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Information Technology for Realizing Sustainable Societies (The second part)

MITSUBISHI ELECTRIC
Changes for the Better

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Mitsubishi Electric ADVANCE

Information Technology for Realizing Sustainable Societies (The second part)

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Technical Reports

Precis

Mitsubishi Electric has established four business areas to achieve sustainable management: "Infrastructure," "Industry and Mobility," "Life," and "Business Platform."
This special feature covers "Information Technology for Realizing Sustainable Societies (The second part)," which is the foundation that supports all four areas.
The first part was published in ADVANCE vol. 180.
Please read it.

Introduction of Internet of Things Suite "ClariSense" Design Guides

Author: *Yohei Matsuura**

1. Introduction

IoT systems are increasingly being used to help achieve the digital transformation (DX) in various fields. The IoT systems business will continue to expand: as shown in Fig. 1, the market in Japan is expected to be worth 10.2 trillion yen by 2025 (1). This paper describes our design guides currently under development.

2. Initiatives for the IoT System

2.1 Organizing the components of the IoT system

Figure 2 shows the basic components of the IoT system.

(1) Data collection and accumulation system function

Collects and accumulates the data generated and held by devices and passes it to applications.

(2) Control system function

Controls devices by event triggers of applications and the data collection and accumulation system function.

(3) Operational function

Provides operation and management, including authentication for connected devices, authentication management for users, administrators and other systems, and management of settings for each functional element.

(4) Application

Performs analysis and processing based on data; control instructions based on the processing; data provision and screen display to users, administrators and other systems; and reception of control instructions.

(5) Wide area network

Refers to the Internet or an intranet used within an organization. Based on the Internet Protocol (IP) network, the protocol is selected according to the communication frequency and data size.

(6) Edge device

Converts the data transmitted from a device into a protocol suitable for the server and network for a certain period of time or at the timing when data acquisition from the device is completed. Performs data encryption and encapsulation processing according to requirements.

(7) Device

Digitizes various physical and chemical characteristics (temperature, humidity, pH, etc.) inside and around the device using sensors, performs protocol conversion according to the network used for transmission, and transmits the data from the communication module to other components.

2.2 Initiatives in each business field

In order to solve diverse social issues, we provide solutions using IoT systems in fields related to "Life," "Industry," "Infrastructure" and "Mobility."

2.2.1 Life

Since 2019, we have provided the global IoT common platform "Linova" for collecting and managing data of our IoT home appliances via the Internet (2). In 2020, we released the home appliance integration application "MyMU" to provide customers with a way of integrally controlling multiple home appliances managed by Linova.

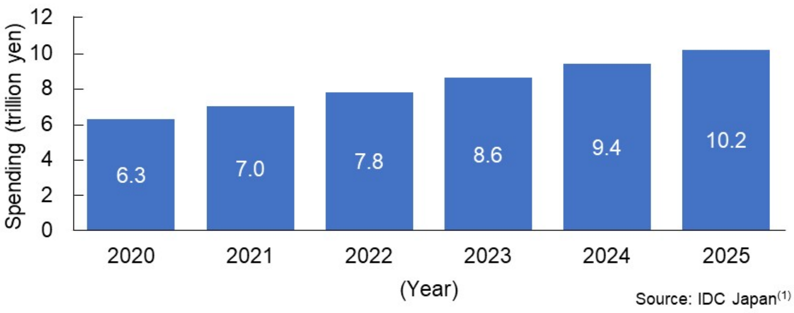

Fig. 1 Trends in spending on IoT in Japan 2020–2025

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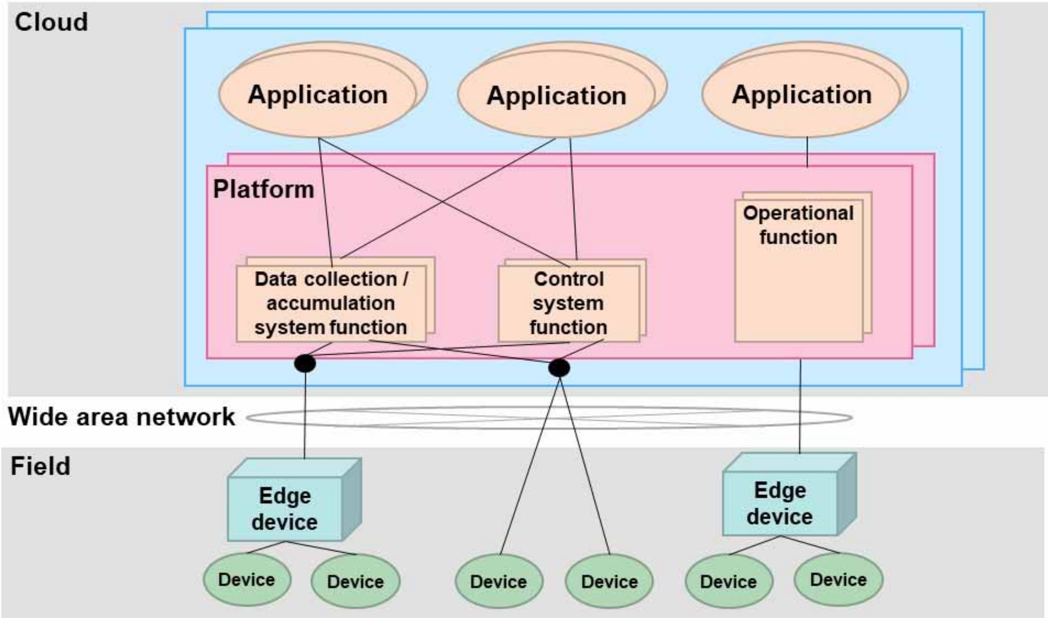


Fig. 2 Components of an IoT system

2.2.2 Industry

Since 2003, we have provided the FA-IT integrated solution "e-F@ctory" for production sites (3). We are also involved in the activities of the Edgecross *1 Consortium. This Consortium aims to create new added value beyond the boundaries of companies and industries by creating an open platform that will connect among different types of equipment and communication standards in the area of edge computing and facilitate the collection and use of data.

2.2.3 Infrastructure

Since 2017, we have provided "INFOPRISM" as an IoT platform for improving the efficiency of operation and maintenance of social and electric power infrastructure equipment (4). INFOPRISM is applied to equipment maintenance systems such as generators, integrated monitoring systems such as public facilities, and systems for optimizing equipment operation such as water supply and sewerage systems. Since 2020, we have provided "Ville-feuille" as an IoT platform that collects and accumulates operating data and sensing data of building equipment and processes data using technologies such as AI and big data analysis (5).

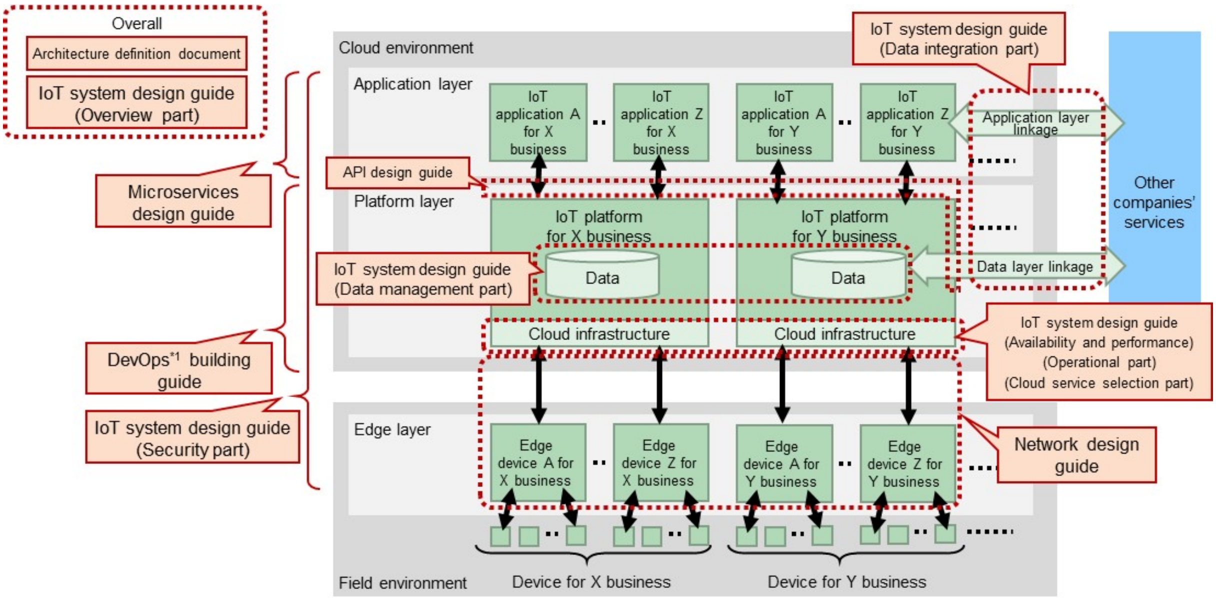
2.2.4 Mobility

Since 2019, we have provided "Railway LMS on INFOPRISM" as an IoT platform that collects and analyzes various information on railway vehicles in real time. In addition, since 2020, using in-building dynamic maps, we have built a service on Ville-feuille for collaborating with and controlling various types of personal mobility such as service robots for cleaning, security, delivery and guidance and next-generation electric wheelchairs, as well as building facilities such as elevators and access control systems.

3. Design Guides in ClariSense

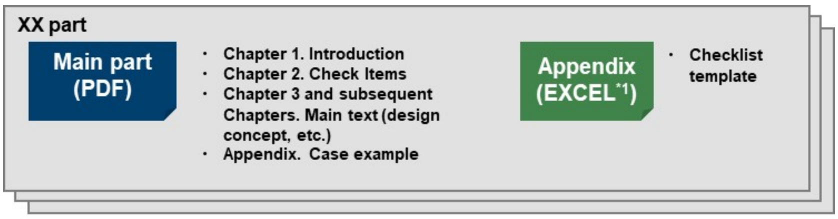
As described in Section 2, ClariSense organizes the knowledge and technical assets related to security, networks, etc. for IoT systems in each business field as design guides and solution libraries, and we are promoting its sharing and use within the Mitsubishi Electric Group (6) to improve the efficiency of IoT system design and realize new IoT system solutions across business fields. This section describes the structure of the ClariSense design guides and the contents of each guide. Figure 3 shows the correspondence relationship between the IoT system components.

[1] Edgecross is a registered trademark of the Edgecross Consortium.



1 A coined word meaning joint development by development personnel and operation personnel.

Fig. 3 Correspondence between architectural layers of IoT systems and design guides



PDF: Portable Document Format
1 Excel is a registered trademark of Microsoft Corp.

Fig. 4 IoT system design guide structure

3.1 IoT architecture definition document

This document focuses on the functional elements of the IoT system and the concept of the API, and provides a basis for common understanding and discussions among stakeholders with different backgrounds related to construction of the IoT systems that Mitsubishi Electric is promoting.

Regarding the architecture of IoT systems, various organizations have defined reference architectures. ClariSense refers to the Industrial Internet Reference Architecture (IIRA), which is a reference architecture for the Industrial IoT (IIoT) developed by the Industry IoT Consortium (IIC). Mitsubishi Electric is also involved in the development of the IIRA; the latest version, v1.9, was developed in June 2019.

3.2 IoT system design guides

This is a collection of guides that organize how to select a managed service on the cloud to balance functionality and cost according to the development purpose, service level management and monitoring design during operation after service development. The IoT system design guides consist of seven separate volumes, and as shown in Fig. 4, each volume consists of a main part and an appendix. The main part explains the items to be checked when designing an IoT system, the concept, and examples of in-house system configurations as case studies.

(1) Overview part: Summarizes the ClariSense design guides, explains the guide system, and lists location examples.
(2) Data management part: Introduces the selection of services according to the requirements in consideration of the data format, usage method, etc., and the items necessary for data management.
(3) Data integration part: Summarizes the items to be confirmed in order to select technologies and products to be used for data integration, and explains examples of useful metadata for finding and using data to be linked.
(4) Security part: Describes how to design a typical security function that is expected to be implemented in an IoT system. It also includes separate volumes for each cloud vendor (Security volume - AWS [*2]-, Security volume - Azure [*3]-).
(5) Availability and performance part: Summarizes the viewpoints that should be considered for the availability and performance required as non-functional requirements for cloud services used to build IoT systems.
(6) Operation part: Related to operation design such as distributed tracing in IT service design.
(7) Cloud service selection part: Summarizes how to perform service selection according to the requirements for cloud services (especially Platform as a Service (PaaS)).

3.3 Microservices design guide

Microservices are software architectures that manage and operate multiple small, individually developed services by linking them. Microservices are an effective means of flexibly adapting to business changes and improving service reusability, but in order to properly implement them, it is necessary to fully understand the design considerations. This guide organizes the matters that various microservices solve, how to divide services when designing them, and the engineering methods used to develop them. This guide summarizes considerations for two development patterns, new system development and migration development from monolithic systems, and describes microservice design methods, agile development processes, and best practices for development.

3.4 API design guide

This guide summarizes the concept of Web API for exchanging data in a loosely coupled manner that takes into account security, ID linkage, etc., mainly in the application layer linkage and platform layer linkage, assuming external system linkage. The guide summarizes notes on endpoint naming conventions and response formats as API design, configuration examples for public cloud services such as Azure and AWS as implementation, and usage management and version control methods as operations.

3.5 Network design guide

This guide summarizes the protocol conversion and data conversion required when collecting data on a field network via a wide area network (IP network). The guide consists of a general part that summarizes common basic design methods that are not dependent on business fields, and individual parts that describe examples of protocol conversion and data conversion for each use case.

3.6 DevOps building guide

This guide shows the concepts and examples of system environment design required to practice DevOps, and consists of separate volumes for introduction, AWS practice, and Azure practice. The guide summarizes the version control method, branch method, and Continuous Integration/Continuous Delivery (CI/CD) pipeline design method, as well as the concept of monitoring in operations and the concept of feeding back the results of monitoring to development.

4. Extending the ClariSense Design Guides

4.1 Expansion of design guide content

The conventional approach to drawing an overall picture and filling in the missing pieces leads to the creation of guides that have no need for rapidly evolving IoT systems, and also accelerates the obsolescence of content. We will constantly monitor internal and external needs and conduct flexible management such as selecting the content to be included.

4.2 Sharing design guides

Currently, we are distributing the created design guides in-house, but in order to quickly identify needs, we are planning to link them with the content management system used in-house. This will provide direct feedback to authors and accelerate the accumulation of knowledge by allowing users to create design guides directly via web browsers.

[2] AWS is a registered trademark of Amazon Technologies, Inc.
[3] Azure is a registered trademark of Microsoft Corp.

5. Conclusion

This paper described our approach to the ClariSense design guides, which are shared within the Mitsubishi Electric Group by centrally organizing the knowledge obtained by combining our strengths in core components with our extensive field knowledge and IoT system construction know-how. We will continue to use the design guides to quickly create flexible and highly scalable IoT solutions.

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Fast Algorithm for Large-Scale Optimization Problems Accelerating System Collaboration

Author: *Hideya Shibata**

1. Introduction

Advances in Internet of Things (IoT) technology are making it possible to collect and utilize data from various devices in real time. Along with this, the concept of System of Systems (SoS), in which multiple systems collaborate with each other to make decisions, is becoming increasingly important.

This paper describes a fast algorithm for large-scale optimization problems developed by Mitsubishi Electric to support decision-making in SoS. When considering SoS planning as a large-scale optimization problem, the problem can be modeled as suboptimization for each element system and mutual coordination between element systems (Fig. 1). Based on this concept, the method developed in this study performs fast and highly accurate optimization calculations by decomposition of the problem into element systems and iterative mutual coordination[1]. As an application example, the paper also describes a case study of the train timetabling problem for multiple routes[2].

2. Scope

The method developed in this study is intended for SoS planning, and utilizes two characteristics of SoS: "loose coupling between element systems" and "coexistence of two types of decision-making." In addition, the method focuses on the "time-based order relation" related to planning.

This section describes these three characteristics using the example of the train timetabling problem.

2.1 Loose coupling between element systems

The individual element systems that make up the SoS are themselves closed systems, while also having relationships with other element systems. The former implies that the individual element systems have some degree of independence, and the latter implies that this independence is not perfect. In this paper, such a state is expressed as loose coupling between element systems. Moreover, the interrelationships between element systems are realized by the output from one element system becoming the input to another element system.

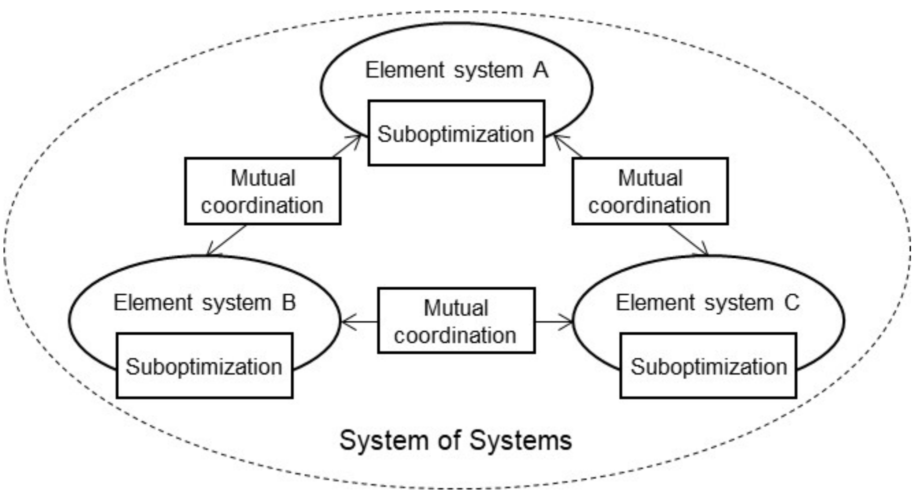

Fig. 1 Model of scheduling for system of systems

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In the example of the train timetabling problem, the railway network can be regarded as an SoS, and each individual route can be regarded as an element system. Individual routes are related to other routes through a limited number of connecting points, or transfer stations. The interrelationships provided by these connecting points are expressed in the form of the arrival time of transfer passengers at transfer stations. In other words, the arrival time (output) of a passenger from one route corresponds to the departure time (input) of the passenger on another route. Viewed in this way, it can be seen that the target railway network has loose coupling between element systems in the train timetabling problem.

2.2 Coexistence of two types of decision-making

The two types of decision-making mentioned here are suboptimization and total optimization. If we assume that the element systems that make up the SoS have some degree of independence, it is natural that the individual element systems are capable of making decisions based on their own closed purposes and means, and have that tendency. This is the aspect of suboptimization. On the other hand, it is not uncommon for both sides to benefit from the relationship between one element system and another element system, and it is also clear that this benefit cannot be obtained simply by aiming for suboptimization. This is the aspect of total optimization. Both aspects are important in SoS decision-making, and ignoring one or the other is not practical.

In the example of the train timetabling problem, determining an individual timetable by using only information about a single route corresponds to suboptimization. If priority is given to ease of train operation and robustness against abnormalities, decision-making by suboptimization is the simplest and most reliable. However, considering the convenience of passengers who have to change trains, the relationship with other routes cannot be ignored. For example, in order to reduce the waiting time of passengers at transfer stations, suboptimization alone is not enough; it is essential to coordinate the train timetable with other routes, that is, from the perspective of total optimization.

2.3 Time-based order relation

Not limited to SoS, problems generally called planning and scheduling have a time-based ordering relationship between the parameters to be determined. The train timetabling problem dealt with in this paper is a type of scheduling and is included in this category.

The method developed this time focuses on the time-based order relation to achieve both high-speed and high-accuracy planning. The method is described in Section 3.

3. Algorithm

This section describes the algorithm of the method developed in this study, using the train timetabling problem as an example.

3.1 Basic policy

The algorithm is designed based on three basic policies. These policies correspond to each of the three characteristics of the applicable scope described in Section 2.

The first is decomposition of the problem into element systems. By utilizing the loose coupling between element systems, the problem is decomposed and the scale of the problem to be handled at one time is reduced. This improves the speed of optimization calculations.

The second is iterative mutual coordination. Utilizing the characteristic that SoS is essentially the coexistence of two types of decision-making—suboptimization and total optimization—suboptimization for each element system and mutual coordination between the element systems are iteratively performed. Here, mutual coordination is a means of total optimization. Mutual coordination suppresses the degradation of approximation accuracy due to problem decomposition.

The third is the sequential determination of parameters. Using the fact that there is an order relation based on the time between the parameters to be determined, the parameters are determined sequentially in order of the earliest time. This suppresses the number of iterations of mutual coordination to a certain number or less, and speeds up the calculation.

3.2 Algorithm

Figure 2 shows the flow of the algorithm; the details of each step are described below according to the figure. In Step 1, the initial state of each element system, that is, the initial solution, is set. Although the method of setting the initial solution depends on the application, the basic policy is to set it so that each element system can be operated to the maximum extent, ignoring costs. The concept of system operation also depends on the application, but, for example, in the train timetabling problem, the departure of a train from the starting station at a certain time can be regarded as the “operation” of the system at that time. In this case, the initial solution corresponds to, for example, a train timetable that runs trains every minute. This is an ideal situation from the user’s point of view, but is not realistic in terms of cost.

In Step 2, mutual coordination between element systems is performed based on the provisional state of each element system. Expressed mathematically, the optimization problem for the entire SoS is solved with the parameters (variables) to be determined, which are closed to each element system, fixed as temporary solutions. This determines the input and output exchanged between individual element systems. The input/output is mutual coordination in practice. Since the problem of total optimization is dealt with here, the apparent scale of the problem is large, but since closed variables are fixed in the element system, the actual scale of the problem is not as large as it seems.

In the example of the train timetabling problem, Step 2 calculates the arrival time of the passenger at the transfer station. That is, with the train timetable of each route fixed, the most efficient route for each passenger to reach the destination, the train to board, etc. are calculated using the total optimization problem. This gives the time of arrival at the transfer station, which is both an output from one route and an input to another route.

In Step 3, the problem is decomposed into element systems based on the results of mutual coordination in Step 2. Since input from other systems is provisionally provided in Step 2, each element system can consider its own problem as an independent suboptimization problem through this provisional input. In the example of the train timetabling problem, the problem is decomposed into an individual timetabling problem for each route based on the arrival time of a passenger who transfers from another route. The decomposed problem does not distinguish between a passenger transferring from another route and a passenger starting travel on that route.

In Step 4, each problem decomposed in Step 3 is calculated and the calculation result is retained as a temporary solution. This step corresponds to suboptimization. In the example of the train timetabling problem, the timetable for each route is determined individually.

In Step 5, among the undetermined parameters, the one with the earliest time is determined based on the provisional solution calculated in Step 4. The parameters determined here will not be changed in later iterations. Once all time-related parameters are determined, the algorithm ends. If an undetermined time exists, the process returns to Step 2. In the example of the train timetabling problem, the timetable for the first time, say 6:00, is determined in the first iteration. In other words, it is determined whether or not a train departs from each station at 6:00. In the subsequent iterations, the timetable for the earlier time is determined successively at 6:01, 6:02, and so on.

Each of these steps can be mapped to the three policies described in Section 3.1 as follows. That is, the problem decomposition into element systems corresponds to Step 3, the iterative mutual coordination corresponds to repetition of a series of processes from Steps 2 to 5, and the sequential determination of parameters corresponds to Step 5.

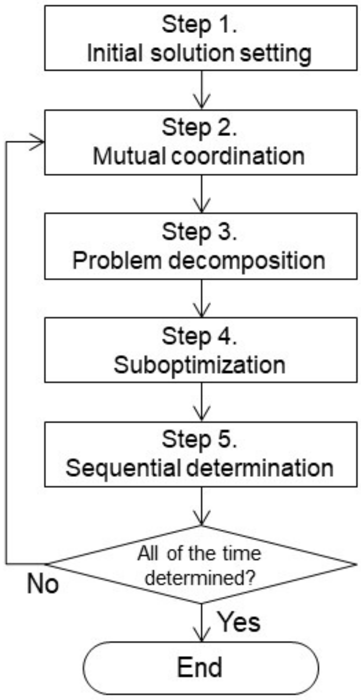

Fig. 2 Flow of algorithm

4. Application Example

This section describes the evaluation results of applying the method developed in this study to the train timetabling problem.

4.1 Evaluation conditions

The evaluation covers a railway network consisting of five routes and 57 stations (Fig. 3). It is assumed that the period to be covered by the train timetable is 1.5 hours (90 minutes) and that approximately 210,000 passengers travel within that period. The quality of the train timetable is determined by the average travel time of passengers.

4.2 Evaluation result

Figure 4 shows the evaluation result. The vertical axis of the figure represents the average travel time of passengers, and the horizontal axis represents the time taken to calculate the train timetable. The solid line corresponds to the method developed in this study, and the dashed line to an existing method for comparison. As the existing method, we set up a local search method that is commonly used in the field of optimization(2). Both the method developed in this study and the existing method are iterative methods; therefore, as the calculation continues, the solution improves and the average travel time decreases. Compared to the existing method, the solution of our method is improved stepwise because the time taken to calculate one iteration is large and the improvement effect is large.

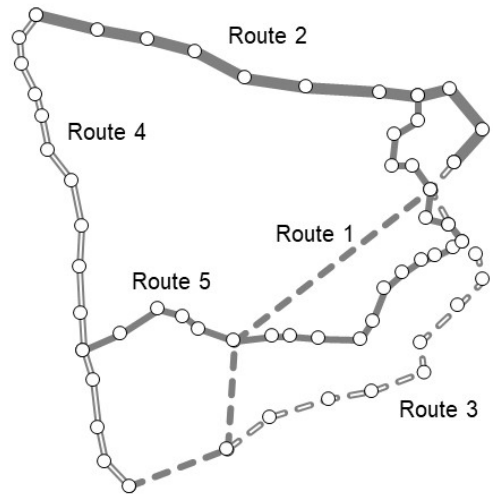

Fig. 3 Target railway network for evaluation

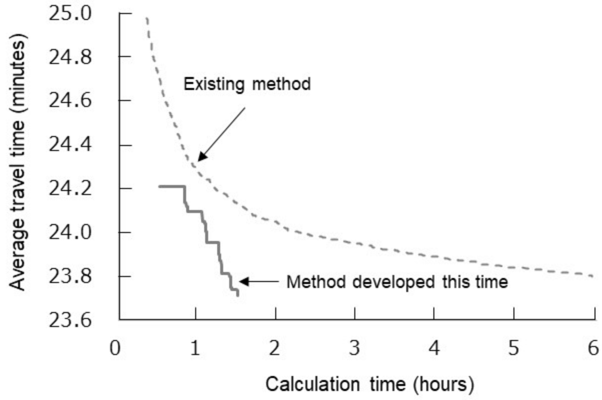

Fig. 4 Evaluation result

Figure 4 shows that the developed method produces a more accurate solution faster than the existing method, deriving a solution with an average travel time of 23.7 minutes and taking 90 minutes for the calculation. On the other hand, the existing method does not reach the same level of accuracy even if the calculation time exceeds 6 hours. The results demonstrate the superiority of our method for the train timetabling problem for a scale of five routes.

5. Conclusion

This paper described the fast algorithm for large-scale optimization problems to support decision-making in the SoS. As an application example, the paper also described the results of evaluating the train timetabling problem consisting of multiple routes, and demonstrated its superiority.

Although not fully described here, we are also trying to apply our method to the unit commitment problem in the electric power sector[3]. With the progress of IoT technology, SoS decision-making will become increasingly important. Accordingly, quantitative planning methods based on data will become crucial. In the future, we will expand the scope of application of this method and accelerate system collaboration.

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A Production Improvement Framework for Reducing Environmental Load while Maintaining Productivity

Authors: *Takaomi Sato*, Shuhei Kawaguchi** and *Kento Kikuchi**

1. Introduction

Countries are promoting efforts to achieve carbon neutrality (CN), one of the Sustainable Development Goals (SDGs) adopted at the 2015 United Nations Summit [(1)]. A representative example is the 14th Five-Year Plan on Industrial Green Development in China.

Especially in the manufacturing industry, where energy consumption and environmental load emissions are high, working toward CN cannot be ignored; the challenge is to reduce the environmental load without reducing current productivity.

Therefore, the Mitsubishi Electric Group has proposed a production management concept called "Environment and Energy Just In Time" that treats productivity and environmental load equally and optimizes them, and aims to solve problems using this concept.

Using simulation technology, this paper proposes a Production Improvement Framework for Reducing Environmental Load while Maintaining Productivity, which continuously helps to determine the optimal balance between productivity and environmental load, and describes the results of demonstration experiments at our factory and future prospects.

2. Environment and Energy Just In Time Concept

The Environment and Energy Just In Time [(2)] concept is a total optimization concept that strikes a balance between productivity and environmental load by supplying producer goods such as raw materials and labor, and resources related to environmental load such as electricity and water, to the required places, in the required amounts, and at the required times. Conventional factories have generally dealt with energy conservation and environmental load measures separately from production, and focused on improvements that are not related to production. Therefore, when complying with stricter environmental laws and regulations in the future, improvements in areas related to production will also be required, so there is a risk that productivity may deteriorate due to facility shutdown, etc. (Fig. 1). On the other hand, the Environment and Energy Just In Time concept treats environmental load measures and production equivalently and quantifies the impact of environmental load measures on production (quantity, time, etc.), thereby making it possible to realize operations that maximize productivity under the constraints of environmental laws and regulations (minimizing the deterioration of productivity). Here, "treating equivalently" means converting the production and environmental load of the factory into costs and evaluating them using a unified index.

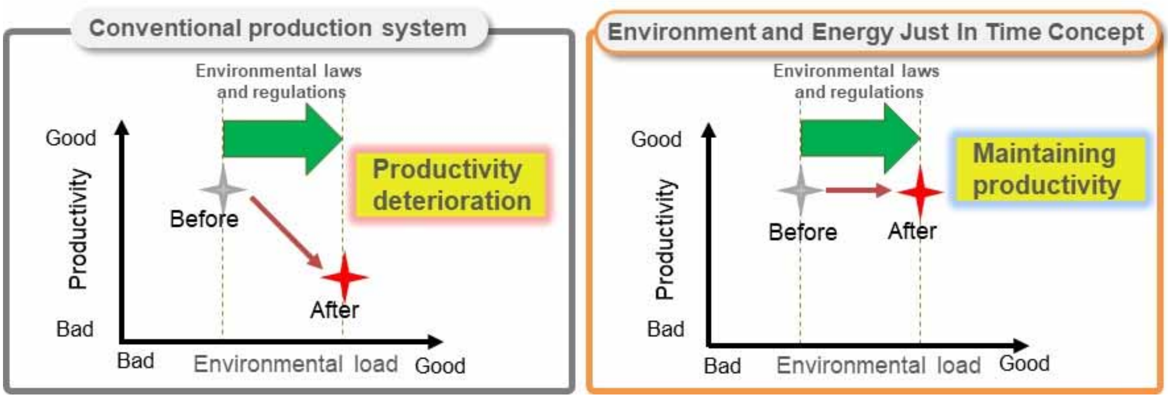

Fig. 1 Production management based on the Environment and Energy Just In Time Concept

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3. Production Improvement Framework for Reducing Environmental Load while Maintaining Productivity

The Production Improvement Framework for Reducing Environmental Load while Maintaining Productivity supports users (production site managers, etc.) in making improvements by presenting them with production operation plans and the magnitude of improvement effects that minimize the costs of producer goods and the costs associated with the consumption and processing of resources related to environmental load, while complying with environmental laws and regulations, before users start daily production.

To improve the efficiency of using this framework, we have developed a function to calculate baselines and optimal values from past production performance data, and a simulation function to calculate costs related to producer goods and environmental load using these values as parameters.

3.1 Calculation of baselines and optimal values

This section describes the method of calculating baselines and optimal values for the amount of electricity, water, gas, and other resources consumed in production, and the amount of greenhouse gases (CO_2) and other harmful substances emitted. In this case, the target is electricity consumption.

3.1.1 Method of calculating the baseline

Since electricity consumption depends on the product model and the operating state of the facility (startup, in production, shutdown, changeover, etc.), data aggregation is performed by combining the electricity consumption data with the production quantity performance data in preparation for calculating the baseline. As shown in Fig. 2, the median value obtained by excluding outliers is taken as the baseline from the electricity consumption data aggregated by product model and facility operating state. In other words, the baseline is the electricity consumption of the facility when "the user operates it normally." Since past experience suggests that it is rare for data to follow a normal distribution, the quartile method (box plot) was used as an outlier extraction method.

3.1.2 Method of calculating the optimal value

In the same way as calculating the baseline, the minimum value after excluding outliers from the distribution of the aggregated data was taken as the optimal value (Fig. 2). In other words, the optimal value is the electricity consumption of the facility when "the user can reach a certain level by operating it well." Here, apart from normal production, the reason for excluding outliers is that prototypes may be produced with a significantly exceeded cycle time (seconds/piece), or express orders from customers may reduce the cycle time of the original facility specifications.

3.2 Production/environmental cost simulator

Figure 3 shows an overview of the production/environmental cost simulator. This simulator adds an environmental cost simulator that calculates the amount of environmental load and associated costs, to the existing production cost simulator that calculates the usage and cost of producer goods [3].

3.2.1 Method of calculating the optimal value

This simulator inputs the three types of data shown in Table 1: production system parameters, environmental load/cost parameters, and production operation plan data, and outputs the amount and cost related to various producer goods and environmental load. Production system parameters and environmental load/cost parameters are static design data such as production capacity and the configuration of production facilities in the target factory. On the other hand, production operation plan data is dynamic data that changes each time the simulation is executed. With these detailed setting data, the behavior of the actual facilities can be

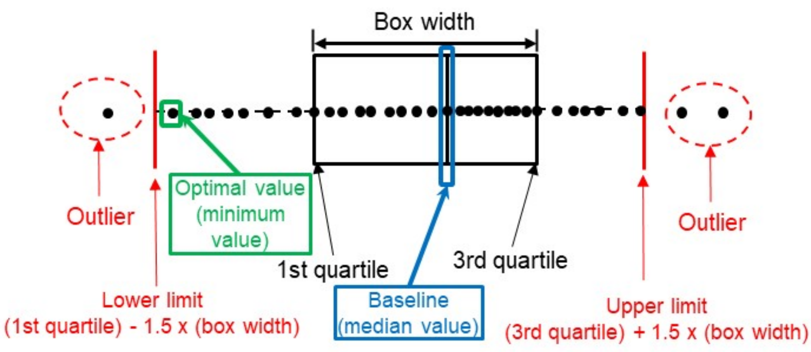

Fig. 2 Calculation of baseline and optimal values using the quantile method (box plot)

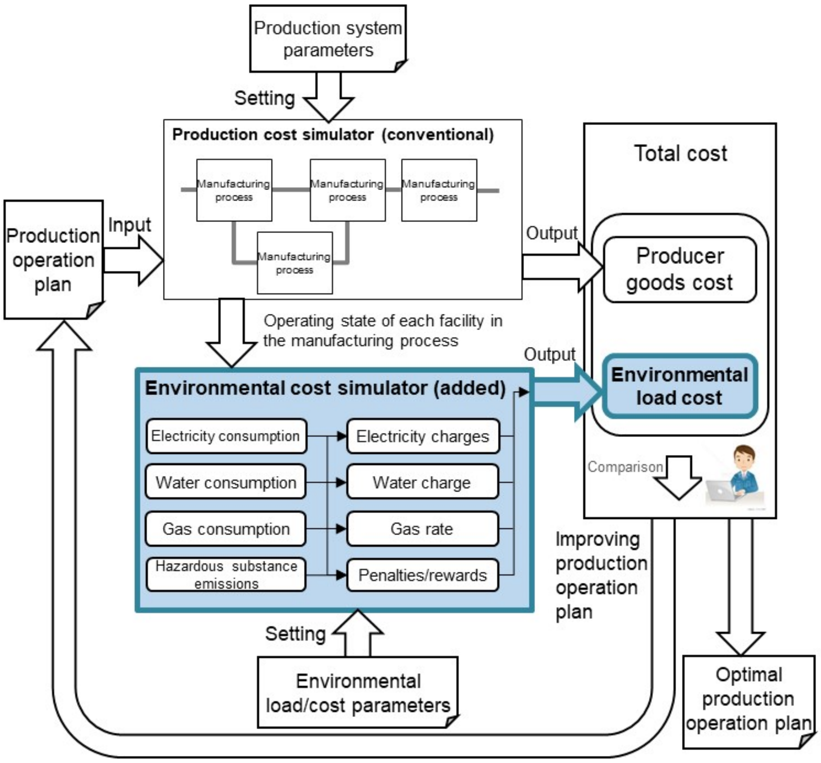

Fig. 3 Cost simulator for production and environmental load

Table 1 Input data of cost simulator for production and environmental load

Production System Parameters	Environmental Load/Cost Parameters	Production Operation Plan Data
• Production facility configuration (connection of the manufacturing processes) • Manufacturing capacity (cycle time, lead time, etc.) • Product model • Amount of material used (per product) • Labor (number of workers) • Changeover time • Work shift (hours) • Workday calendar • Unit price of producer goods	• Amount of environmental load for each operating state of various production facilities • Price list for electricity, water, gas, etc. • Penalties/rewards associated with environmental laws and regulations	• Production plan • Facility operation plan

reproduced. The baselines and optimal values calculated in Section 3.1 are used as the above production system parameters and environmental load/cost parameters.

3.2.2 Usage method

According to various improvement plans, the production system parameters, environmental load/cost parameters, and production operation plan data are varied, and then the costs are calculated accordingly to confirm the effects of the improvement plans. It is assumed that the person in charge of improvement and the user will repeatedly change various data so as to maximize the improvement effect. However, since it takes many man-hours to search for the data that maximizes the effect, we are currently working on automating part of the production plan.

3.3 Procedure for implementing the framework

The Production Improvement Framework for Reducing Environmental Load while Maintaining Productivity proposed in this study assumes that Steps 1 to 6 below will be repeated.

Step 1: Calculation of baselines and optimal values

Baselines and optimal values are calculated based on the performance data distribution of past consumption of resources such as electricity, water, and gas by production facilities and emissions of harmful substances such as greenhouse gases.

Step 2: Prediction of environmental load and cost when improvement measures are not applied

The person in charge of improvement enters the baseline and executes the simulation to calculate the amount and cost related to producer goods and environmental load under normal operation, that is, when improvement measures are not applied (hereafter referred to as the "unapplied value").

Step 3: Prediction of environmental load and cost when improvement measures are applied

The person in charge of improvement reflects various improvement plans, such as shortening the facility startup/shutdown time and changing the combination of changeover, in the production operation plan and parameters, and calculates the amount and cost related to producer goods and environmental load by simulation (using the optimal value) (hereafter referred to as the "applied value").

Step 4: Visualization of amount of improvement effect

To aim to bring the unapplied value closer to the applied value by applying various improvement plans, the difference between the improvement-unapplied value in Step 2 and the applied value in Step 3 is output and visualized as the amount of improvement effect.

Step 5: Improvement (by users)

The amount of improvement effect is presented to users, and after obtaining their approval, the improvement is performed mainly by the users.

Step 6: Analysis of differences between improvement-applied values and actual values

The person in charge of improvement collects the actual values during production, analyzes the causes of differences from the improvement-applied values, and extracts improvement plans for the next and subsequent times.

4. Demonstration Experiment

At an iron core press facility of our motor manufacturing factory, we conducted an experiment to demonstrate our view that it is possible to reduce environmental load without reducing current productivity, by using the Production Improvement Framework for Reducing Environmental Load while Maintaining Productivity.

4.1 Experimental conditions

(1) Target production facilities

Three production lines in the factory, including motor iron core press facilities that consume a lot of resources related to environmental load (in this case, electricity consumption)

(2) Target period

About two weeks from January 31, 2022 to February 11, 2022

(3) Period covered by data used to calculate baselines and optimal values

April 1, 2020 to March 31, 2021 (1 year)

(4) Targeted producer goods and environmental load resources

- Producer goods: labor (labor cost)
- Environmental load resources: Electricity (electricity rate), CO_2 (emissions trading cost)

CO_2 emissions were converted from electricity consumption, and CO_2 emissions trading costs used in some provinces in China were used for CO_2-related costs (transaction rate: approximately 1,000 yen/t-CO_2).

(5) Improvement plan

If the constraint is set to prevent deterioration in productivity, such as product quality and delivery time, the following three improvement plans are possible in this case.

- Improvement plan 1: Changing the production sequence
- Improvement plan 2: Shortening the facility startup time (before starting production)
- Improvement plan 3: Shortening the facility shutdown time (after the end of production)

4.2 Experimental results and discussion

Table 2 shows an example of calculating the baseline and optimal value of electricity consumption for each operating state (startup, shutdown, changeover, in production) of facilities when producing the product model A by implementing Step 1 of the framework. Table 3 shows three types of costs (annualized) for producer goods and environmental load: improvement-unapplied values, applied values, and actual values, when one cycle (Step 1 to Step 6) of the framework is performed using the baseline and optimal value for each facility operating state of all product models, including the results shown in Table 2. In this experiment, we were able to reduce the environmental load and cost by 1.5% without reducing productivity (2.3% improvement in this case), mainly due to the effect of implementing improvement plan 3.

Table 2 Example of calculation of baseline and optimal values for electricity consumption

Product Model	Facility Operating State	Baseline	Optimal value
Model A	Startup	5.1 [kWh] (3 hours)	1.0 [kWh] (1 hour)
	Shutdown	3.2 [kWh] (2 hours)	1.0 [kWh] (1 hour)
	In prduction	2.3 × 10-3 [kWh/piece]	2.0 × 10-3 [kWh/piece]
Model A → Model B	Changeover	2.0 [kWh] (2 hours)	1.0 [kWh] (1 hour)

Table 3 Producer goods and environmental load costs in the first cycle of improvement

	Producer Goods	Environmental Load	
	Labor cost (ten thousand yen/year)	Electricity (ten thousand yen/year)	CO_2 (ten thousand yen/year)
Unapplied Value	555	322	18
Applied Value	453	272	15
Actual Value	542	318	17

Table 4 Improvement plans and effects after the second cycle

Problems	Improvement Plans	Electricity (ten thousand yen/year)	CO_2 (ten thousand yen/year)
The cycle time setting value in production is lower than the facility specifications.	Operating the cycle time setting value at the minimum value in the facility specifications	25.2	1.4
Due to concerns about equipment failure (controller board), the (facility) shutdown has not been implemented after the end of production.	Improvement of the heat environment inside the control panel (addition/replacement of heat exchangers)	8	0.4
	Isolation of problem areas (division of power circuits in the control panel)		
It takes a long time to replace materials each time.	Work standardization (Educate beginners on the efforts of experts)	1.8	0.1
	Improving the work environment (effective use of lighting such as headlights)		
	Improving jigs (for inserting material only)		

In particular, there was a 14% difference between the (improvement) applied values and the actual values regarding the environmental load cost. Therefore, we analyzed the factors through interviews with users and data confirmation, and identified the problems shown in Table 4. In order to solve these problems, we extracted the improvement plans after the second cycle and calculated the amount of effect, and found that the environmental load cost can be reduced by 420,000 yen/year including the cost reduction in the first cycle (Table 4).

This demonstration experiment showed that it is possible to reduce the amount of environmental load and cost without reducing productivity, but this did not lead to the implementation of production improvement considering environmental laws and regulations.

In addition, using data from a period different from that of this experiment, we have confirmed, in previous evaluations, that the differences between the unapplied values calculated by simulation and the actual values when improvement was not implemented were sufficiently small, that is, the differences were not large enough to misjudge the amount of improvement effect presented in this study.

5. Conclusion

This paper proposed the Production Improvement Framework for Reducing Environmental Load while Maintaining Productivity to help determine the optimal balance between productivity and environmental load.

The results of the demonstration experiment showed that the first cycle for improvement using the framework can reduce the environmental load by 1.5% without reducing productivity. The results also showed that improvements after the second cycle can reduce environmental load and cost by 420,000 yen per year including the cost reduction in the first cycle. In the future, we will continue to conduct demonstration experiments at our factory with the aim of providing solutions using this framework.

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Versatile Mobile Robot System Realizing Contactless and Manpower-saving Solutions

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1. Introduction

In recent years, the market for service robots has been expanding with the acceleration of digital transformation (DX: transforming people's lives for the better by the spread of advanced digital technology). In particular, as the birthrate declines and the workforce shrinks, the demand for robots is increasing as a way of resolving the labor shortage and reducing the workload of essential workers to help create a sustainable society. In addition, the demand for mobile telepresence robots that enable non-face-to-face contact is increasing due to the novel coronavirus pandemic (Covid-19).

Therefore, we are developing a versatile mobile robot system with a telepresence function to realize contactless and manpower-saving solutions.

2. Concept

To date, robots that perform routine tasks, such as autonomous mobile robots that transport objects in factories, have been the mainstream, but in order to realize contactless and manpower-saving solutions, robots must be able to not only perform routine tasks but also respond according to the situation as humans do, including in emergencies.

Therefore, we are developing a versatile mobile robot with a telepresence function. This robot can perform routine tasks autonomously and, depending on the situation, can be operated remotely (telepresence) by human intervention to perform non-routine tasks, thereby enabling versatile use. As example applications, in this section we consider "use in a hotel to support peak times" to save manpower in hotel operations, and a "remote use in non-face-to-face work equivalent to face-to-face work regardless of time and space."

2.1 Hotel support

In a hotel, each employee typically handles a wide variety of tasks, and the busiest tasks differ depending on the time of day and situation, so employees dynamically switch between tasks depending on the peak. Therefore, even if robots, etc. are used to improve the efficiency of a single routine task, it is unlikely that enough manpower can be saved. Therefore, robots are designed to support the tasks of employees depending on the time of day and situation as follows:

(1) Transport guests' baggage to their room at check-in.
(2) Direct guests to restaurants during breakfast/dinner hours.
(3) In restaurants, help serve and clean up by moving between tables and kitchens and by carrying dishes.
(4) Patrol the facility at night and contact the hotel staff upon finding a fallen person, garbage or lost item.
(5) Deliver amenities and sheets for cleaning guest rooms at night to the linen room on each floor.
(6) Search the relevant area if a child or item becomes lost, and notify the hotel staff of the result.
(7) In a disaster, move to a branching point and guide the evacuation along the appropriate route.

Such abilities would improve efficiency during the busiest hours according to the situation, and help save manpower.

2.2 Remote robot operation

Currently, remote work, in which workers can do their tasks anywhere by using e-mail and phone, is spreading. However, many types of local work are difficult to do remotely, making it necessary to come to the office. In such cases, or where there are spatial or physical constraints, etc., the fact that only limited types of work can be done is a problem.

The following types of non-face-to-face remote work can be realized by remotely controlling a robot that acts on behalf of a worker who is working remotely at home:

(1) When receiving visitors, the person in charge remotely guides them to the work site via a video call. The work continues in a coordinated manner.
(2) If equipment in the building malfunctions, move close to the equipment and remotely check it with a camera.
(3) Robots can complement non-verbal communication such as gestures, thus facilitating dialogue.

This will enable workers who cannot come to the office due to spatial or physical constraints to handle a wider range of tasks, and thus help to alleviate the labor shortage.

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3. Feasibility Verification by PoC

When developing the versatile mobile robot system to implement the concept described in Section 2, it is necessary to increase customer acceptance and technical feasibility in order to encourage commercialization and expansion. To increase customer acceptance, it is important to consider not only the actual needs that customers are already aware of, but also their potential needs that they have not yet noticed. Therefore, the cycle of proof-of-concept (PoC) design, construction, evaluation, and verification based on customer feedback is repeated to clarify potential needs.

As the first phase of PoC, we have developed a versatile mobile robot system that can set tableware, which is one type of hotel support, in cooperation with our arm-type collaborative robot MELFA ASSISTA (1). This PoC is intended to verify the technical feasibility and to identify customer requirements for moving objects through dialogue with customers.

The PoC scenario is as follows.

(1) A versatile mobile robot moves from its home position to a tableware receiving position when a remote operator instructs it to start serving dishes.
(2) An on-site worker puts a tray with tableware on the shelf of the robot.
(3) The robot moves to the handover position of MELFA ASSISTA, which arranges the dishes. After handing over the tray, the robot returns to its home position. Figure 1 shows how the tray is handed over.

When communication is needed, such as when the on-site worker informs the remote operator that the robot has started delivering tableware, the remote operator and the on-site worker can make a video call via the robot.

Our demonstration confirmed that the following functions are technically feasible in this scenario; the detailed functions of the versatile mobile robot system are described in Section 4 below.

(i) The robot can move autonomously to a designated location remotely.
(ii) The movement of the robot can be controlled while checking the camera image of the area in front of the robot, which is taken from a remote location.
(iii) A video call allows the remote operator and tableware dispenser to communicate.
(iv) Autonomous movement, remote control and video call can be switched seamlessly.

This versatile mobile robot system is exhibited at XCenter (2), a venue which exhibits DX and smart city-themed solutions. Discussions with customers are currently underway.

Furthermore, while collecting knowledge from the first PoC, we are considering external demonstrations with customers for operations such as transporting baggage between floors at hotels. Movement between floors is assumed to be done by elevator linkage using Ville-feuille (3).

4. Details of the Versatile Mobile Robot System

This section describes the details of the versatile mobile robot system developed in the first PoC.

4.1 System architecture

The versatile mobile robot system consists of ceiling cameras, infrastructure positioning devices equipped with Ultra Wide Band (UWB), a robot, a remote-control terminal held by the robot operator, and a server unit that controls these devices, which communicate with each other via 5G

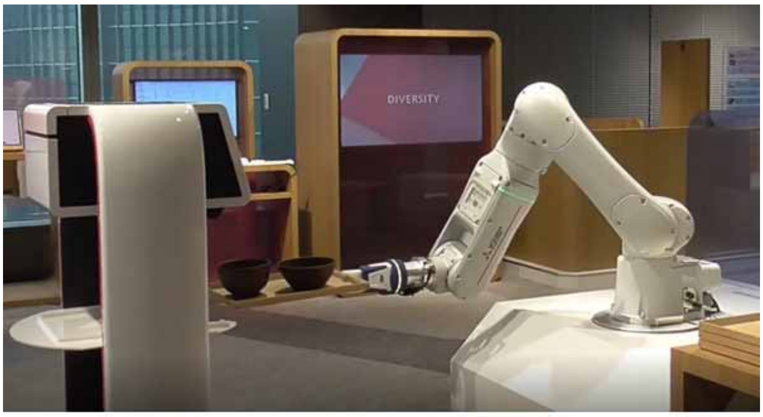

Fig. 1 Cooperative working between the versatile mobile robot and MELFA ASSISTA

(fifth-generation mobile communication system), Long-Term Evolution (LTE), and Wi-Fi *1. Figure 2 shows the system architecture. In this study, the server unit, which includes camera processing, sensor processing, bird's-eye view image creation processing, mobility control processing, and applications for robot operation, was configured on-site; part or all of it could also be constructed in a cloud server.

In the effective range from where ceiling cameras and UWB infrastructure positioning devices are installed, the robot can drive autonomously even in areas where there is no pre-built map information or where the layout changes frequently.

4.2 Functions provided

The versatile mobile robot system has a remote control function, an autonomous driving function, and a remote video call function, which can be executed by a remote control terminal.

4.2.1 Autonomous driving

In autonomous driving, the remote operator sets the waypoints and destination of the robot on the bird's-eye view image, and then the robot sets the driving route and moves. If there is an obstacle on the movement path, the robot generates an avoidance path and then moves while avoiding the obstacle. Figure 3 shows the operation display for autonomous driving.

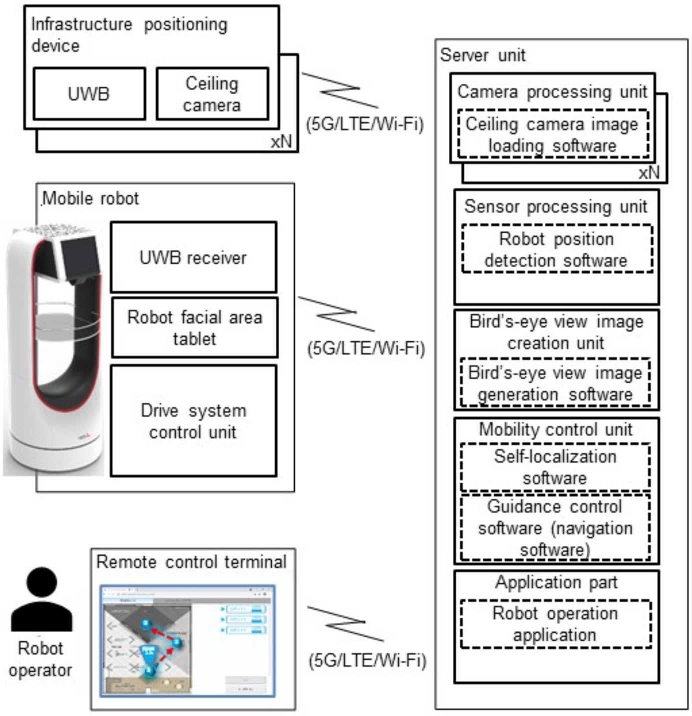

Fig. 2 System architecture

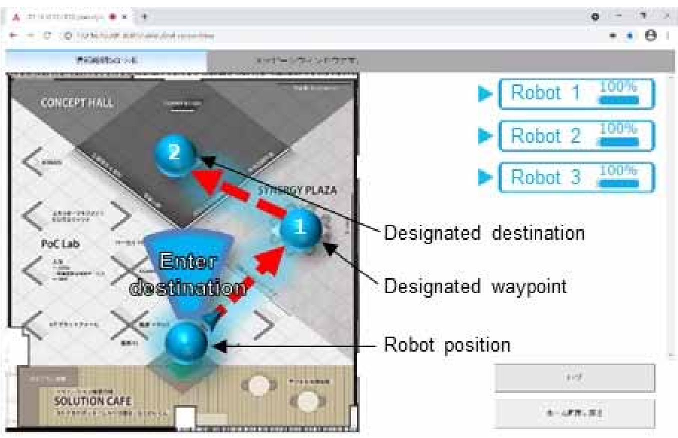

Fig. 3 Operation display of autonomous driving

1 Wi-Fi is a registered trademark of the Wi-Fi Alliance.

4.2.2 Remote control

Remote control is performed by switching between two movement operation modes as necessary while watching the image of the camera capturing the area in front of the robot.

In the first movement operation mode, ClicktoDrive, the destination of the robot is designated by touching the desired location on the remote control terminal, which is effective when the robot moves to a distant place. Figure 4 shows the operation display of ClicktoDrive. The cross-shaped area is where the robot can move based on information from Light Detection And Ranging (LiDAR: a device that measures the distance to an object using light); when the operator touches any point in the area, a marker is displayed at that point and the robot moves to it.

In the second movement operation mode, DirectDrive, the robot moves according to the movement amount, direction, or rotation specified on the operation display, which is effective for fine-tuning the position. Figure 5 shows the operation display of DirectDrive. When the operator touches the arrow indicating forward or backward, or the arrow indicating rotation, the robot moves accordingly.

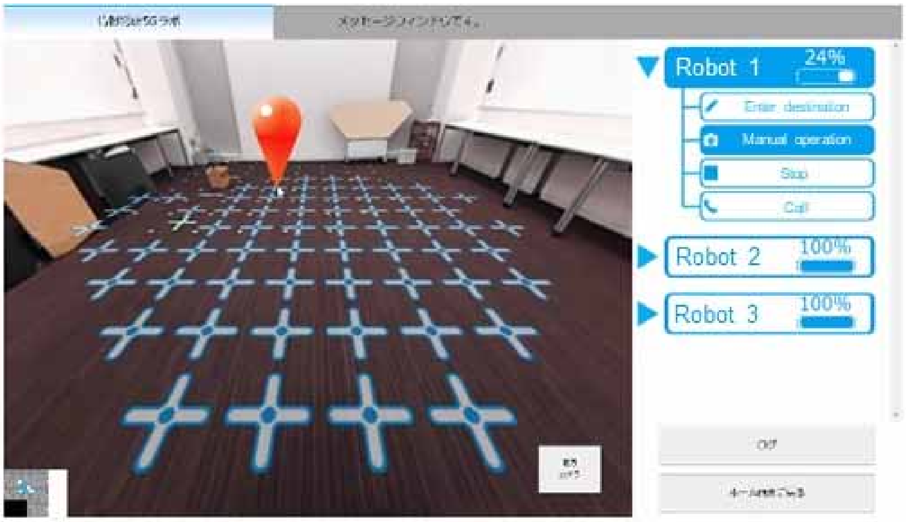

Fig. 4 Operation display of ClicktoDrive mode

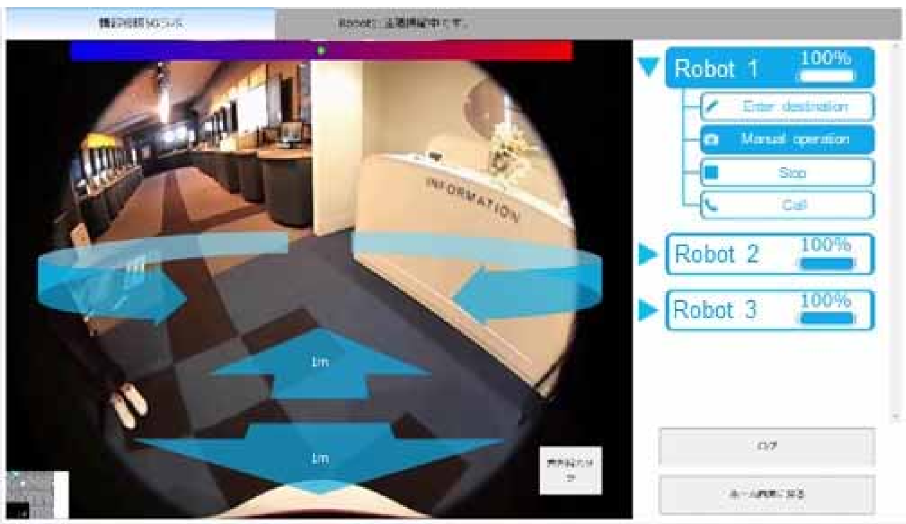

Fig. 5 Operation display of DirectDrive mode

Fig. 6 Situation of remote video call

4.2.3 Remote video call

Remote video call enables video calls between the remote control terminal and the robot. On the robot side, the camera image of the remote control terminal is displayed on the tablet installed in the robot's face area, and on the remote control terminal side, the image of that camera is displayed. Figure 6 shows the situation of a remote video call.

The video call can be made from either the remote operator or the robot side, and can be used by the remote operator to call the site, or by the person on site to contact the remote operator.

5. Conclusion

This paper described our development of a versatile mobile robot system that offers contactless, manpower-saving solutions, as well as our first PoC of the system for the two applications of tableware serving and remote communication.

Currently, we are verifying and validating the first PoC, and will repeat the cycle of PoC design, build, evaluation, and validation by utilizing the knowledge obtained. This will result in solutions that are popular with customers and lead to the expansion of our robot business.

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