. Research for achieving a connected-car society

When services for connected cars are introduced, the volume of data exchanged by vehicles will increase dramatically. To ensure reliable, robust, and real-time communication, the Ministry of Internal Affairs and Communications is promoting studies on advanced use of frequencies. They include upgrading existing systems, appropriate introduction of new wireless technologies, combined use of different radio systems for intelligent transport systems (ITS), and a platform that enables efficient use of data. As part of these studies, NTT DATA has carried out, in

Fig. 3. Tokyo waterfront demonstration experiment.

collaboration with NTT Network Technology Laboratories and NTT Communications, research and demonstration experiments of technologies required in the coming era of connected cars. The study subjects have included high-speed data processing and a data-platform infrastructure needed for control and management of multiple radio frequencies for ITS.

To study the data-platform infrastructure, we developed several use cases that incorporated different types of vehicle behavior, classified them according to the following four criteria, and investigated the system architecture of the data-platform infrastructure.

(1) Immediacy: whether the use case needs to be implemented as quickly as possible or designed to be used for analyses and improving precision.
(2) Usage: whether the use case is mainly designed to provide services to vehicles or to interwork with external servers.
(3) Locality: whether the use case requires the collection of data over a wide area or can work even with data collected from a small area.
(4) Data volume: whether the use case collects only a small amount of data, such as location data, or a large amount of data, such as video data.

Study items for the above system architecture included allocation of functions to cloud servers and edge servers, connection configuration, and logical topology for each use-case category. We conducted a demonstration experiment based on these study items. The aim of the experiment was to identify implementation-related technical issues in providing services. The configuration of the data platform infrastructure for the demonstration experiment is shown in **Fig. 4**.

MQTTS (Message Queueing Telemetry Transport) was adopted as the communication protocol for vehicle-information collection and obstacle-information transmission. It is a representative communication protocol using the pub-sub model. We decided that it is suitable for collecting vehicle information because its header size is smaller than that of HTTPS (Hypertext Transfer Protocol Secure), thus is also suitable for transmission of IoT data. We adopted the dynamic-map specification for the map data used for identifying lanes and used the high-precision 3D map of the Japan Automobile Research Institute (JARI) test course (Jtown) (**Fig. 5**).

In this experiment, we examined two use cases: generation of obstacle-estimation information for each lane and collection of fixed-cycle continuously recorded images. A traffic pylon, which served as an obstacle, was placed on the test course. As vehicles drove along the course avoiding the traffic pylon, images taken with vehicle-mounted cameras were collected. We verified whether the obstacle can be estimated based on vehicle location and behavior information. The measured location information matched the map information at a lane-resolution level since Jtown is located in a field with a clear view of the sky, and JARI's high-precision 3D map was accurate. As a result, the behavior of avoiding the traffic pylon was successfully determined. However, it was not possible to distinguish obstacle-avoiding behavior from normal lane changes. The experiment clarified issues requiring additional study. For example, estimation of obstacle-avoiding behavior needs to take other factors into account, such as reduction in vehicle speed and behavior of multiple vehicles.

Based on the above investigation of a system architecture for the data-platform infrastructure and demonstration experiment, we identified the following technical issues that need to be resolved before implementation (**Fig. 6**).

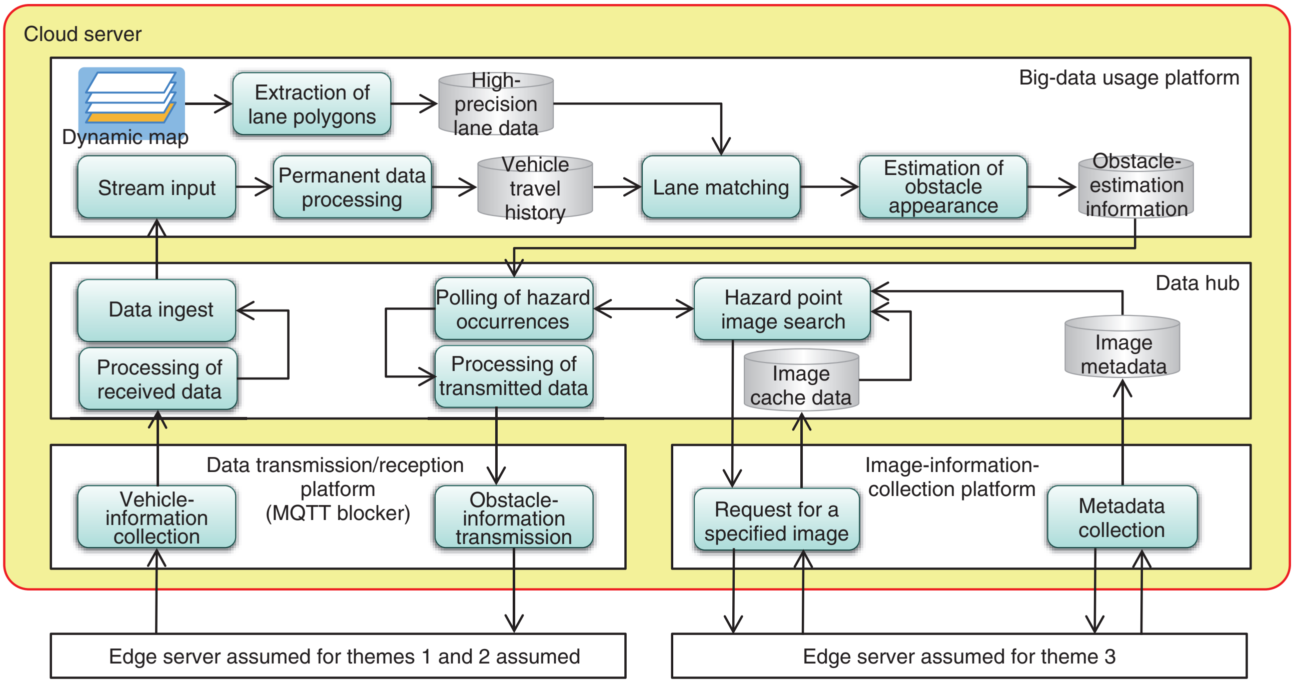


Fig. 4. Configuration of the data-platform infrastructure.

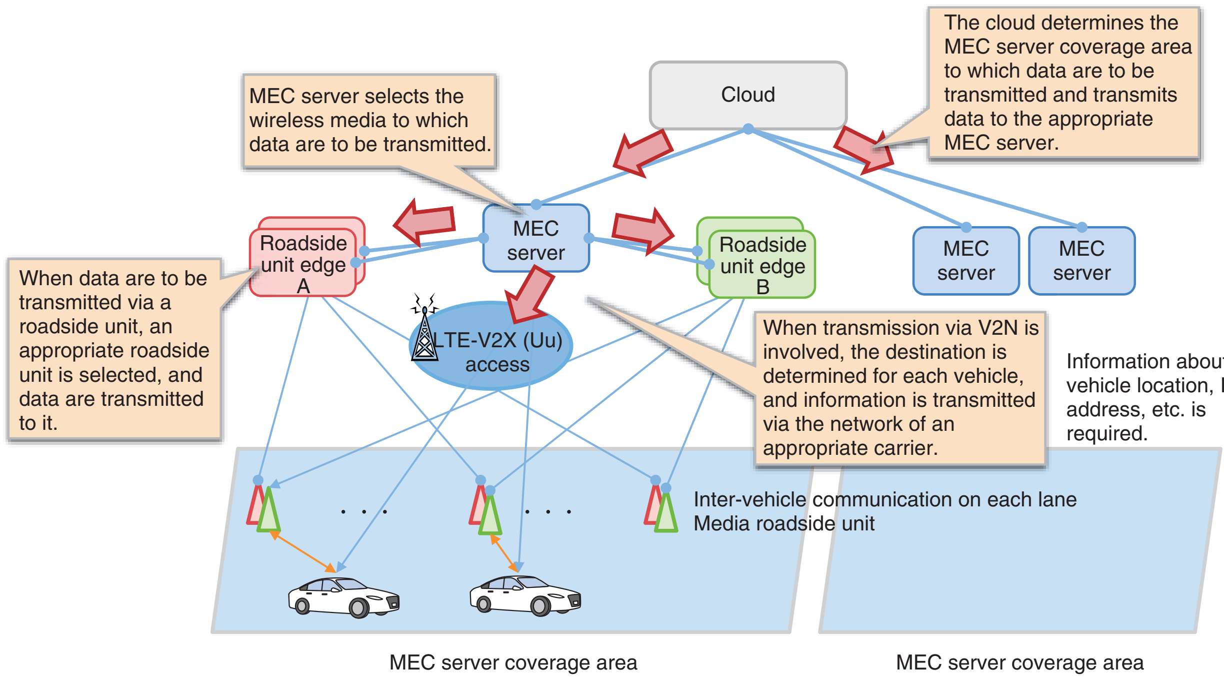
Fig. 5. Demonstration experiment field: Jtown.

- Information transmission to a specific area: It is necessary to transmit information to an appropriate target via an appropriate route.
- Collection of high-precision location information: High-precision positioning and a high-precision map are required to identify lanes.
- Reliability of generated information: A mechanism is needed to guarantee the reliability of information generated from AI algorithms for road safety, etc.
- Support of multiple communications carriers: It is preferable to be able to transmit information for providing services through any communications carrier.

If we are to achieve a highly optimized connected-car society through cooperation between the public and private sectors, it will be necessary to solve these problems through social implementation that involves a wide range of stakeholders.

4. Future activities

It will be mainly private companies that will drive development of new technologies and creation of innovation services in the automotive field. Society will demand that social problems be solved by



IP: Internet protocol
LTE: Long Term Evolution
MEC: multi-access edge computing
V2N: vehicle-to-network
V2X: vehicle-to-everything

Fig. 6. Technical issues for developing the necessary architecture.

combining various data and functions proposed by Society 5.0. For these reasons, it will be essential to create an environment that facilitates such activities. We also believe that it will not be possible to optimize mobility of all segments of society unless automated vehicles can access a common data platform at high speed via multiple means of communication.

To achieve such a society, NTT DATA, and broadly the NTT Group, will study what form a service platform that can serve as a social infrastructure should take through communication with owners of assets, such as vehicles and infrastructures, and service-developing companies, and undertake research and development to build a next-generation social infrastructure.

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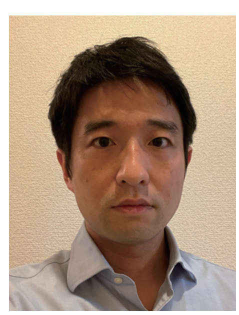

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Data-driven and Optimized Smart Cities Using Urban DTC

Chihiro Yamamoto, Ippei Shake, Satoshi Fukada, and Shinichiro Ueno

Abstract

Urban development assisted by information and communication technology has been attracting attention. For such development, it is necessary to promote, for example, advanced data usage, adapt to post-COVID-19 changes in lifestyle, and proactively prepare for diverse and fragmented lifestyles. This article describes NTT's efforts to create new value through urban Digital Twin Computing, which is based on the Innovative Optical and Wireless Network (IOWN).

Keywords: urban DTC, smart city, urban development

1. Introduction

To make smart cities a reality, many activities using information and communication technology (ICT) are being undertaken around the world. There are different approaches to achieve this goal. In an infrastructure-centered approach, for example, the focus is on energy-management systems. In a sensing-centered approach, sensors are installed throughout a city to visualize data and provide services based on these data. The Society 5.0 initiative and a data-driven society, approved by the Cabinet Office, Government of Japan, in 2018, call for the creation of a super-smart society by integrating cyberspace and the physical space through the maximum use of ICT while balancing economic development and the resolution of social problems in a human-centered society [1].

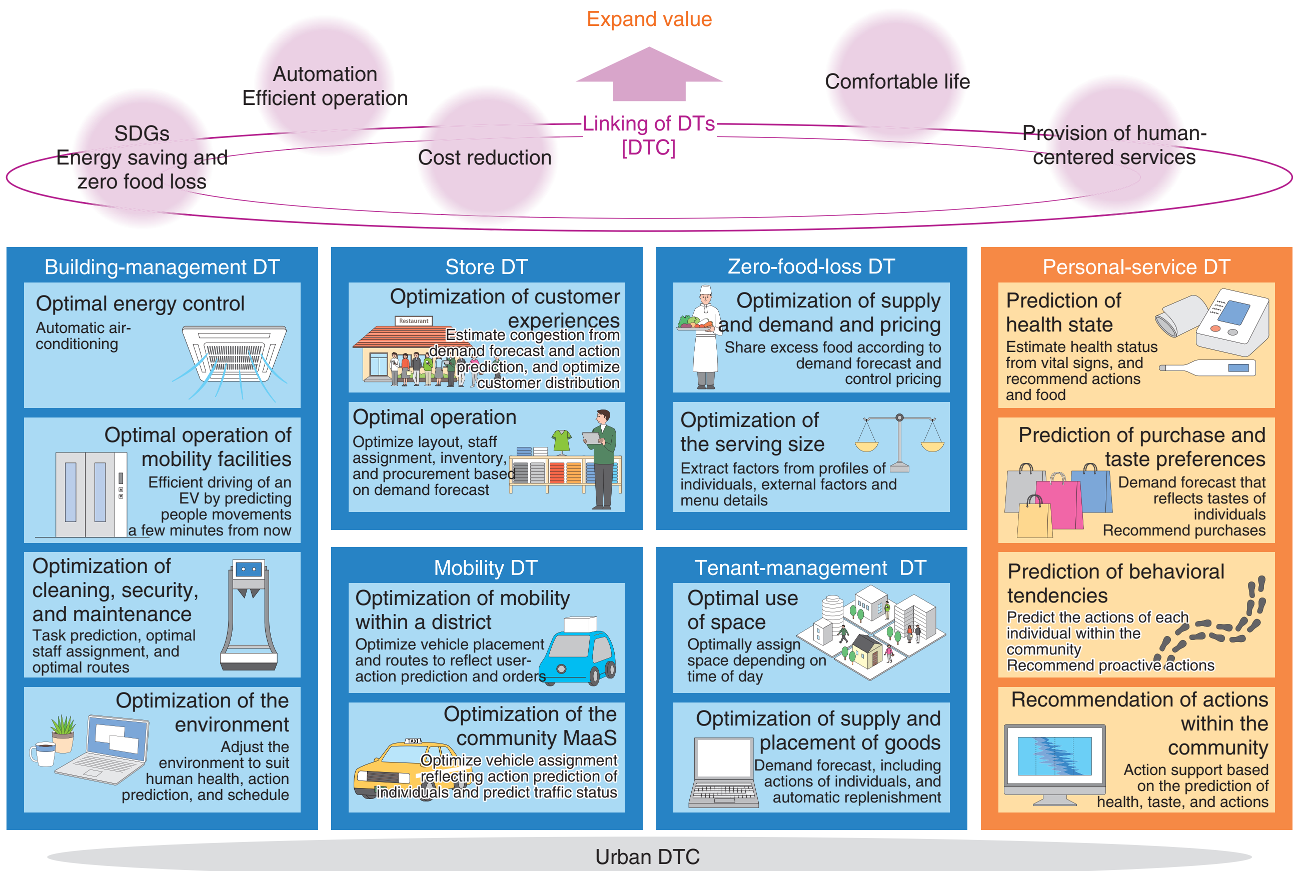
As the ongoing pandemic is forcing changes to our lifestyles, there is a strong demand from users for increasingly diverse services. Therefore, it is necessary to provide services adapted to accommodate these changes. Conventionally, services have been provided separately in each industry. As services that span multiple industries emerge, value provided by services will become more varied than before.

The NTT Group is working on urban Digital Twin Computing (DTC) in an attempt to provide new value by globally optimizing services provided in an urban community. It captures environments, objects, and people that are associated with each service provided in a community, creates their digital twins (DTs), and uses DTC [2] to link the DTs across different industries. By combining urban DTC with the 4D digital platform™, which is being developed separately, we aim to create a data-driven and optimized smart city, which both enhances the value of services made available by service providers in a district and offers unprecedented experiences for service users.

2. Data-driven and optimized smart cities made possible by urban DTC

Urban DTC is being developed in an actual urban redevelopment project in which the NTT Group is involved. By referring to discussions held among various providers who are pondering future urban development, we are studying how to achieve services that provide value, i.e., *desired user experiences (UX)*, that are in line with future lifestyles and workstyles and undertaking technical development based on this study.

For example, value-providing services (desired UX) for commercial and office functions can be classified into several categories: building management (building owners), store operation, tenant management, sustainable development goals (SDGs), and



EV: electric vehicle

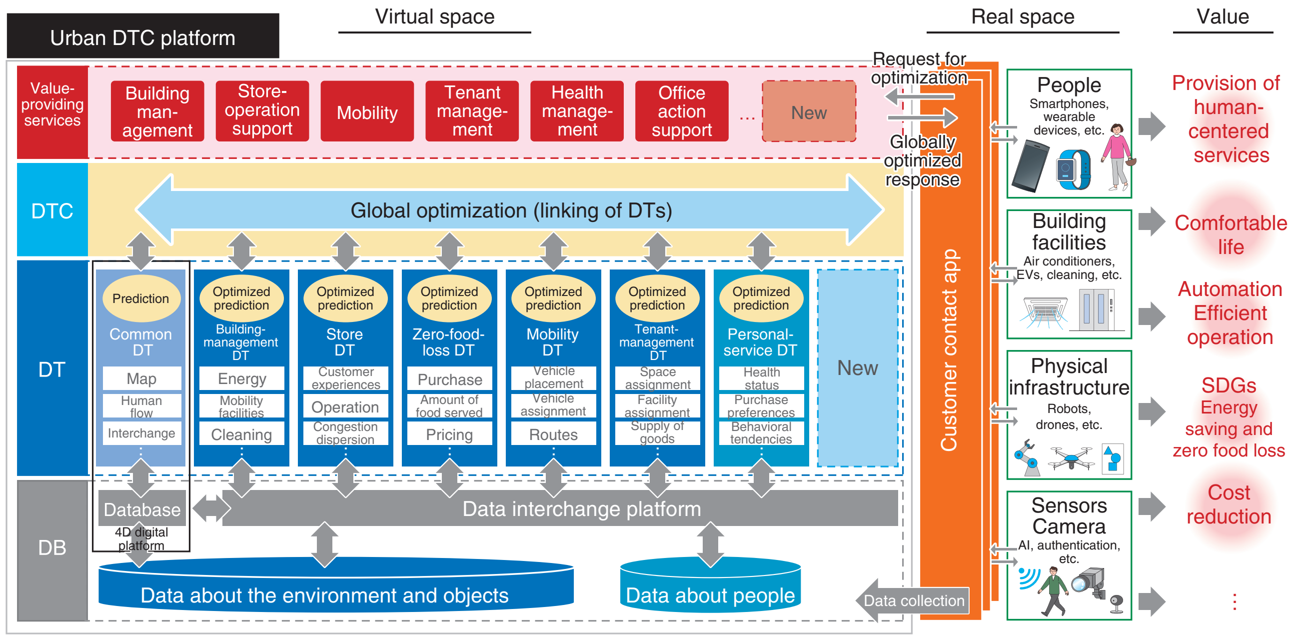
Fig. 1. Urban DTC.

common means of mobility in the community (**Fig. 1**).

- Building management: It is necessary to optimize energy control, which in turn increases the efficiency and reduces the cost of building and tenant management. This optimizes operation of mobility facilities, cleaning, security, and maintenance and makes the best use of the environment so that users can enjoy comfort and convenience.
- Store operation: It is necessary to optimize store operation and customer experiences to enhance customer satisfaction, estimate the health status and purchase preferences of individual customers, as well as have the ability to predict behavioral tendencies. This will allow more attentive and individualized services to be provided to customers than was possible.
- Tenant management: It is important to optimize space usage so that tenants can use the required space at the required time in light of the recent extensive adoption of working remotely. It is also necessary to optimize supply and placement of goods to provide office-subscription services, including goods and facilities.
- SDGs: It is important to optimize supply and demand and pricing of food to eliminate food loss. It is also important to optimize the size of servings to support good health, cater to individual tastes, and reduce food loss.
- Mobility: It is necessary to optimize systems that support mobility within a community and introduce a community mobility as a service (MaaS).

Implementation of these services requires the ability to predict the future by observing the state of each facility, people movement, as well as the surroundings of the district in real time.

A technology for predicting the future by capturing



DB: database

Fig. 2. Architecture of urban DTC.

people movements in a specific area as a mass (macroscopic approach) is currently being developed. If the movement of each individual can be captured (microscopic approach), it will be possible to precisely control the functions of the district [3]. Since multiple service providers, who influence each other, exist in a district, it is possible to expand the value of their services by linking and concatenating them.

These services can be developed in the following steps:

- Step 1: Create a model of the district and people movement and reproduce the model in cyberspace. Make predictions and conduct optimized simulation (through DTs).
- Step 2: Reproduce DTs of individuals. Reflecting microscopic people movements on the DT of the community improves the degree of precision of predictions and optimization.
- Step 3: Linking and concatenating DTs of individual services improves the degree of precision of interactions between services and globally optimizes services for all segments of community.

3. Architecture of urban DTC

Urban DTC links DTs of the environment, objects, and individuals. The architecture of urban DTC can be represented, as shown in **Fig. 2**.

Data on the community and people are collected from sensors installed in the community and worn by individuals. Various types of system data within the community and external open data are also collected.

The data-interchange platform stores collected data and converts their formats into the required formats. As well as data required by individual DTs, community datasets, such as maps, human flow, and traffic, which are commonly required by DTs, are also collected and given to DTs as necessary.

DTs create a model of elements (people, objects, and environment) that are required when pursuing specific, real-world objectives (UX) and reproduces them in cyberspace. In cyberspace, predictions and optimizations are made using artificial intelligence (AI) and simulation.

Urban DTC provides DTs, which operate in independent value-providing services, with functions that will be required when all segments of the community are taken into consideration. Global optimization is pursued so that new value can be created through linking DTs. Value-providing services control elements to reflect the results of optimization by DTs and DTC in the real world.

The correspondence between the architecture of

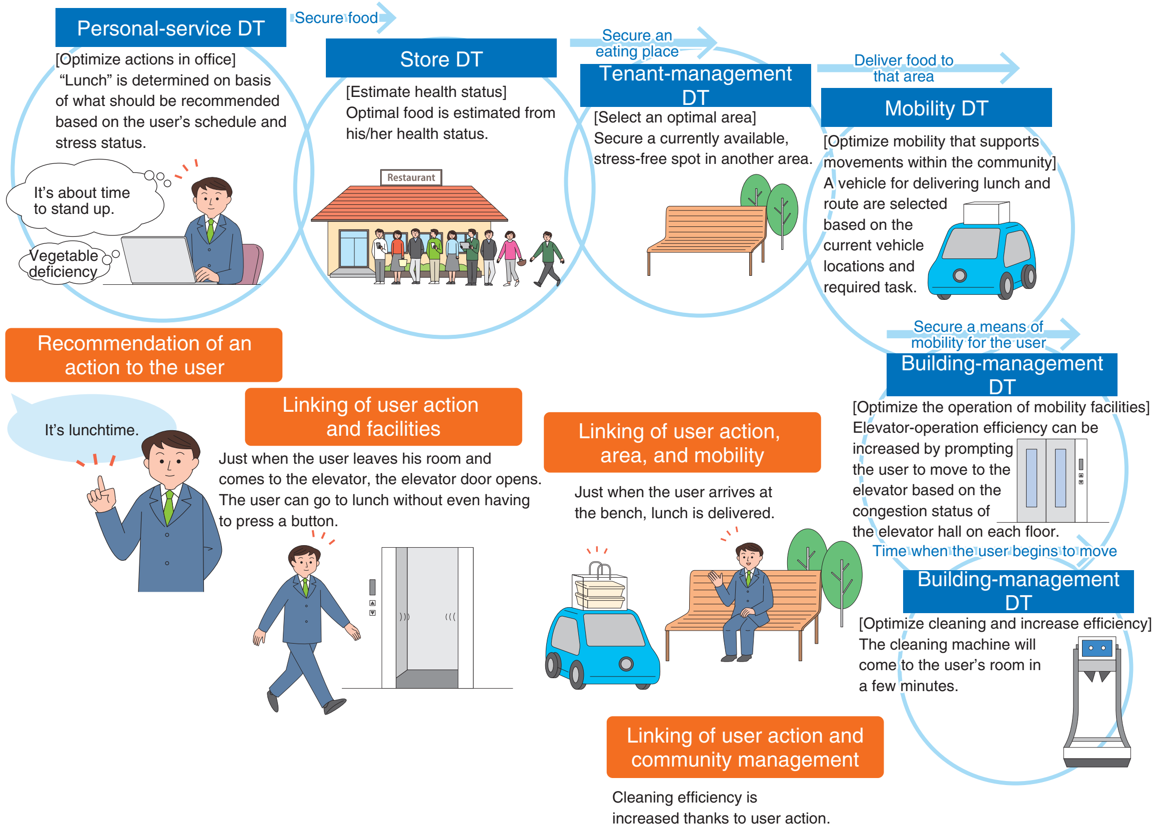


Fig. 3. Service example for a user in a community.

urban DTC and that of DTC described in the DTC white paper is as follows. The data-interchange platform and DTs in urban DTC correspond to the DT layer in the DTC white paper, and DTC in urban DTC corresponds to the digital-world-presentation layer.

4. Features of urban DTC

There are two main features of urban DTC: (1) value enhancement through linking DTs and (2) heightened prediction precision.

4.1 Feature 1: value enhancement through linking DTs

An example of a service that can be provided by concatenating DTs for community services is shown in **Fig. 3**.

(1) A personal-service DT predicts that a particular worker will need to eat at a certain time from his/her vital signs and schedule.

(2) A store DT and personal-service DT, linked to each other, select a dish good for the worker's health from the restaurant's menu. From the current and predicted congestion status of the restaurant, DTC determines that it is better for the worker to eat in another area than in this restaurant, requests a tenant-management DT to secure a spot in another area convenient for the worker, and requests a mobility DT to deliver food from the restaurant to that spot. DTC is aimed at global optimization covering several DTs, taking the worker's comfort, congestion status of the current restaurant, and operation of the restaurant into account.

(3) The personal-service DT predicts the worker's health status from his/her collected vital signs and selects an area that is optimal for his/her health status and globally optimal for the community.

(4) From the current locations of delivery vehicles and demand forecast, the mobility DT selects a vehicle most suitable for carrying lunch from the restaurant to the specified location. The selected vehicle goes to the restaurant.

(5) The mobility DT collects information about the operational status of the elevator that the worker has to take to get to the specified area and predicts the best time when he/she should take the elevator from information about the predicted congestion status of the elevator.

(6) A building-management DT finds from the operational status of security and cleaning that cleaning can be done efficiently if the worker moves within several minutes. Thus, the worker receives a suggestion at the right time that he/she should go and have his/her lunch. When he/she comes to the elevator, the elevator promptly arrives. Just when he/she arrives at the destination, food suitable for his/her health status is delivered.

For user actions that involve multiple DTs, DTC can link DTs to provide highly satisfying UX, something that cannot be achieved by a single DT.

4.2 Feature 2: heightened prediction precision (regarding zero food loss)

Another use of urban DTC is introduced below with an example of the zero-food-loss DT.

In Japan, 28.42 million tons of food and foodstuff are thrown away annually, and a stunning 6.46 million tons is edible food loss [4]. They are thrown away because they are unsold, returned, leftovers, or non-standard. The following measures can be considered for restaurants in the community to reduce food loss (**Fig. 4**).

(1) Optimization of foodstuff purchase based on demand forecast

Food loss at restaurants includes unsold food due to excessive production and disposal of ingredients because too much has been purchased. If demand can be forecast accurately and the amount of food purchased and the amount of food prepared are adjusted accordingly, both food loss and cost can be reduced. The prospective usage of restaurants in a community can be predicted from the trend of demand up to the previous day.

(2) Active sales of unsold food by optimal pricing

Even if demand can be forecast and the amounts purchased and produced are adjusted accordingly, an error may occur leading to unsold food. In other words, some food may unexpectedly remain unsold. Such unsold food can be actively sold by creating a *salable state* through optimal pricing based on real-time sales data and historical sales data (price, amount sold, etc.).

(3) Zero leftovers by optimizing the serving size

The largest proportion of food loss is the food left over from restaurant patrons. The main reasons for leftovers are excessive portions served by restaurants and too much food ordered by diners. It is necessary to consider means to avoid such excess. The serving size, type of dish, and amount of food ordered that results in leftovers can be predicted based on historical leftover trends and analysis of the amount of leftovers. The amount of leftovers can be reduced by adjusting the serving size, type of dish, and amount of food ordered according to the prediction.

Measures (1)–(3) indicate what DTs can do to achieve a specific goal (desired UX), i.e., zero food loss in this case. In accordance with the steps followed by urban DTC, a prediction is made by taking into account the human flow in the community on a macroscopic level in Step 1. After that, in Step 2, the degree of precision of this prediction can be improved by predicting the purchase behavior of individuals using services that are provided to individuals rather than to groups of people.

In Step 3, advanced services can be provided by concatenating DTs. For example, when a store DT is linked with a personal-service DT, it can predict the optimal serving size for an individual from his/her health status and what he/she has eaten, thus making it possible to focus on his/her health and reduce food loss at a stroke.

5. Future prospects

We will take into account the interest of landowners and business operators in a community, set a specific goal (desired UX) for value provision that reflects current problems and future prospects, and create DTs and DTC, which enables interactions among DTs, required for achieving the goal. We will study DTs and DTC in more depth in actual community development initiatives.

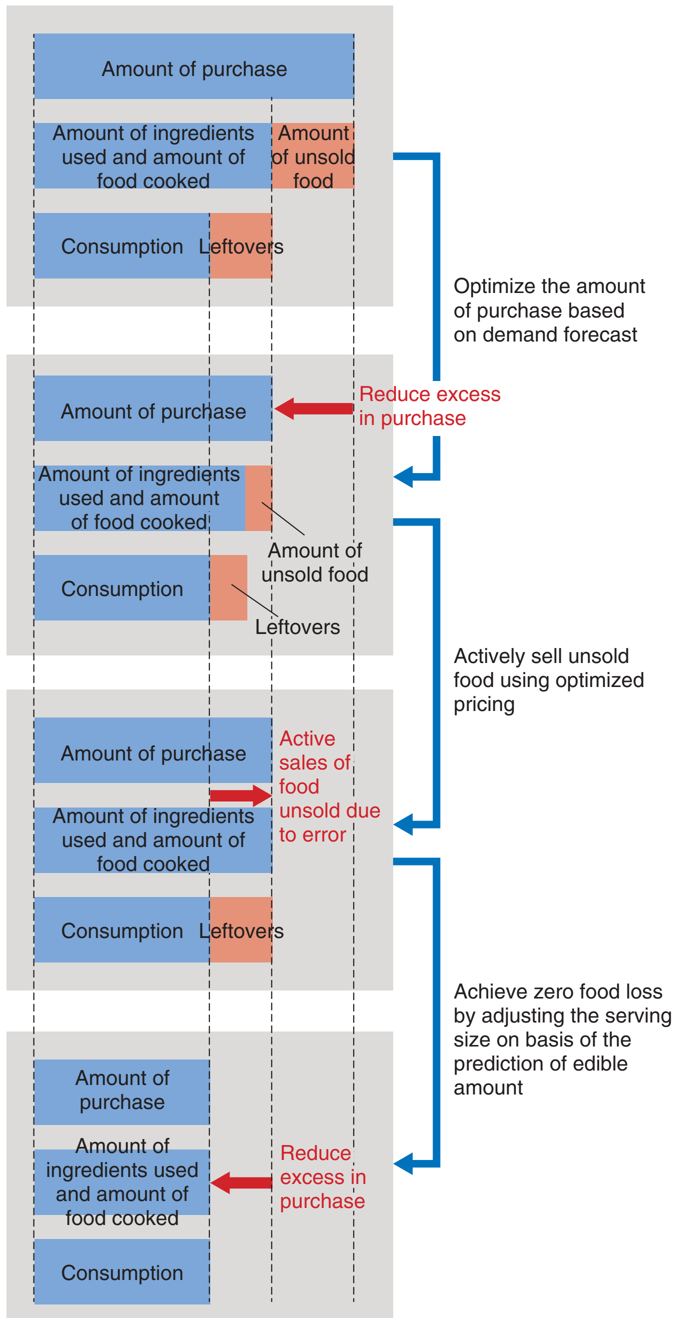


Fig. 4. Approach to zero food loss.

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Developing Smart Infrastructure Platform Based on the Smart Infra Business Concept

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Abstract

This article introduces the *Smart Infra Business Concept* promoted by NTT Infrastructure Network Corporation (NTT InfraNet) for using information and communication technology to *smartly* implement maintenance and management work related to the telecommunication infrastructure facilities (such as utility poles and manholes) of the NTT Group. This concept is not limited to the NTT Group's digital transformation but also forms the basis of the *Smart Infra Platform* to be implemented to solve problems faced by social-infrastructure companies. Three use cases for using the Smart Infra Platform are also introduced.

Keywords: facility-management information, smart maintenance, Smart Infra Platform

1. Current status of the NTT Group's telecommunication infrastructure

As mobile communication evolves to the fifth- and sixth-generation systems, the amount of data is expected to keep increasing. The traffic volume in 2030 is expected to be about 1000 times larger than that in 2010; thus, it will be necessary to increase the capacity of communication facilities in accordance with the increasing traffic volume. Accordingly, the demand for access networks connected to wireless base stations and core networks (relay networks) will also increase.

Construction of the telecommunication infrastructure facilities that support the NTT Group's telecommunication networks peaked from the 1960s to 1980s. About 20 years from now, about 85% of such facilities will be more than 50 years old. In short, facilities are aging.

To address this aging issue, communications via the aging metal cables will be switched to via optical cables. Due to advances in optical-cable technology and optical-communication technology, the amount of data transmittable via the same conduit has increased enormously. Therefore, it is not necessary to install additional conduits; however, it is necessary to continue to use the existing conduits. There is also the issue of the aging of the working population. As the working-age population declines in Japan, the number of maintenance personnel will decrease sharply; thus, there is an urgent need to improve the efficiency of facility maintenance and establish maintenance methods that do not require advanced skills or expertise.

NTT Infrastructure Network Corporation (NTT InfraNet) has been maintaining the telecommunication infrastructure facilities of the NTT Group using information and communication technology (ICT). For example, our smart maintenance business includes inspecting communication facilities by using a mobile mapping system (MMS) and developing and operating a geographic information system (GIS) based facility-management system called *Triple I+P* (Infrastructure, IT, Innovation Platform) linked with the map system GEOSPACE created by the NTT Group.

Table 1. Key concepts of sharing.

• Sharing operations: joint construction, inspection, and observation with other companies
• Sharing facilities: joint housing of equipment with other infrastructure companies
• Sharing data: joint management of underground-space database

Considering that the industry that operates other social infrastructure facilities is in the same situation as that in which the NTT Group is operating, we have launched the Smart Infra Business Concept to solve problems faced by social-infrastructure companies by implementing facility-management technology that uses ICT owned by NTT InfraNet, and are aiming to develop smart maintenance businesses for such infrastructure companies.

2. The Smart Infra Business Concept and Smart Infra Platform

2.1 The Smart Infra Business Concept

The issues related to facility maintenance involving social-infrastructure companies are listed below:

- Aging of the entire social infrastructure (40 to 60 years have passed since the peak of construction)
- Aging maintenance personnel (declining working population)
- Discrete operations by each company (business operations differ according to the owner)

NTT InfraNet has been promoting the Smart Infra Business Concept to create a new business based on the key concept of *sharing* = (*joint construction* + *existing facility utilization* + *openness*) as a guideline for initiatives in the infrastructure-facilities field (**Table 1**).

By sharing facility-management data possessed by each company, we aim to share infrastructure facilities with other companies by means such as joint housing of equipment and jointly carrying out operations that are commonly carried out by each company (such as construction, inspection, and on-site observation), which will contribute to reducing human resources and costs related to maintenance. It should be noted that the facility-management data mentioned here are not trade-secret information such as customer information or facility information but facility-location information and structural information (such as outward appearance) used for maintaining infrastructure facilities.

2.2 The Smart Infra Platform

Digital Twin Computing is a technology that reproduces the people and objects that make up the real world in cyberspace and combines them for conducting advanced simulations. Technology for reproducing information about the movements of humans and vehicles and their surrounding environment in real time in a *digital-twin world* is currently being researched and developed and expected to be introduced in the MaaS (mobility as a service) model, which includes autonomous driving. By constructing a static database on facilities of each infrastructure company in the digital-twin world and by planning and designing construction in cyberspace, the Smart Infra Platform enables infrastructure companies to determine the impact of the planned construction on the facilities of other companies in cyberspace, reflect that impact on actual construction work in the real world, and use this information for maintenance and equipment installation (**Fig. 1**).

The facility-management information of each company is currently managed on the basis of the map data of each company. If the original map data differ, the error between the map data and real wrold will also differ from company to company. As a result, when building a facility-management information database in a digital-twin world based on the facility-location information of each company, even if a facility is supposed to be in the same place in the real and digital-twin worlds, the facility locations in the two worlds will deviate by several centimeters to several meters.

The Smart Infra Platform collects high-precision three-dimensional (3D) geospatial information as a core function. It then corrects the facility-location information of each company on the basis of the high-precision 3D geospatial information and builds a digital-twin world with that information. As a consequence, the error between the digital-twin world and the real world is reduced to a standard deviation of within a dozen centimeters. However, the location information of old underground facilities may be inaccurate, and if such information is managed with the position relative to the road edge, because the layout of roads is often changed through city planning implemented after the facility was buried underground, the initial position of the facility may be

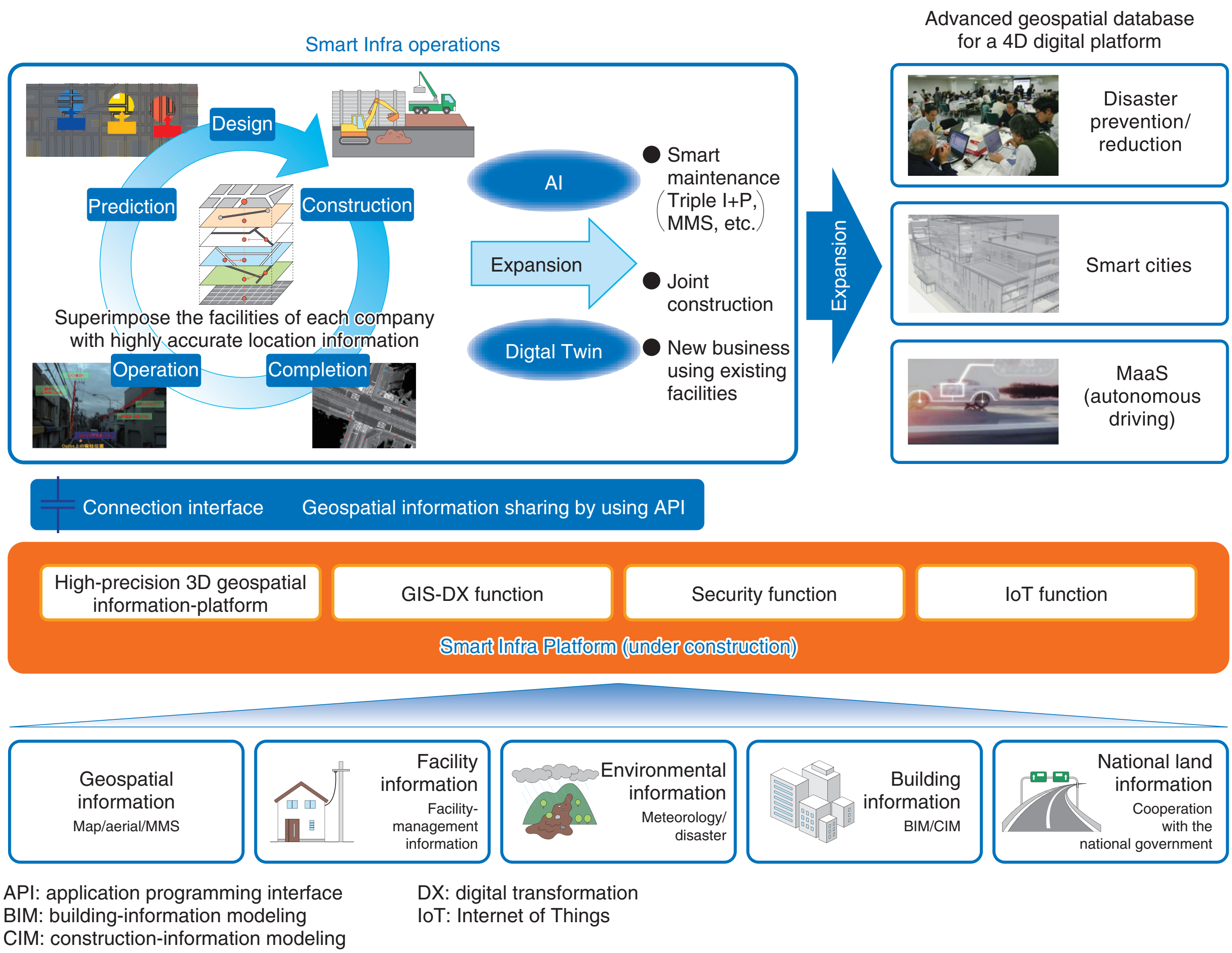


Fig. 1. Smart Infra Platform.

unclear. Through the Smart Infra Platform, when facility-location information is imported into the digital-twin world, the reliability information of the original data is also simultaneously imported; thus, when using the facility information in subsequent simulations, the risk associated with the simulation result can be determined. In addition, underground facilities cannot be viewed directly; therefore, a method for improving the reliability of unclear underground-facility location information is needed. To develop such a method, we are considering cooperating with NTT Access Network Service Systems Laboratories for their electromagnetic-wave search technology and AIREC Engineering for their underground-conduit-search technology.

2.3 Use cases concerning Smart Infra Platform

The following three use cases are identified related to on-site observation of construction, which is one type of facility-management operation.

(1) Automatic determination of presence or absence of a company's underground facilities within the construction area

When a construction contractor requests an operator of infrastructure facilities to carry out excavation work, the presence or absence of underground facilities of various companies in the construction area is determined. The operator confirms the results and reports the results to the construction contractor. The determination standard can be changed on the basis of the reliability of the location information of the underground facilities, and that determination can be fully automatic in areas with high reliability.

(2) 3D display of underground facilities for consultations regarding construction

Facilities buried in an underground space are displayed in 3D during consultations on construction work with a construction contractor. Currently, plan views, vertical profiles, and cross-sectional views are used during consultation. Displaying the underground space in 3D makes it possible to investigate high-risk points from various angles. In the future, this capability will lead to the implementation of remote construction consultations.

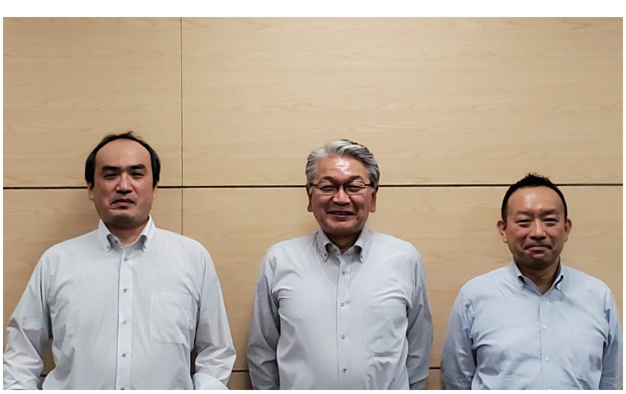
(3) Augmented-reality display for supporting on-site observations

On-site observers at a construction site confirm the impact on a company's facilities by checking drawings of those that are buried underground. It is possible to improve the accuracy of predicting high-risk points by superimposing 3D information about the underground facilities on the site image and displaying the superimposition result as an augmented reality (AR) image. In the future, it will be possible to install remote cameras at the construction site and generate AR images that combine on-site remote images and 3D images of underground facilities, which may lead to implementation of remote observation.

3. Future directions of the Smart Infra Platform

The Smart Infra Platform can contribute to *smarter* operations concerning digital transformation in each company; however, it can be even more effective by linking not only a company's information but also linking to the facility-management data of other companies. By linking with the construction-related information of other companies, joint construction will be possible when different companies are constructing facilities in the same place, freeing different companies from having to excavate and re-pave the same area several times. As a result, it is possible to contribute to a better society by reducing construction costs and the impact of construction work on the general public (namely, road users) by shortening the construction period. By enabling further openness, the Smart Infra Platform can be used not only to share information between infrastructure companies but also provide danger-prediction information for autonomously driven vehicles.

Sharing facility-failure information (i.e., failure area and failure factors) in the event of a large-scale natural disaster and prioritizing inspection areas of a company in consideration of the failure situation of other companies will make it possible to understand failure situations with higher accuracy and formulate an efficient recovery plan.



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High-precision Management of 3D Location Information of Underground Facilities by Using High-precision 3D Geospatial Information

Shigeru Chiba, Akihiko Minamino, and Tomoki Suizu

Abstract

By enabling the management of underground facilities with high-precision three-dimensional (3D) location information, the Smart Infra Platform was developed by NTT Infrastructure Network Corporation (NTT InfraNet) to improve the efficiency of facility-management operations, such as improving the efficiency of inquiries about facilities and reducing the number of on-site observations during construction. However, most underground facilities are managed with drawings created during the design of the facilities; thus, facility-location information is not provided. To provide geospatial information for underground facilities, it is necessary to create high-precision 3D geospatial information that represents the real world with high precision then identify the location of the underground facilities and give accurate 3D location coordinates.

Keywords: high-precision 3D geospatial information, geospatial information, Smart Infra Platform

1. Issues concerning underground facility management and the Smart Infra Platform

1.1 Issues concerning management of underground facilities

Currently, underground facilities are managed with plan and cross-sectional views, and those views are stored in the form of drawings created during facility design. Most of such information is generated by converting computer-aided design (CAD) drawings to image data, which do not contain geospatial information indicating the burial location. A road-ledger map is generally used as a background map showing the location of facilities. However, it is difficult to accurately identify the location of facilities due to changes to, for example, the current road layout from that when the facilities were designed. During construction work, it is therefore necessary to bring the drawings to the construction site, where the maintenance personnel of the infrastructure company can compare the drawings with the site to determine the location at which the underground facility is buried. To identify the location of underground facilities in this manner, it is necessary to use the experience and expertise of skilled people to estimate the burial location on a facility-by-facility basis. To respond to the shortage of experienced maintenance personnel and further improve operational efficiency, it is necessary to improve the conventional means of managing underground facilities through digital transformation (DX). As a first step in this DX, it is necessary to manage the location of underground facilities in the real world with high accuracy.

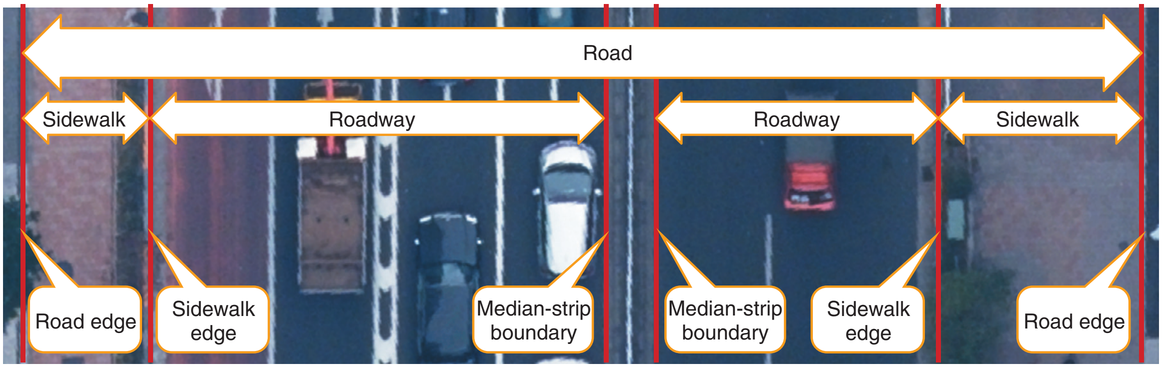


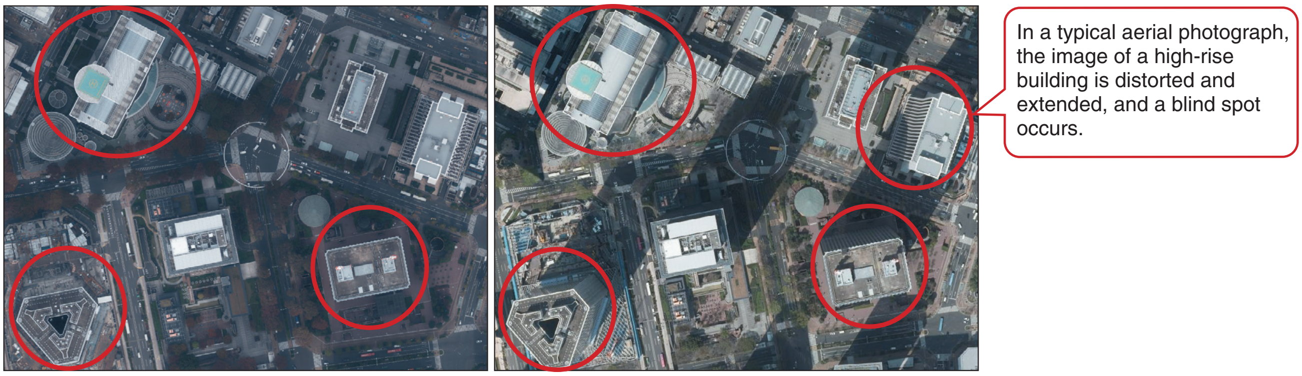
Fig. 1. Content of road boundaries acquired as high-precision 3D geospatial information.

1.2 Underground facilities on the Smart Infra Platform

The Smart Infra Platform manages the locations of underground facilities with computer-computable three-dimensional (3D) geospatial information, namely, latitude, longitude, and altitude, which mark burial locations in the real world. It uses the 3D geospatial information of underground facilities, excavation areas, and depth information to determine the presence of underground facilities and the impact of the excavation on nearby facilities in that 3D space. It is also possible to reduce the operational burden on on-site maintenance personnel by converting the highly accurate location information on underground facilities into a format that can be represented in virtual reality and mixed reality. Accordingly, the 3D geospatial information on underground facilities must have a strong positional correlation with the real world. The tolerance error between the location of real-world underground facilities and that of managed underground facilities is expressed using the map-information level, an index that indicates map-representation accuracy of numerical topographic map data and average total accuracy of the data inside the numerical topographic map. Underground facilities managed using the Smart Infra Platform has a map-information level of 500, the error (accuracy) of which is within a standard deviation of the horizontal position of 0.25 m and standard deviation of the elevation point of 0.25 m. This accuracy is similar to the positional accuracy of the road-ledger map, and it is sufficient to determine the relative position of not only underground communication facilities but also other underground facilities such as of electricity, gas, and water and sewage. However, current underground facilities are managed via drawings without location information; therefore, a site must be surveyed to incorporate highly accurate location information having a map-information level of 500. This survey is prohibitively costly as well as being unrealistic because the site has to be excavated. To solve this problem, NTT Infrastructure Network Corporation (NTT InfraNet) is developing a location standard and high-precision 3D geospatial information to ensure drawings of underground facilities have high positional accuracy with a map-information level of 500.

1.3 High-precision underground facility management using high-precision 3D geospatial information

High-precision 3D geospatial information consists of high-precision location and altitude data of manholes in roads, road boundaries, and entrances and exits to underground facilities in the real world (**Fig. 1**). The reason that high-precision 3D geospatial information consists of such pieces of information is because they are easy to measure using aerial photographs and a mobile mapping system (MMS) because they are exposed on the ground surface in the real world, and these locations cannot be easily changed (i.e., they stay at the same location for a long time). By creating high-precision 3D geospatial information from aerial photographs and an MMS that satisfies the map-information level of 500, the original positional accuracy is improved through the creation of high-precision 3D geospatial information with this map-information level. Using manholes and road boundaries in this high-precision 3D geospatial information as a positional reference and by aligning the position of the manholes and road boundaries in the drawings of underground facilities, it is possible to incorporate highly accurate location information and



High-precision, high-resolution aerial photograph (ground resolution: 5 cm)

General aerial photograph (ground resolution: 16 cm)

Fig. 2. Differences in aerial photographs due to different types of photography.

altitude into the drawings. Moreover, if underground facilities already have coordinates as geospatial information, by selecting data with the appropriate shape and size for the type of underground facilities from the high-precision 3D geospatial information of manholes and by matching the facilities that are closest, it is possible to provide highly accurate position and altitude information on underground telecommunication facilities.

2. Creation of high-precision 3D geospatial information

2.1 Means of creating high-precision 3D geospatial information

To create high-precision 3D geospatial information, it is first necessary to survey the real world with high precision. Unlike general surveying, it is necessary to measure a wide area, so measurement can be roughly classified into two types. One type involves surveying with high-resolution and high-precision aerial photographs. Such photographs are suitable for initial data development because the data-acquisition cost is determined by the capturing area regardless of the length of the road to be measured. However, it is impossible to survey sections that cannot be photographed, such as under overpasses and railways. Therefore, it is impossible to create high-precision 3D geospatial information for such sections. The other measurement type involves using an MMS for surveying. Since an MMS involves measuring an area from a roadway using laser scanners or stereo cameras mounted on vehicles, it is possible to acquire data on areas below overpasses; however, it may not be possible to acquire data on sections of sidewalks that cannot be seen from the roadway. Moreover, the data-acquisition cost depends on the road length, so it is necessary to narrow the number of roads from which data are to be acquired, and an MMS is suitable for data acquisition for maintenance operations. In our latest case at NTT InfraNet, we used high-resolution, high-precision aerial photographs for the initial development of high-precision 3D geospatial information on the 23 wards that make up central Tokyo.

2.2 Creation of high-precision 3D geospatial information using high-precision, high-resolution aerial photographs

High-precision, high-resolution aerial photography does not allow for ortho-processing (distortion correction) based on a conventional digital elevation model (DEM)*1. Instead, it is used to construct a high-precision and high-definition digital surface model (DSM)*2 and carry out geometric-correction processing of captured image data with the DSM. An aerial photograph taken in this manner is called a *true ortho* (i.e., a perfect orthographic image), and unlike conventional aerial photographs, it is not affected by the distortion of high-rise buildings, so it is easier to obtain the location and shape of ground structures (**Fig. 2**). In such an aerial photograph, 5 cm on the ground is treated as one data unit, so highly accurate

*1 DEM: A digital dataset in three coordinates representing the elevation of the ground surface, excluding buildings and trees.

*2 DSM: A digital dataset in three coordinates consisting of the elevation of the ground surface and that of the top surfaces of the natural and artificial features above it, including buildings and trees.

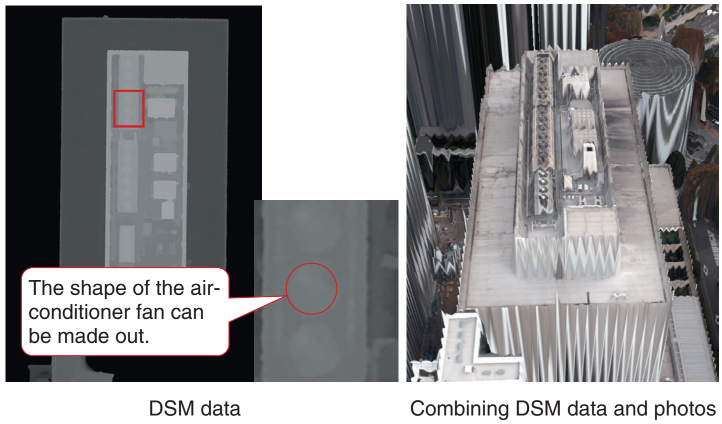


Fig. 3. Representation of height by using a DSM.

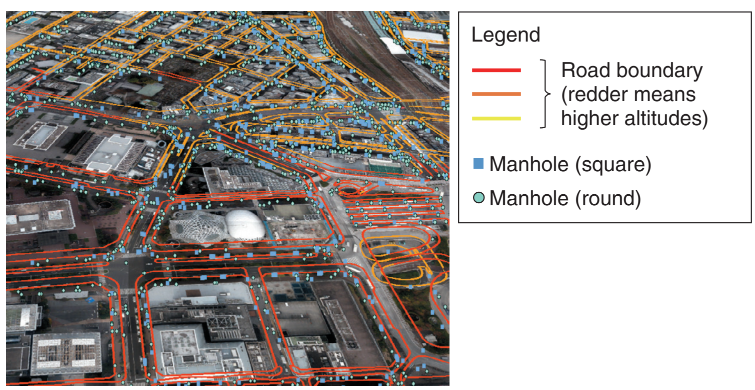


Fig. 4. Representation of high-precision 3D geospatial information.

location information and altitude can be obtained. Its resolution is high enough to show the detailed shape of above-ground structures such as an air-conditioner fan installed on the roof of a building (**Fig. 3**).

High-precision 3D geospatial information with a map-information level of 500 can be created by stereo-drawing the shapes of road boundaries, manholes, and entrances and exits to underground facilities by using high-precision, high-resolution aerial photographs (**Fig. 4**).

2.3 Data structure of high-precision 3D geospatial information

High-precision 3D geospatial information is defined in Environmental Systems Research Institute, Inc. (ESRI)'s shapefiles, and the data structure differs according to data type such as road boundaries, manholes, and entrances and exits to underground facilities. The graphic information is defined as a 3D graphic, and the information used for aligning underground facilities is defined as attribute information. Road-boundary data are used to align underground facilities, such as gas pipes, which are located by offsetting the distance from the road boundary. Therefore, boundary-type and boundary-identification attributes are used to select the appropriate data for alignment. Manholes are used to align underground facilities with exposed facilities above ground, such as for telecommunications, electricity, and water and sewage services. Manhole-shape and -size attributes are therefore used to select the appropriate data for alignment (**Table 1**).

The management identifier and date of data creation/update for managing high-precision 3D geospatial information as well as identification information for high-precision, high-resolution aerial photographs

Table 1. Overview of data containing high-precision 3D geospatial information.

Data type	Graphic information	Examples of attribute information	
Road boundary	3DPolyline	Boundary type • Road edge • Sidewalk edge • Median strip, etc.	Boundary identification • Identifiable • Some unidentifiable • Linear-prediction impossible
Manhole	3DPoint	Type of manhole • Round • Square	Size of manhole • Diameter • Length • Breadth
Entrance/exit to underground facilities	3DPoint 3DPolygon	Type of entrance/exit • Railway • Subway (train) • Commercial facility • Passageway	

referred to when creating high-precision 3D geospatial information are defined as common attribute information. Such information is used for future maintenance of high-precision 3D geospatial information. The advantage of choosing ESRI's shapefiles is that the specifications are open. As a result, data can be easily exchanged with other systems and converted to formats such as GeoJSON (geospatial data interchange format based on JavaScript Object Notation), which is widely used in open-source systems, and DXF (Drawing Exchange Format) and DWG (Drawing), which are used in architectural CAD.

3. Future of high-precision 3D geospatial information

NTT InfraNet is currently creating high-precision 3D geospatial information of the 23 wards of central Tokyo, and it is scheduled to be completed by the end of November 2020. We then plan to expand its development to ordinance-designated cities by the end of FY2021. For this expansion, we are aiming to further improve the efficiency of the maintenance of high-precision 3D geospatial information. We are currently verifying technologies using artificial intelligence (AI), including the automation of manhole detection, automatic road determination, and automatic boundary extraction from high-precision, high-resolution aerial photographs. AI makes it possible to not only reduce the cost of data creation for high-precision 3D geospatial information but also shorten the period for data maintenance, which will make the similarity of the data with the real world more reliable. Although we are currently using a data-creation method that uses high-precision, high-resolution aerial photographs, we are considering using another data-creation method that uses an MMS to take into account data maintenance.

The ultimate goal of developing high-precision 3D geospatial information is not only to identify the location of underground communication facilities but also all underground facilities owned by electricity, gas, and water/sewage companies and share that information with them. If underground facilities of all companies had high-precision location and altitude based on high-precision 3D geospatial information, the location of underground facilities could be handled in common by all those companies. As a result, facilities management and maintenance carried out by individual companies can be integrated, and that integration will lead to the implementation of *smart maintenance*, i.e., efficiently and effectively manage facilities through DX.

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Triple I+P: A GIS Platform for Advanced Geospatial Data Management

Hirotaka Yoshida, Makoto Ise, Toshihiko Sekiguchi, and Chie Kamachi

Abstract

NTT Infrastructure Network Corporation (NTT InfraNet) centrally manages an enormous amount of telecommunication infrastructure owned by the NTT Group. Accordingly, we have developed proprietary middleware that controls various open-source software for managing the location and attribute information about infrastructure facilities and built a geographic information system platform called *Triple I+P* (Infrastructure, IT, Innovation Platform). Triple I+P enables users to freely set, for example, drawing settings, data input and output, and combinations of databases and tables without having to carry out programming. By constructing and using a facility database based on Triple I+P, we are promoting digital transformation of facility-management operations inside and outside the company. This article introduces technologies for supporting Triple I+P and some of its use cases.

Keywords: GIS platform, digital transformation, open source software

1. GIS platform

A geographic information system (GIS) comprehensively manages, processes, and visualizes data related to location information (geospatial information) in a manner that enables advanced analysis and quick decisions. As shown in **Fig. 1**, each type of information is stored on a separate layer, and the various types of information are superimposed and displayed geographically in a unified manner by using geospatial information as a key. It is possible to obtain a bird's-eye view of the information, which will contribute to improving operational efficiency, promoting business collaboration, and speeding up the provision of information.

NTT Infrastructure Network Corporation (NTT InfraNet) has developed a GIS platform called *Triple I+P* (Infrastructure, IT, Innovation, Platform) for managing facilities by integrating information on NTT Group's infrastructure facilities and external public data.

2. Features of Triple I+P

The features and unique functions of the software configuration of Triple I+P are introduced as follows.

2.1 Adoption of open-source model

This platform extends the open-source model and is based on core software that controls a large number of open-source-software (OSS) programs. As a GIS environment, we can benefit from using OSS, which is used by an overwhelming majority of users and where the latest technology is constantly incorporated. Using OSS also makes it possible to unlock hidden parts of the databases and avoid vendor lock-in.

2.2 Degrees of freedom by non-programming

Management of telecommunication facilities requires multiple geospatial calculations for route management, such as extracting facilities around a route. Triple I+P enables attribute search and geospatial-distribution visualization combining various

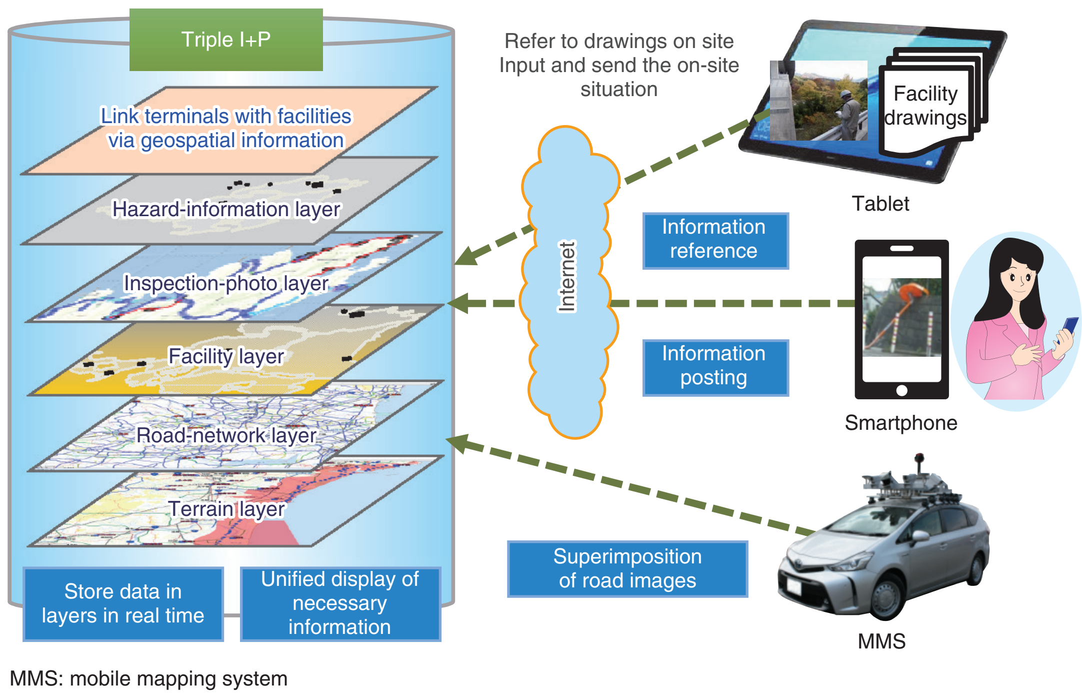

Fig. 1. GIS platform (Triple I+P).

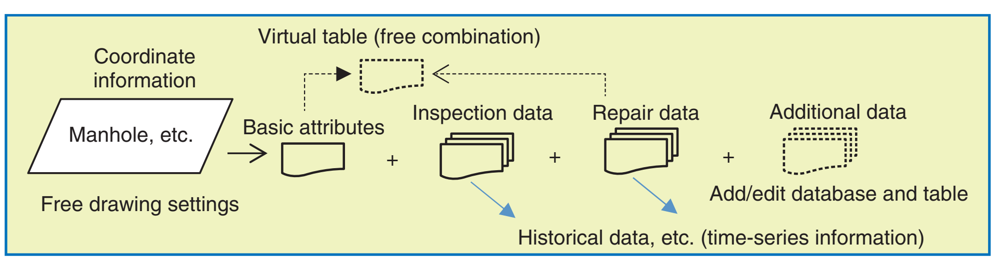

Fig. 2. Geospatial search across different databases under various conditions.

conditions, such as and/or/ = /not =/ ≥ / ≤, for related data. In addition to these degrees of freedom in searching, multiple degrees of freedom in geometric drawing and database definition are also provided (**Fig. 2**).

Regarding the degrees of freedom of a database, functions such as (i) combining multiple databases without programming and (ii) adding multiple tables to a basic table for managing coordinates—based on arbitrary key information specified by the user without writing SQL (Structured Query Language)—are available. Therefore, time-series management of facility inspections and repair history are possible. It is also possible to virtually treat different independent databases as one database, aggregate and search data under various conditions, and add attribute information without modifying the table in which basic information is stored.

For example, even if the data related to manholes exist independently in a fixed-asset database, inspection/repair database, database of facilities installed in public geospaces, or other databases, it is possible to specify conditions across databases without physically merging each database and search for manholes that match those conditions. Moreover, when historical data concerning inspections and repairs related to manholes are added, the data can be added without duplicating the basic data, so time-series management

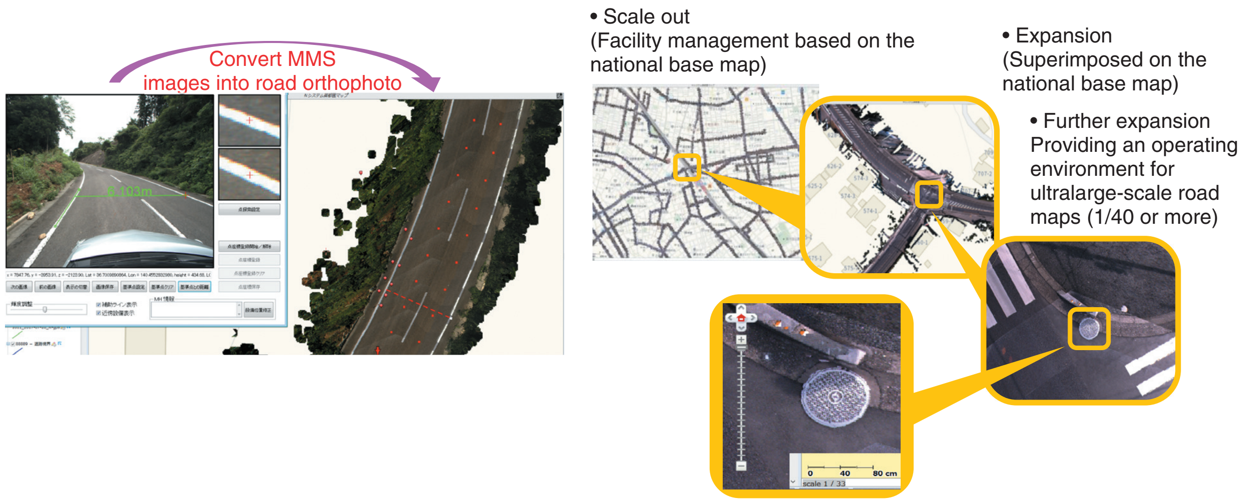

Fig. 3. Generation of road map by using MMS.

is possible without changing the base data.

2.3 Incorporation of external information

Triple I+P has functions for supporting standard protocols for sending and receiving geospatial data and multiple external data-exchange formats (e.g., Shape, WMS (Web Map Service), and KML (Keyhole Markup Language)) as well as for geocoding (i.e., converting a place name and address into its latitude and longitude coordinates) even in arbitrary-format data. Data can therefore be acquired from various external geospatial databases in real time, processed in an easy-to-use manner, and used.

For example, original data possessed by the Japan Meteorological Agency, such as earthquake and rainfall information, are acquired and processed in real time, damage to facilities is predicted, facilities to be inspected are selected, and damage to those facilities is predicted several hours ahead. Moreover, information disclosed by local government and information disclosed temporarily is acquired in real time by designating it as acquisition source by users.

3. Use cases

3.1 Application to facility management

Thus far, we have managed a huge amount of infrastructure facilities using paper drawings. Using the advanced display, search function, external-data aggregation function, and three-dimensional (3D)-measurement function of Triple I+P makes it possible to manage facility data collectively and use the data for digital transformation of facility-management operations.

(1) Absolute-coordinate conversion of facility-record drawings by using 3D-measurement technology

Improving the efficiency of facility-management operations necessitates accurate location information, that is, technology to acquire absolute coordinates with high accuracy is essential. If an orthophotograph (road orthophoto) obtained through the orthographic-projection conversion of a frontal stereo image captured using our mobile mapping system (MMS) [1] is spread on a national base map, it is possible to obtain a live-action road map with absolute location accuracy. This road map corresponds to an ultralarge-scale drawing with a scale of 1/40 or more and is handled using the large-scale-display function of Triple I+P (**Fig. 3**). By superimposing a facility-record drawing in portable document format (PDF), which is converted from an image of a paper drawing, on this road map and digitally tracing an underground route on the drawing, it is possible to impose absolute coordinates on the drawing and digitize the underground facility (**Fig. 4**). By importing the incidental information about facilities recorded on the paper drawing as attribute data and using that information and the manhole positional coordinates obtained by running the MMS, vertical profiles and cross sections of the manhole can be automatically generated.

(2) Promotion of smart maintenance through comprehensive reform of facility-inspection operations

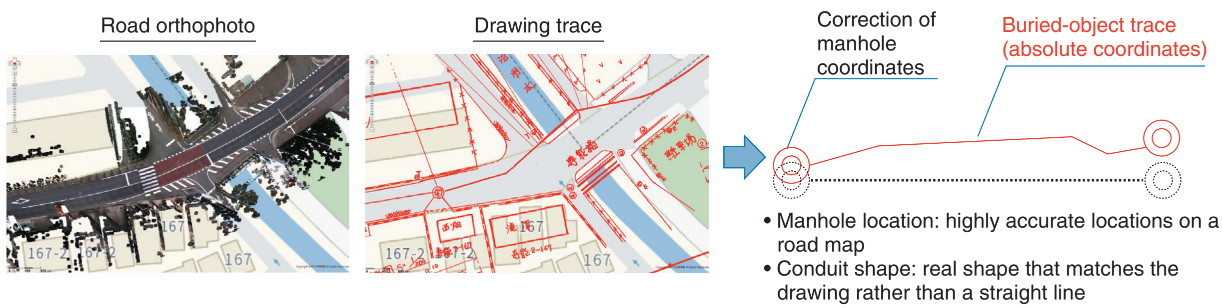

Fig. 4. Absolute-coordinate conversion of paper drawings.

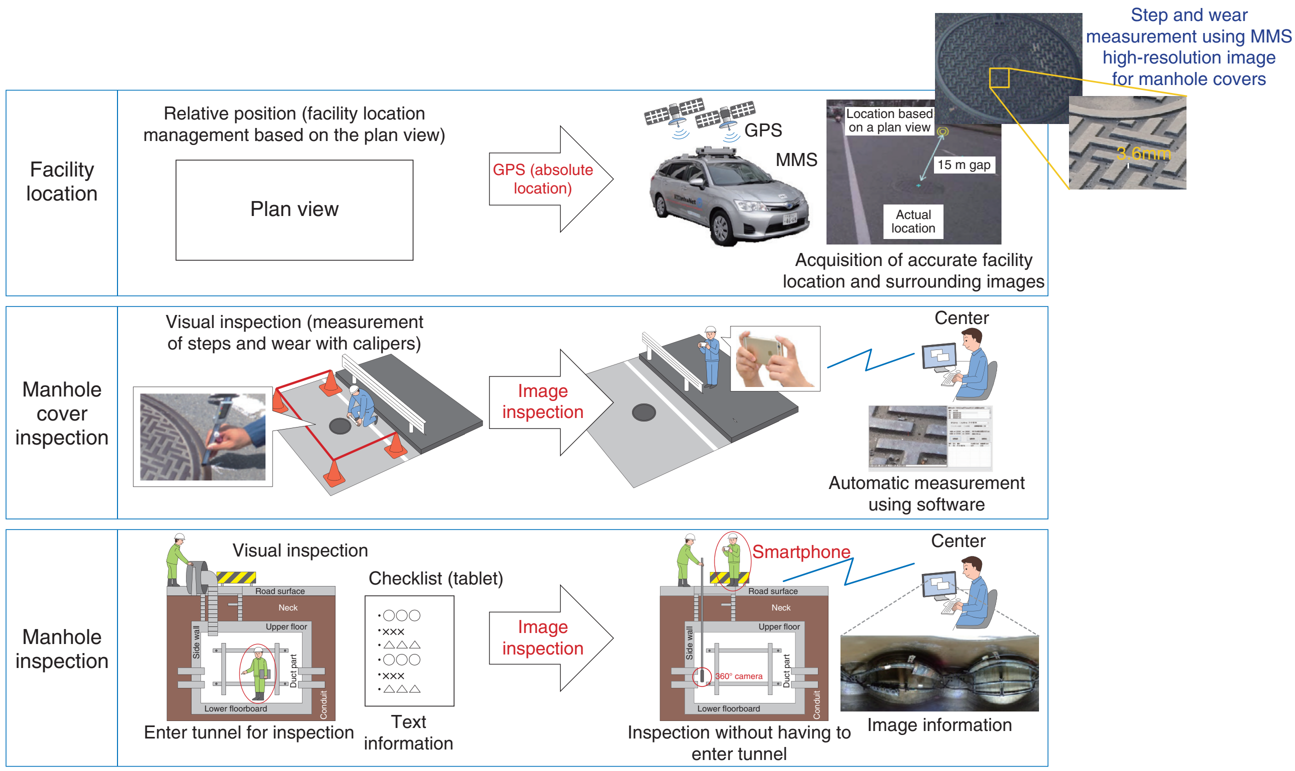

Fig. 5. Implementation of smart maintenance using facility-location measurement technology.

There are about 690,000 manholes owned by the NTT Group throughout Japan, and a large amount of labor and cost is required for inspecting them; however, 3D measurement technology, such as MMS, has made it possible to determine the absolute coordinates of individual manholes (upper part of **Fig. 5**). Therefore, by only holding a smartphone over a facility on site, the facility name is displayed on the smartphone. The Global Positioning System (GPS) coordinates of the smartphone are then processed by software for high-precision positioning, and when a photo at the spot is taken, the displayed facility name is affixed to the photo and GPS coordinates and then sent to the center. At the center, information sent from various locations will pop up on the map on the Triple I+P.

These basic functions are used for inspecting facilities and investigating their failures in the event of a disaster, greatly reducing on-site operations (middle and bottom of Fig. 5). This way of linking geospatial

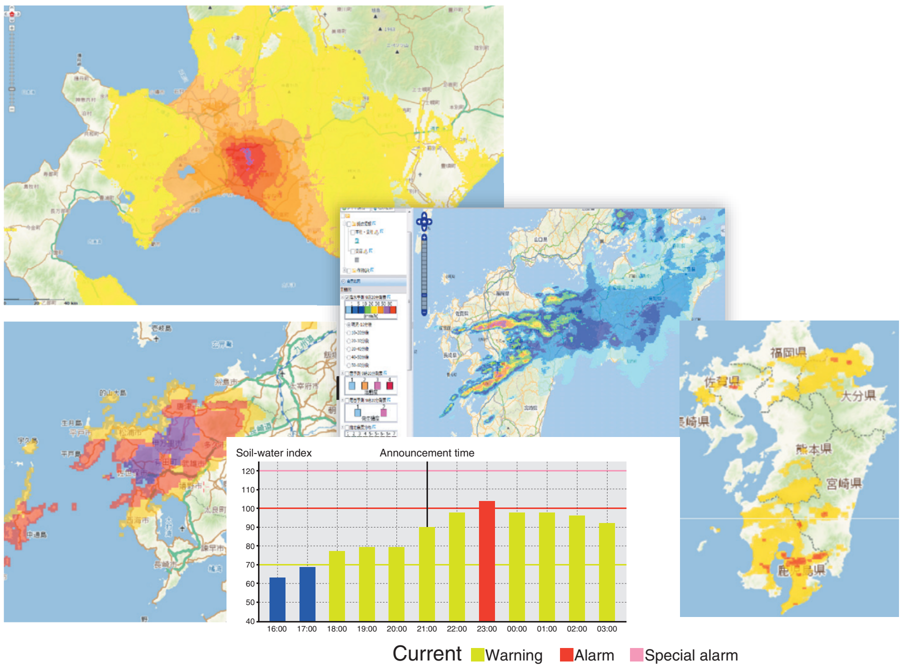

Fig. 6. Major real-time disaster-related information provided from Triple I+P.

information between the 3D database and on-site information devices makes smart maintenance possible.

3.2 Application for disaster countermeasures

Triple I+P is a platform that flexibly supports tablet functions and functions for receiving photos taken with smartphones in addition to basic functions such as superimposing, searching, and extracting various types of information. Taking advantage of these features, we can effectively apply Triple I+P for countermeasures against earthquakes and heavy rainfall.

By *mashing up* the facility information stored in the database, information collected by NTT InfraNet and information published by government agencies, local governments, and other companies in the geospatial space, it is possible to determine quantitatively and intuitively the area and quantity of the damaged facility, and that information can be used for tasks such as quickly establishing facility-restoration plans, efficiently inspecting facilities, and managing the progress of facility repairs.

The main disaster-related information that can be superimposed on a map on Triple I+P is shown in **Fig. 6**. These sources of information are provided regularly by government agencies in the event of a disaster; however, they cannot be deployed in geospatial space as is. Accordingly, the original information is imported, processed into a mesh, converted into a form that can be handled in geospatial space, and automatically reflected onto Triple I+P.

Triple I+P is equipped with functions for linking with on-site information such as tablet functions and a function for receiving smartphone photos. Since Triple I+P is compatible with tablets, tablets can be used to remotely access Triple I+P from the disaster site and check a multitude of mashed up information. Since Triple I+P can receive photos of the disaster situation taken with a smartphone via the Internet, it is possible to understand the situation at the disaster site in real time from the office of the disaster-countermeasures headquarters. A screenshot of the Triple I+P display for checking the location and status of a disaster is shown in **Fig. 7**.

4. Future initiatives

Triple I+P will continue to evolve by expanding its functions into a platform for advanced facility management using a large-scale database and various applications. We will promote further automation by making full use of technologies such as artificial intelligence (AI), augmented reality, and virtual reality in conjunction with advanced database management.

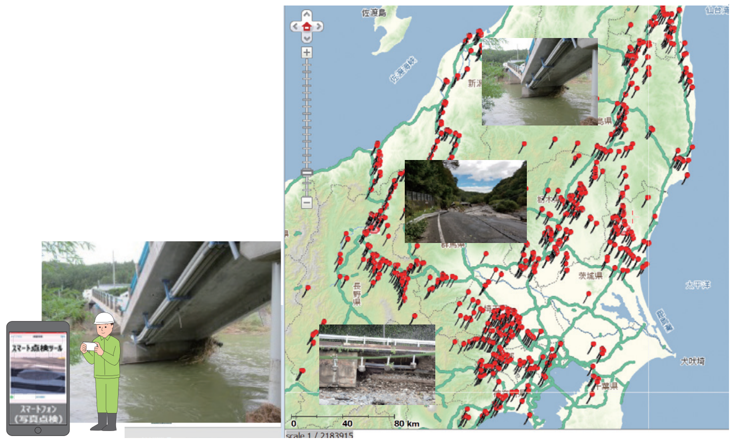

Fig. 7. A screenshot for checking the location and status of a disaster.

We will also develop technology for automatically determining the degree of deterioration of facilities by AI processing of photographs taken during inspections.

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Evolving MMS from 3D Measurement of Road Area to Facility Inspection—Diagnosing Wear in Millimeters and Deterioration in Terms of Rust, Stains, and Cracks

Toshihiko Sekiguchi, Tomomi Matsuda, and Yasufumi Yamamoto

Abstract

A mobile mapping system (MMS) measures surrounding structures (including roads) in three dimensions and creates a database based on the obtained information. Measurement equipment mounted on a vehicle mainly consists of devices for measuring the position of the vehicle and measuring around the vehicle three-dimensionally (laser devices are the mainstream). Efforts by NTT Infrastructure Network Corporation (NTT InfraNet) to address issues concerning an MMS are introduced in this article.

Keywords: MMS, GNSS, stereo camera

1. Overview of our MMS

The key feature of the mobile mapping system (MMS) developed by NTT Infrastructure Network Corporation (NTT InfraNet) is that it uses stereo cameras, which enables three-dimensional (3D) measurement using a camera-only photography function. For this function, we developed a technology for synchronous shooting involving multiple cameras, enabling highly accurate measurement (**Fig. 1**). By improving the resolution of still-image shooting, which must satisfy a frame rate of 10 frames or more per second, we have been able to evolve an MMS (which is mainly used for measuring the shape of structures) to beyond its normal applicable area, namely, to a level at which it can be used to inspect the deterioration and wear of facilities such as manholes to the millimeter.

The main issues concerning the practical use of an MMS are as follows: reducing the cost of equipment and vehicles while improving accuracy; eliminating calibration running before and after measurement; reducing interruptions for stabilizing satellite positioning during measurement; enabling drivers and system operators to do their work without expert skills; and improving efficiency in post-processing of data. To resolve these issues, we targeted tasks such as processing the characteristics of individual cameras (analyzing lens distortion, etc.), implementing 3D high-precision measurement using cameras only, analyzing data from the in-vehicle electronic platform, and increasing the sensitivity of satellite positioning. Achieving these targets made it possible to significantly reduce the burden of vehicle operation and reduce equipment costs. We were thus able to significantly reduce vehicle-manufacturing and operating costs as a whole. By providing degrees of freedom in regard to the arrangement and directivity of the measurement equipment suitable for the measurement target, we were able to expand the scope of

Fig. 1. 3D measurement from MMS images (vertical offset measurement from the pedestrian-road boundary to target facility).

Fig. 2. Our MMS (camera placement).

applications of an MMS to facility inspection, such as inspecting utility poles for defects and inspecting the iron covers of manholes for wear (**Fig. 2**).

2. Reduced cost of measurement equipment and significantly improved measurement resolution

Many MMSs are equipped with a laser scanner, so they are considered complete surveying devices for measurement. An MMS equipped with a laser scanner for measuring the area around a road can easily extract information about objects having a clear shape. It has been used for automatically extracting information about utility poles, etc. Since the identification of road signs requires more than measuring their shape, cameras have also been used in conjunction with laser scanners. For measuring all features with a single device, we have been developing an MMS to measure shape with cameras. Many laser scanners (i.e., surveying devices) have been used to acquire a point cloud of tens of thousands of points per second while the measurement vehicle is moving. Laser scanners that measure with a measurement pulse of one million points per second have also been installed; however, laser scanners with higher densities are not being used because of their high equipment cost and long post-processing of data. Moreover, the measurement pulse of a laser scanner at a scan rate of one million points per second has a point-group interval of several centimeters that extends 5 m in the scanning-line direction, and when the measurement vehicle is traveling at 40 km/h, the point-group interval is about 10 cm. Therefore, it has not been possible to obtain sufficient data to determine the

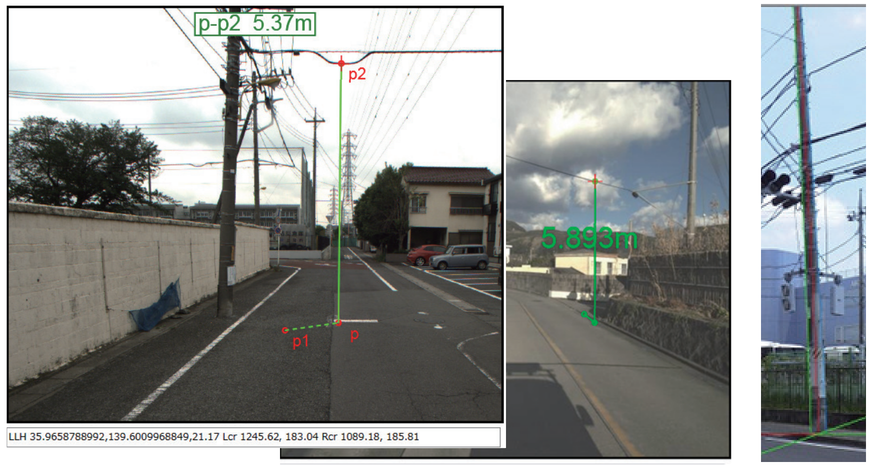


Fig. 3. Measurement of cable height and utility-pole bending.

shape of small-diameter cables and colored features having high reflectivity.

To enable 3D measurement only by shooting the subject with cameras, our MMS improves measurement accuracy by implementing a measurement technology using stereo cameras. Since the original data obtained with this technology has a high measurement resolution on the order of millimeters, it is possible to measure small-diameter cables (**Fig. 3**). When up to eight cameras are installed and operated, two stereo cameras are placed in the front and six cameras can be optimally configured according to the measurement target. Our MMS is currently equipped with cameras with resolutions of 20 to 30 million pixels (roughly equivalent to 8K). To improve the performance of our MMS, we have been verifying many types of cameras with various specifications every year and practically applied them as a system applicable to MMSs.

3. Reducing cost of measuring self-position of a vehicle

The equipment of an MMS for measuring the self-position of a vehicle mainly consists of a global navigation satellite system (GNSS), inertial measurement unit (IMU), and odometer. These devices generally increase the cost of configuring an MMS. Many satellite-positioning systems are equipped with one or more high-precision GPS (Global Positioning System) antennas, which contribute to their high cost. When the measurement method based on virtual reference points is used, satellite correction data are sent and received after the vehicle with an MMS starts running, so improving the efficiency of data post-processing is another issue.

We adopted a high-sensitivity receiver that can be used when the vehicle is moving. It eliminates the need for calibration running before and after measurement and stopping operation for a certain period to maintain a fixed state (i.e., stabilization of satellite positioning) while the measurement is being conducted. As a result, the actual time that the measurement can be conducted over a day has been extended.

While verifying devices that integrate GNSS receivers and IMU functions, devices that can receive GNSS positioning signals at two frequencies, and devices that can receive a correction signal from the quasi-zenith satellite system MICHIBIKI, we are currently striving to improve the accuracy of self-position measurement. Our other initiatives include verifying IMU devices (aiming to reduce prices) and testing the performance of different types of odometer systems.

4. Expanding application area to facility inspection

Our MMS manages 3D measurement data (latitude/longitude, altitude, and dimensions) and image information (cracks, corrosion, wear, etc.) by using a GIS (geographic information system) platform called *Triple I+P* (Infrastructure, IT, Innovation Platform) and can be used together with information about communication facilities. Since images that enable 3D measurement are acquired, it is easy to apply

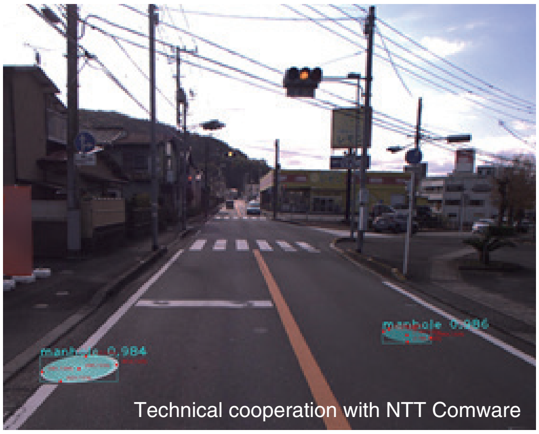
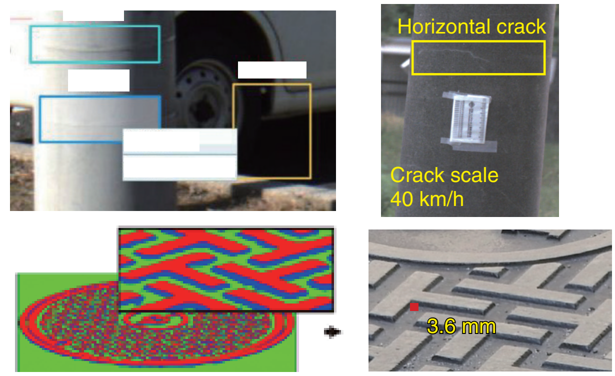


Fig. 4. AI determining types of manhole covers.



Technical cooperation with NTT EAST and NTT Media Intelligence Laboratories

Fig. 5. AI degradation estimation of utility poles and manhole covers for efficient inspection via MMS.

image-based artificial intelligence (AI) to those images, which makes it possible to significantly improve the efficiency of facility inspection. In the case of image AI, it is common to learn and identify images. However, by taking advantage of 3D measurement capability and adding the size of the object (in addition to image information) to the index for identifying objects, our MMS can determine the type of object in the image. In other words, inspection accuracy is improved by applying AI processing that adds the dimensions of the target object to the image diagnosis (**Fig. 4**).

NTT EAST and NTT WEST are already operating our MMS for inspecting communication facilities such as utility poles. The practical application of our MMS has made it possible to use AI in areas containing features that are difficult to measure with a laser scanner, such as rust, stains, and cracks (**Fig. 5**).

5. Future developments

Our MMS uses data obtained via an in-vehicle electronic platform, so its operation is not limited to a specific vehicle model. In the future, we plan to design, develop, and commercialize MMSs using small (lightweight) vehicles and an MMS using push carts for sidewalks and narrow roads along which vehicles cannot pass while making it possible to efficiently digitize geospatial information.

Authors (from left): Tomomi Matsuda, Manager, DX Promotion Headquarters, NTT InfraNet; Toshihiko Sekiguchi, Manager, DX Promotion Headquarters, NTT InfraNet; and Yasufumi Yamamoto, Assistant Manager, DX Promotion Headquarters, NTT InfraNet

Standardization Activities on Future Networks in ITU-T SG13

Yoshinori Goto

Abstract

ITU-T SG13 is one of the study groups of the Telecommunication Standardization Sector of the International Telecommunication Union, which is responsible for developing the concept of Future Networks. Its technical area includes, but not limited to, network slicing, machine learning, and quantum key distribution. This article introduces the history of Future Networks studies and recent topics.

Keywords: Future Networks, IMT-2020, quantum key distribution

1. Introduction

ITU-T SG13 is one of the study groups in the Telecommunication Standardization Sector of the International Telecommunication Union. It is responsible for developing the requirements and architecture of Future Networks. It has recently developed the recommendations on emerging network technologies such as network slicing and quantum key distribution. One of the unique features of SG13 is the diverse participation of experts around the globe, which includes not only Europe, North America, and Asia but also Africa, which promotes collaboration through SG13 Regional Group for Africa. Diverse views based on global participation are considered in creating recommendations. SG13 was well known as a place to develop a set of recommendations on Next Generation Networks (NGNs). However, as NGNs becomes mature, it is focusing more on academic subjects to try to attract more attention of industry experts. SG13 is going to play an important role in making such academic subjects more practical for industries.

2. Standardization history of Future Networks

Figure 1 shows a brief history of the standardization of Future Networks in ITU-T SG13. The study of Future Networks dates back to 2009. At that time, most standardization activities on NGNs had completed, and SG13 was considering a new vision of networks beyond NGNs. To promote this vision, SG13 established the Focus Group (FG) on Future Networks, which allows the participation of experts of non-ITU-T members including academic organizations. ITU-T Recommendation Y.3001 (objectives and design goal of Future Networks) was developed on the basis of the results of this activity. Y.3001 is not a technical specification that is implementable as a product or service but identifies four important aspects of Future Networks, i.e., service awareness, data awareness, environmental awareness, and socio/economic awareness. Instead of traditional standardization activities, it focuses on the vision and goal rather than implementable specifications to achieve interoperability among different components/devices/systems. This recommendation is referred to in various new network standardization activities due to this unique feature.

Non-radio parts of mobile networks have been an important study area in SG13 for many years. Contrary to FG Future Networks, which studied the high level concept of Future Networks, as mentioned above, FG IMT (International Mobile Telecommunication)-2020, which was established by SG13 to study non-radio parts of IMT-2020 (the ITU-defined generation of mobile networks corresponding to fifth-generation (5G)), studied more practical technical solutions such as network softwarization. To avoid potential overlap regarding study efforts with

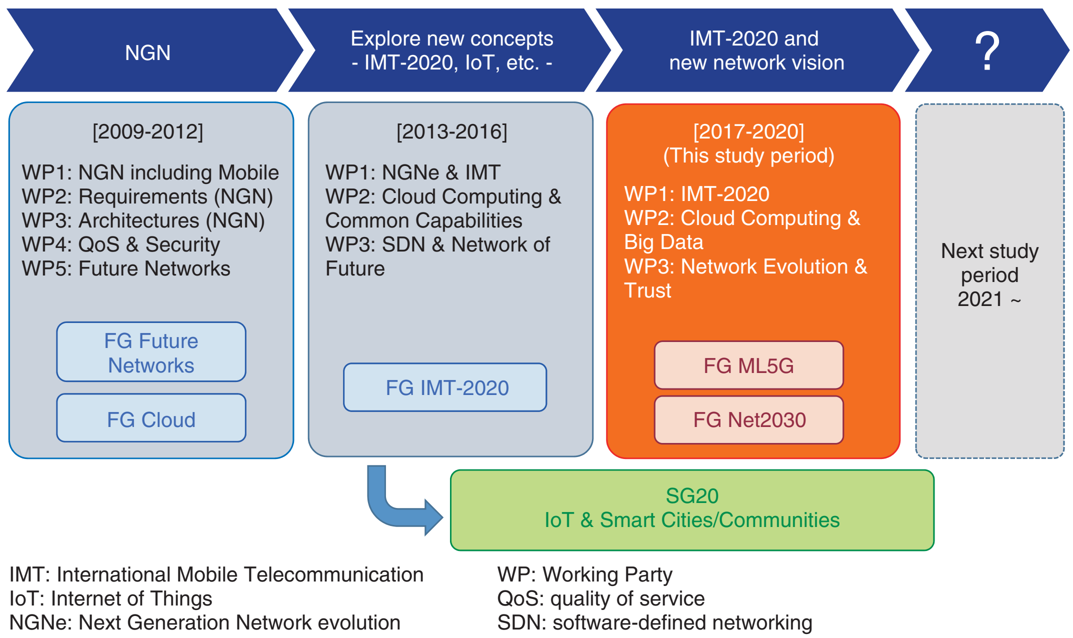


Fig. 1. History of study subjects in SG13.

the 3rd Generation Partnership Project (3GPP), which plays a central role in developing technical specifications for mobile networks to be implemented by industry players, FG IMT-2020 conducted a gap analysis to identify relevant areas before it started actual standardization. The results of this FG were transferred to the questions of Working Party (WP)1 of SG13, and a series of recommendations, such as Y.3150 (high level technical characteristics of network softwarization for IMT-2020), were produced.

As the study on IMT-2020 becomes mature, the study focus has shifted to more advanced features based on the network architecture of IMT-2020. SG13 established two FGs, FG ML5G (Focus Group on Machine Learning for Future Networks including 5G) and FG-Net2030 (Focus Group on Technologies for Network 2030), which are, for example, working on possible applications of artificial intelligence/machine learning (AI/ML) and a new network vision for 2030.

3. Recent study subjects

The following topics are being studied in SG13.

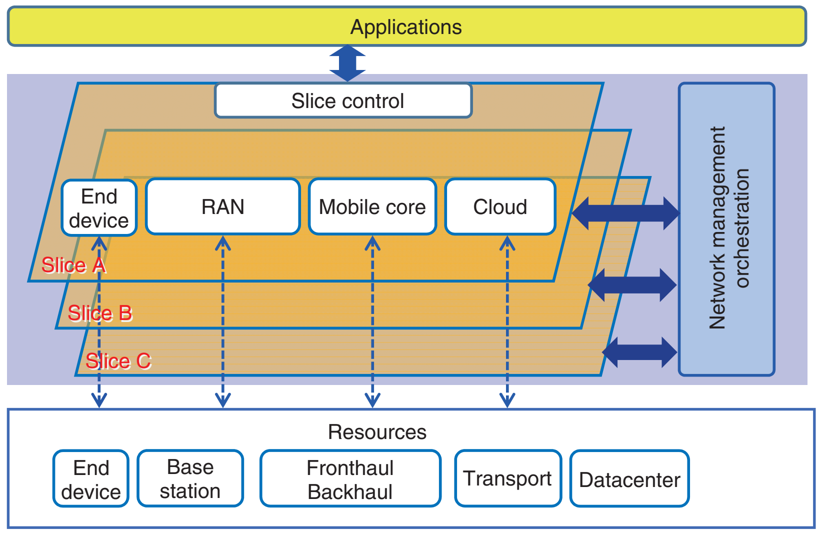
3.1 Network softwarization and IMT-2020

Network softwarization is a technical approach for designing, implementing, deploying, managing, and maintaining network equipment and/or network components by using software programming. As **Figure 2** shows, a typical use case of network softwarization is to virtualize various network components, such as base station fronthaul and mobile core, and produce a network slice collecting these virtualized components. SG13 produced a basic concept of network slicing to be applied to IMT-2020, while 3GPP studied network slicing to create a set of implementable specifications.

The domestic discussion of network softwarization for preparing the contributions for SG13 was conducted in 5GMF (The Fifth Generation Mobile Communications Promotion Forum). Japanese experts play a leading role in the study of network softwarization including the responsibility as rapporteur for Question 21, which is mandated to address this issue. A series of recommendations, such as Y.3150 mentioned above, Y.3151 (software-defined networking parts including fronthaul), and Y.3154 (resource pooling for network slice management), have been produced.

3.2 Cloud computing

The study on cloud computing was started by FG Cloud (Focus Group on Cloud Computing) established in 2020. Historically, so-called de facto standards prevailed over de jure standards including



RAN: Radio Access Network

Fig. 2. Concept of network softwarization.

ITU-T recommendations in the computing industry. Therefore, particular consideration should be made in terms of standardization strategy for ITU-T to have influential outcomes. SG13 has been attempting to establish a collaborative relationship with other standard bodies that are more influential than ITU-T. Even though the influence of de jure standard bodies is limited, ITU-T could play a role in specific issues such as terminology and reference architecture. SG13 established two collaborative teams with ISO/IEC JTC1* Subcommittee 38 Working Group 3 to jointly address these issues. The outcomes of this collaboration resulted in ITU-T Recommendations Y.3500 (terminology of cloud computing) and Y.3502 (reference architecture of cloud computing).

Japanese experts focus on the system called "inter-cloud," which combines cloud computing and a wide area network connecting different datacenters. An overview of the inter-cloud is given in ITU-T Recommendation Y.3511 (framework of inter-cloud) to which Japanese experts contributed and played a leading role.

The cloud study in SG13 is moving to big-data-related subjects running on clouds rather than the cloud itself. The current structure of big data in the industry is the silo type structure in which dominant players collect and manage their own big data. The model studied in SG13 is more horizontally federated among different players with specific roles. A set of recommendations of the Y.3600 series describe this issue.

3.3 AI/ML

AI/ML is one of the hottest topics in this industry. SG13 started AI/ML-related activities through FG ML5G, which was established to consider possible applications of AI/ML in networks. The initial target of AL/ML study was automation of network management. Similar activities are being conducted in the European Telecommunications Standards Institute (ETSI) (e.g. ZSM-ISG (Industry Specification Group (ISG) Zero Touch Network and Service Management), and SG13 liaises with these groups. FG ML5G, which was established in 2018, concluded its activities in June 2020 and submitted the deliverables to SG13. Further discussions including development of ITU-T recommendations will progress in relevant questions such as Question 20.

The basic architecture of ML studied in FG ML5G is described in ITU-T Recommendation Y.3172 (architecture framework for machine learning in future networks including IMT-2020). The architecture in Y.3172 contains two different environments, i.e., sandbox in which an ML algorithm learns using a simulator and pipeline in which the algorithm is applied in an actual management task (**Fig. 3**).

* ISO/IEC JTC1: International Organization for Standardization/ International Electrotechnical Commission Joint Technical Committee 1

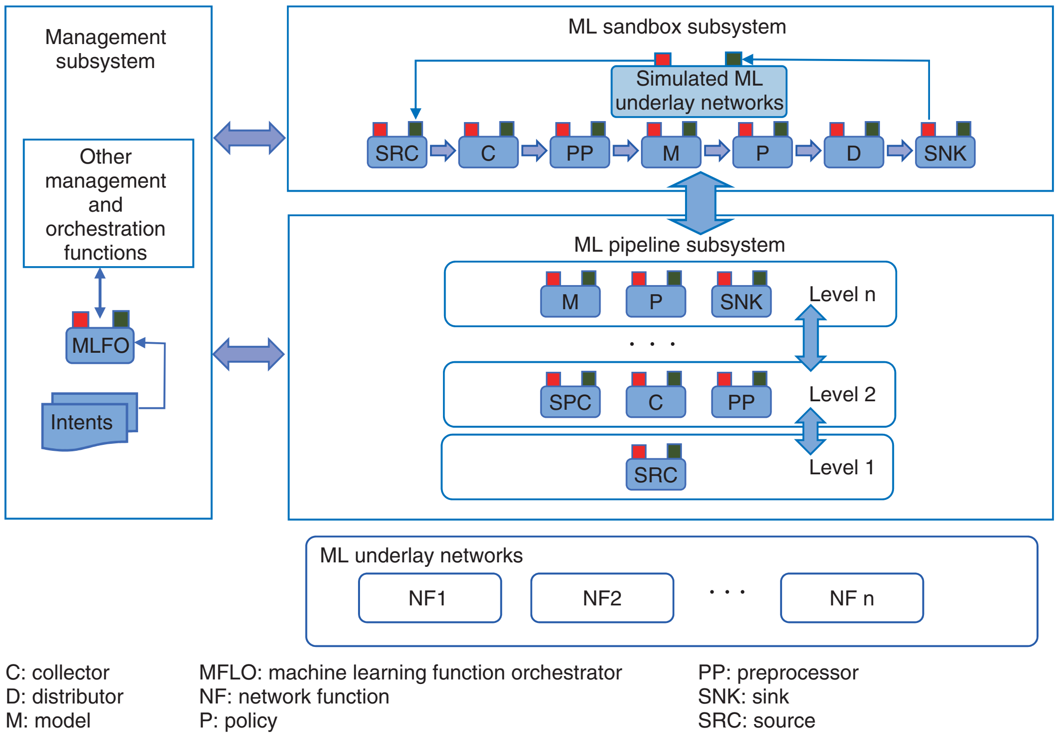


Fig. 3. Machine learning architecture in Y.3172.

Big data, which is being studied in SG13 in the context of cloud computing, would be applicable to AI/ML. Questions 17, 18, and 19 working on big data will join the AI/ML-related activities.

3.4 Quantum key distribution

Quantum key distribution is a system to distribute encryption keys to remote nodes in a secure manner by using quantum physics. Quantum key distribution is becoming mature for small-scale deployment including commercial services for specific applications. Question 16 has been working on networks for quantum key distribution since 2018.

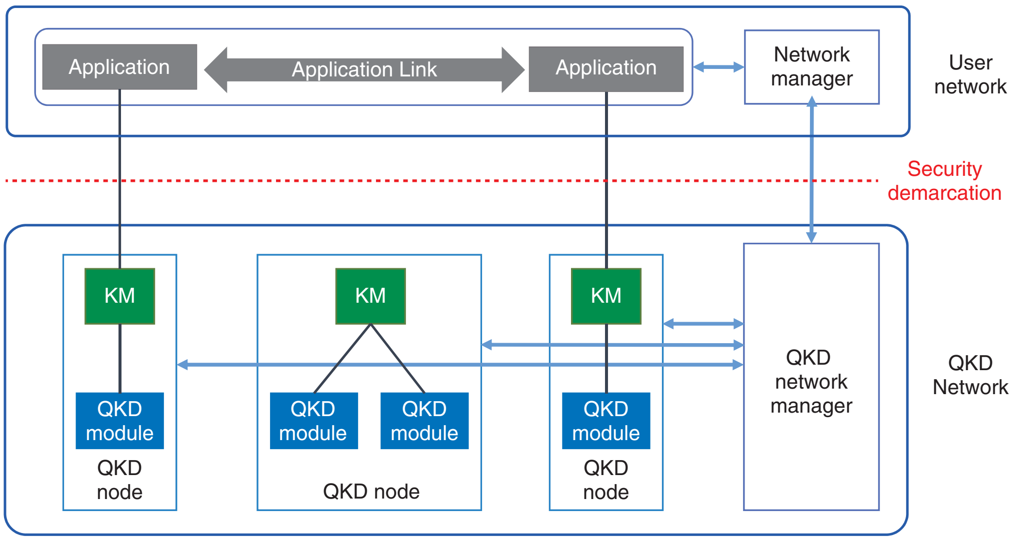
It is not possible to provide quantum key distribution over a long-distance fiber network due to attenuation of optical signals on the fiber. The distance between nodes of quantum key distribution is not more than 100 km, even with the latest techniques. This imposes constraints on the design of large-scale networks such as nation-wide and global networks. The architecture being studied in SG13 introduces intermediate nodes that are placed in secure locations such as central offices of a telecom carrier (**Fig. 4**). This allows the provision of long-distance key distribution beyond the limitation of quantum key distribution without intermediate nodes.

In principle, quantum key distribution provides the capability of sharing only a small amount of data, such as an encryption key, rather than a huge volume of data such as audio, video, and text. Therefore, quantum-key-distribution networks are assumed to provide enhanced security for communication applications on traditional networks. How quantum key distribution networks and traditional networks work together is an important subject of standardization, and SG13 is working on this issue.

There are other areas of quantum-related information and communication technologies such as quantum computing. ITU-T established FG QIT4N (Focus Group on Quantum Information Technology for Networks) to promote studies in these areas.

3.5 Network 2030

FG Net2030, which was proposed by a Chinese company, was established to promote study on the network vision called "Network 2030," which will be achieved in 2030. Network 2030 supports emerging applications, such as holographic-type communications and tactile internet, which will not be available for current network technologies. In this work, a new



KM: key manager
QKD: quantum key distribution

Fig. 4. Conceptual structure of quantum key distribution network.

network technology called "New IP" was proposed. Although the relationship of New IP and a set of Internet Protocol (IP)-based network technologies is not yet clear, this stimulated a significant political discussion on whether ITU-T should handle IP-related technologies. One party of the discussion expressed their concern of New IP, stating that IP-related technologies should be discussed using the multi-stakeholder approach and that the Internet Engineering Task Force (IETF) rather than ITU-T should be responsible for this study. The proponent responded that the proposed study items do not overlap with the current work items in IETF, and ITU-T can conduct the proposed study items. The proponent also proposed to change the name from "New IP" to "Future Vertical Communication Networks" to avoid misunderstanding. The discussion on this new study subject is still continuing.

4. Conclusion

SG13 played a central role in the standardization of NGN architecture. It is now exploring new areas for Future Networks, such as network slicing, AI/ML, and quantum key distribution. Although the role of SG13 as an organization to produce implementable standards for the telecommunication industry is becoming weak, it is still developing emerging network technologies and concepts. We, the management team of SG13, wish to make SG13 a place of bridging academic study and industrial standardization, which is a unique role in the global standardization community.

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He received a B.E. and M.E. in applied physics from Tohoku University, Miyagi, in 1992 and 1994. He joined NTT Basic Research Laboratories in 1994 and has been researching and developing cable television systems, Internet protocol television (IPTV), and machine-to-machine technology. He has been engaged in the standardization of IPTV in ITU-T as a member of the IPTV Focus Group and Global Standards Initiative since 2006. He has also served as Rapporteur of Question 11 of ITU-T SG9, Questions 5 and 25 of ITU-T SG13, and Question 21 of ITU-T SG16. He has been a vice-chair of ITU-T SG13 since 2013. He is a member of the Institute of Electronics, Information and Communication Engineers.

External Awards

Young Researcher's Award

Winner: Kei Fujimoto, NTT Network Service Systems Laboratories
Date: October 7, 2020
Organization: The Institute of Electronics, Information and Communication Engineers (IEICE) Technical Committee on Network Systems

For "KBP: Kernel Enhancements for Low Latency Networking without Application Customization in Virtual Server."
Published as: K. Fujimoto, M. Kaneko, and K. Matsui, "KBP: Kernel Enhancements for Low Latency Networking without Application Customization in Virtual Server," IEICE Tech. Rep., Vol. 120, No. 183, NS2020-54, pp. 1–6, Oct. 2020.

Best Paper Award

Winners: Manabu Yoshino and Hiro Suzuki, NTT Access Network Service Systems Laboratories; I Gede Astawa and Mahyar Koswara, IRS, Telkom DDS, PT Telekomunikasi Indonesia Tbk; Tri Trinh and Bang Nguyen, R&D Center, Viet Nam Posts and Telecommunications Group
Date: October 8, 2020
Organization: 25th OptoElectronics and Communications Conference (OECC 2020)

For "Zero-touch Multi-service Provisioning with Pluggable Module-type OLT on Access Network Virtualization Testbed."
Published as: M. Yoshino, H. Suzuki, I. G. Astawa, M. Koswara, T. Trinh, and B. Nguyen, "Zero-touch Multi-service Provisioning with Pluggable Module-type OLT on Access Network Virtualization Testbed," OECC 2020, Taipei, Taiwan, Oct. 2020.

Papers Published in Technical Journals and Conference Proceedings

Gamifying World Wide Web Using Web Browsers

Y. Shirai, M. Matsuda, S. Fujita, T. Kobayashi, and Y. Kishino
IPSJ Journal, Vol. 61, No. 11, pp. 1660–1679, November 2020.

We propose a World Wide Web (WWW)-based game concept that applies the characteristics of location-based games to the WWW. While location-based games can offer benefits such as improving fitness, WWW-based games can offer the function of computation, website navigation, and education. Based on our concept, we developped "text monster," a game that enables users to scramble for websites using Japanese words. This paper describes text monster and discusses the process of designing games on the WWW.

Collection and Analyses of Exemplary Speech Data to Establish Easy-to-understand Speech Synthesis for Japanese Elderly Adults

H. Nakajima and A. Aono
Proc. of the 23rd Conference of the International Committee for the Co-ordination and Standardisation of Speech Databases and Assessment Techniques (Oriental COCOSDA 2020), pp. 145–150, Yangon, Myanmar, November 2020.

This paper describes a newly developed Japanese speech database used to find speech characteristics and speaking styles that elderly adults actually think it is easy to understand to develop a speech-synthesis method for elderly adults (senior citizens). This speech database is characterized by two features: i) its sentences are largely taken from newsletters beyond just the content that elderly adults tend to know and ii) the sentences are spoken by exemplary speakers selected through an audition process from the perspective that elderly adults actually think it is easy to understand. This paper describes the design of our database and the basic characteristics measured by applying conventional theories. Finally it indicates the extension directions of the conventional theories to establish an easy-to-understand speech synthesis method for elderly adults.

Gain Instability in Forward-pumped Raman Amplifier and Its Suppression Utilizing Dual-arm Depolarizer for Pump Light

H. Kawakami, S. Kuwahara, and Y. Kisaka
The 46th European Conference on Optical Communication (ECOC 2020), Brussels, Belgium, December 2020.

We clarified the requirements for the depolarizer for the pump light used in a forward pumped Raman amplifier. Management of the optical phases is required to achieve stable gain. Utilizing a dual-arm depolarizer, we demonstrated successful improvement of the 16-QAM (quadrature amplitude modulation) transmission specification.
