Proposals and Evaluations of Robotic Attendance at On-Site Network Maintenance Works*

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SUMMARY   While the introduction of softwarelization technologies such as software-defined networking and network function virtualization transfers the main focus of network management from hardware to software, network operators still have to deal with various and numerous network and computing equipment located in network centers. Toward fully automated network management, we believe that a robotic approach will be essential, meaning that physical robots will handle network-facility management works on behalf of humans. This paper focuses on robotic assistance for on-site network maintenance works. Currently, for many network operators, some network maintenance works (e.g., hardware check, hardware installation/replacement, high-impact update of software, etc.) are outsourced to computing and network vendors. Attendance (witness work) at the on-site vendor's works is one of the major tasks of network operators. Network operators confirm the work progress for human error prevention and safety improvement. In order to reduce the burden of this, we propose three essential works of robots, namely *delegated attendance at on-site meetings*, *progress check by periodical patrol*, and *remote monitoring*, which support the various forms of attendance. The paper presents our implementation of enabling these forms of support, and reports the results of experiments conducted in a commercial network center.

key words: network management, automation, robot, ROS, cyber-physical world

1. Introduction

It is essential for network operators to reduce CapEx and OpEx of maintained networks. Especially focusing on the reduction of OpEx, automation of network management has been widely discussed. For example, the Experiential Networked Intelligence Industry Specification Group (ENI ISG) in ETSI [1] is taking on the challenge of defining architecture of automated network management and developing the necessary standards. The ENI ISG has also begun to incorporate emerging artificial intelligence (AI) technologies into these works. The network management system collects various types of data from the network and analyzes it to solve problems of network deployment and operations.

One of the efficient approaches in OpEx reduction is incorporating softwarelization technologies, such as software-defined networking and network function virtualization. Introduction of such softwarelization technologies is moving the main target of network management from hardware to software; however, network operators must still handle a large amount of diverse network and computing equipment that is located in network centers. When network operators want to expand the system, they have to install the equipment in server racks, connect network cables, turn on and configure the equipment, etc. These operations are usually carried out manually.

Toward fully automated network operations, we believe that it will be important for physical robots to handle network and computing equipment on behalf of humans. At a past APNOMS conference, we presented a roadmap for a network management robot [2], which raised three possible use cases i.e., environmental monitoring, operator assistance, and autonomous equipment maintenance. This paper focuses on robotic assistance for on-site network maintenance works, which corresponds to operator assistance because human attendance works account for a large part of the network maintenance works of network operators. In order to reduce the burden of network operators, we derived three functionalities and evaluated them.

In the following sections, the roadmap of robot utilization and related works are explained in Sects. 2 and 3, respectively. In Sect. 4, current attendance work of on-site maintenance works is reviewed. Based on this, Sect. 5 derives three functionalities that support the various forms of attendance. Our hardware and software implementation are explained in Sect. 6, and experimental results are reported in Sect. 7. Toward practical use of the robots, Sect. 8 discusses related issues and shows comparison with other IT system. Finally, this paper is concluded in Sect. 9.

2. Roadmap of Robot Utilization for Network Maintenance Works

Toward fully automated network operations, we believe that another important approach will be for physical robots to handle network and computing equipment on behalf of humans. In [3], the robot is defined as "intelligent mechanical systems with three elemental technologies: sensors, intelligent/control systems, and drive systems" with capturing the robot from the market side. This paper follows the same definition.

At a past APNOMS conference, we presented a roadmap for a network management robot as shown in Fig. 1 [2]. While robotic technologies are rapidly evolving, there
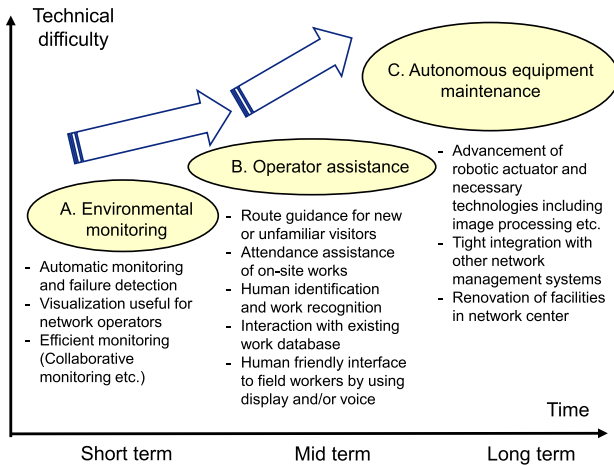
Fig. 1   Roadmap of network management robot.

are still many technical issues to be addressed before versatile robot operations can be realized. Thus, we suppose that utilization of robots for network management will be promoted in an incremental manner. In the following, three possible use cases for robots' utilization are explained in which the target time ranges from short term to long term.

- *Environmental monitoring (short term):* As the initial step, the robot can be utilized to monitor environmental data (e.g., temperature, humidity, noise or air flow, etc.) in the network center. The robot, to which some sensors are attached, periodically moves around the network center and collects the environmental data. If the robot identifies an abnormal value, it sends an alert to the network operator.

- *Operator assistance (medium term):* We suppose that human operators and robots will coexist in each of the network maintenance works. This would continue within the next decade since it would take considerable time to actualize fully automated network management robots. One of the typical use cases during this period would be robots assisting the work of network maintenance. Route guidance using the robot can be included in this use case since the network center is very large and new, or unfamiliar visitors often become lost. In addition, attendance (witness work) at on-site vendor's works (e.g., hardware check, hardware installation/replacement, high-impact update of software, etc.) is one of the major tasks of network operators. With the help of robots, the workload of attendance can be reduced. Moreover, in an advanced example, when the robot locates the workers (i.e., operators and/or vendors) in the network center, it automatically identifies which planned works the workers are dealing with, and judges whether the work is progressing on schedule or not.

- *Autonomous equipment maintenance (long term):* In the final stage of the robotic approach, when the robot receives a message indicating that network or computing equipment is broken, it autonomously replaces the

broken equipment with new ones. To actualize such a scenario, some technical challenges must be tackled. That is, the robot first determines the specific solution to deal with the broken equipment, identifies and removes it, installs new equipment, connects network cables, starts the equipment, etc. Meanwhile, automatic checking of LED status by the robots is also included in this use case (i.e., autonomous equipment maintenance). There should be a discussion of what type of robot is appropriate (whether a self-supporting robot is the best match or not).

3. Related Works

There are some related works regarding utilization of physical robots for the management of a network center and a data center. The works are applicable to any of the three use cases described in Sect. 2 (i.e., environmental monitoring, operator assistance, and autonomous equipment maintenance). Since the number of published papers is limited, patents and its applications were also investigated on the Japan Platform for Patent Information (J-PlatPat) [4].

Related works and inventions are described below for each use case.

- Environmental monitoring

  Many of the related works and inventions fall into this use case. As pioneers of the robotic approach, IBM researchers developed a robot for temperature monitoring within a data center in 2011 [5], [6]. The robot was equipped with a web camera and some thermal sensors on top of the iRobot Create robotic research platform [7]. It then realized real-time generation of the data center layout and thermal map. A similar approach was taken in [8], which especially focused on temperature monitoring in small or medium-sized server rooms. Following these efforts, a more versatile robotic system was developed based on the Robot Operating System (ROS) [9] to autonomously navigate in a data center by using general LiDAR equipment [10], [11]. The ROS is an open-source, meta-operating system used for robot software development, providing a collection of packages, software-building tools, and an architecture for distributed inter-process and inter-machine communication. The ROS is nowadays becoming the de-facto standard for robotic software development. In [12], a specially structured robot was invented that could quickly measure spatial temperature distribution in a data center by measuring temperature and airflow on the move.

- Operator assistance

  In order to assist the operator's work in a network and data center, some efforts have been made. In [13] and [14], IIJ engineers conducted experiments in a data center by utilizing a commercial security robot (i.e., ALSOK REBORG-Z [15]). In their approach, the robot was used for route guidance to a designated server room for new visitors. It was also used for patrol works in the data center to check whether the doors are properly locked and whether there are
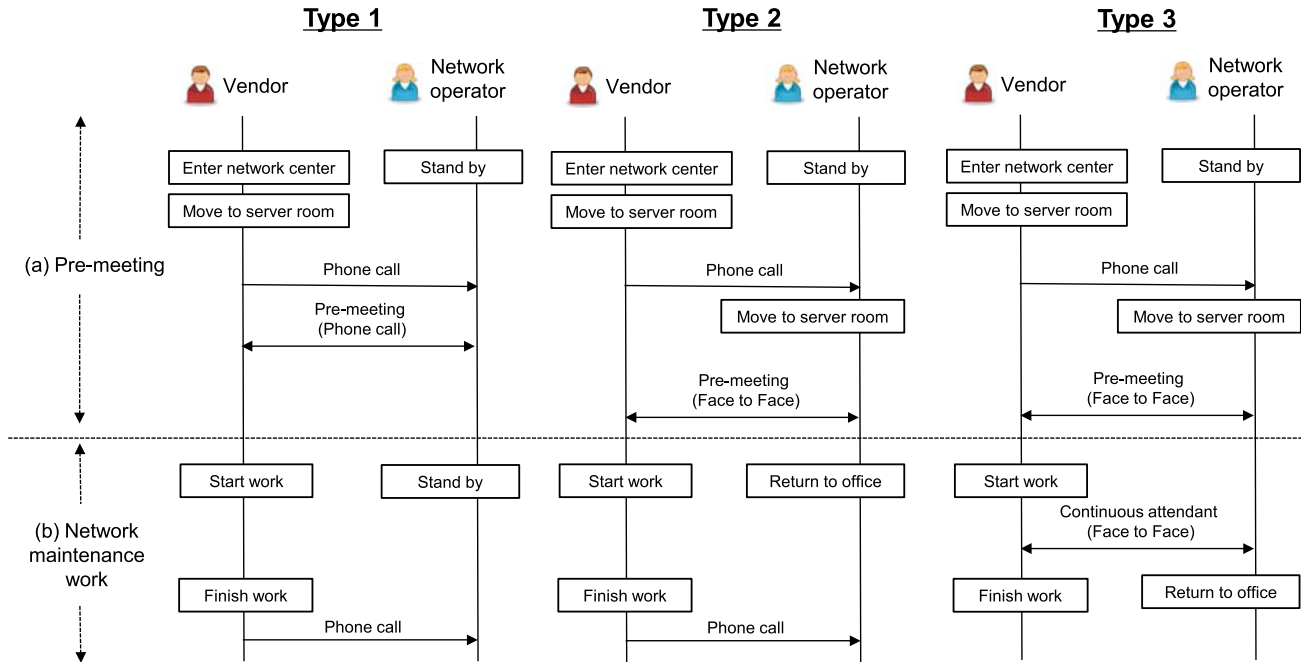
Fig. 2 Three types of attendance at on-site maintenance works.

any falling objects. In [16], a high-security guiding system was invented that creates an optimal route from a security perspective and designates the route to the guiding robot. When the visitors deviate from the designated route or enter an unauthorized zone, the system detects it and then sends an alert to the network operators. However, these past works do not take into account the use case of assistance for on-site network maintenance, which is the target case in this paper.

• Autonomous equipment maintenance

While the road to fully autonomous equipment maintenance is still long, some initial steps have been taken. In [17], the robot was equipped with an optical camera and it autonomously detected the LED emission status of the network and computing equipment. In [18], a robot was invented that further determined the status of equipment based on its LED emission and pressed the button on the equipment according to the status.

This paper especially focuses on robotic assistance for on-site network maintenance works, which corresponds to operator assistance because human attendance works account for a large part of the network maintenance works of network operators. As described above, past related works do not address this use case.

4. Attendance at On-Site Maintenance Work

In this paper, network operators are defined as companies that provide telecom services and operate the systems necessary to provide those services. For the most network operators including KDDI (one of the major network operators in Japan), some network maintenance works are outsourced to vendors. The vendors may be companies which manufacture and sell computer or network equipment by themselves, or special-

ized companies for operations and maintenance. Based on a maintenance contract with the network operator, the vendor maintains and operates part of the network operator's overall system. While some works are conducted from remote sites (e.g., status check, alert monitoring, low-impact update of software, etc.), other works are conducted on site (e.g., hardware check, hardware installation/replacement, high-impact update of software, etc.).

The vendor authority and responsibility vary widely depending on the maintenance contract. Meanwhile, ultimate responsibility lies with the network operator when the network operator's system fails and the telecom services are affected. For example, in Japan, the law stipulates that if the network operator experiences a serious failure, the network operator must report it to the government without delay, along with the reason or cause of the failure. Therefore, the network operators need to supervise the vendor's work. Regarding the above vendor's on-site works, attendance at the vendor's maintenance works is an essential work for the network operators. It helps to not only prevent human error and but also improve safety on site. In this paper, the vendor's on-site works are focused because attendance at the works is one of the major tasks of the network operators.

In KDDI's network centers, attendance is classified into three types according to the risk points evaluated in advance. The three types are illustrated in Fig. 2 and explained below.

• **_Type 1:_** The network operator only attends a pre-meeting in a remote manner. It is the most lightweight method of attendance and is applied to low-risk maintenance works. Specifically, when the vendors arrive at the reception desk of the network center, they take necessary procedures such as ID verification, fill-in of

the required information, etc. After moving to a server room, they make a phone call to the network operator in charge in order to have a pre-meeting ((a) in Fig. 2). In the pre-meeting, they confirm the contents of the day's work and its schedule, and also check the required tools and discuss how to deal with possible risks. The pre-meeting is indispensable to prevent human error and improve safety of the works. After the pre-meeting, the vendors start the maintenance work ((b) in Fig. 2) and the network operator stands by in their office. When the vendors finish the work, they make a phone call to the network operator and report the results of the work.

- ***Type 2:*** In this type, the vendors and the network operator have the pre-meeting face to face. When the vendors arrive at the server room, they make a phone call to the network operator and then the network operator moves to the server room. In the pre-meeting, the network operator can check the required tools with their own eyes and they can discuss possible risks while seeing the target server and network equipment. After the pre-meeting, the network operator returns to their office and waits for the phone call from the vendors to share the results of the work.

- ***Type 3:*** This type is the most heavyweight method of attendance and is applied to high-risk maintenance works. Simply speaking, the network operator attends the server room during the entire work. The network operator has the pre-meeting face to face as in Type 2, and continuously attends the entire maintenance work.

In KDDI's network center, server rooms are distributed in several buildings. In such a large network center, the travel time from the office to the server room is not negligible (e.g., it takes up to 15 minutes) even in the same network center. In Type 3, the actual attendance time of the entire work varies on a case-by-case basis, and the more critical network maintenance works vary more easily, which makes it difficult to be tightly scheduled.

5. Proposals of Robotic Attendance at Network Maintenance Works

In order to reduce the burden of network operators, we discussed how the robots are utilized and derived the necessary functionalities of robots. In this section, we propose three functionalities: A. *Delegated attendance at on-site meetings*; B. *Progress check by periodical patrol*; and C. *Remote monitoring*. By utilizing these functionalities, our approach supports all types of attendance (Table 1). The pre-meeting in Types 1, 2, and 3 is supported by A. *Delegated attendance at on-site meetings* whereas attendance at maintenance work of Types 1 and 2 is supported by B. *Progress check by periodical patrol* and that of Type 3 is supported by C. *Remote monitoring*.

Table 2 summarizes comparisons between current attendance works and our approaches. As shown in Table 2, our approach contributes to reducing the burden of network

Table 1 Relationship between three functionalities (from A to C) and existing three types of attendance (from Type 1 to 3).

Type of attendance	Risk	A	B	C
Pre-meeting in Type 1	Low	X		
Maintenance work in Type 1			X	
Pre-meeting in Type 2	Middle	X		
Maintenance work in Type 2			X	
Pre-meeting in Type 3	High	X		
Maintenance work in Type 3				X

A: Delegated attendance at on-site meetings
B: Progress check by periodical patrol
C: Remote monitoring

Table 2 Comparisons between current attendance and our approach.

No.	Current attendance works	Our approach
1	For face to face attendance, the network operator has to move to the server room. In a large network center, travel time to the server room is not negligible (e.g., 15 mins.).	All attendance works are conducted remotely. It saves time of network operators.
2	There is no attendance for network maintenance work in Type 1 and 2 ((b) in Fig. 2).	Attendance is supported by B. *Progress check by periodical patrol*. It contributes to the reduction of human errors.
3	Attendance work of the pre-meeting in Type 1 is conducted by a phone call (i.e., voice only).	The attendance is support by A. *Delegated attendance at on-site pre-meetings*. Throughout the video call, the network operators can check required tools and so on with their own eyes.

operators (No. 1 in Table 2) as well as further human error prevention and safety improvement (No. 2 and No. 3).

Details of each functionality are explained in the following sub-sections.

5.1 Delegated Attendance at On-Site Meetings

Basically, it should be demanded that the robot attend the on-site pre-meeting on behalf of the network operator. Ideally, the robot has information on the contents and schedule of the day's work and confirms them with the vendors by voice conversation, etc. In addition, the robot takes photos of tools brought by the vendors, analyzes them by image recognition technologies, and checks whether the tools are appropriate or not. Moreover, the robot has or accesses the knowledge database storing information of past maintenance works and identifies possible risks by using AI-based analyzing technologies, etc. and discusses how to deal with them with the vendors. However, necessary technologies to realize this scenario have not been sufficiently developed, and the knowledge database is not fully maintained, either. Since, in such an environment, the fully automated attendance explained here is not realistic, we take a different approach.

In our approach, attendance at the on-site meetings is divided into two phases. In the first phase (called the simple check phase hereinafter), predetermined items are checked in the prescribed way. Examples of predetermined items are

confirmation of check of the worker's physical condition, division of roles among work managers and workers, check of the version of procedure manuals, etc., and identification of a contact person in the event of a problem. In our current approach, these checks are performed by using a touch panel with which the robot is equipped without the intervention of the network operator. After the vendors inputs the necessary information on the touch panel, the information is sent to the network operator. The network operator can check the input information on their screen if necessary.

On the other hand, some check items require complex decisions and it is difficult to check them in the prescribed ways. Examples are checking whether the required tools are properly prepared and confirmation about possible risks, etc. In our approach, these checks are performed by a video call between the vendors and the network operator, as the second phase (called the deep check phase hereinafter). The network operator can check the required tools with their own eyes and they can discuss possible risks while seeing the actual server and network equipment.

Based on the above consideration, overall operations are summarized as follows (Fig. 3).

- Firstly, the robot has information of the contents and schedule of the day's work. It automatically moves to the designated server room prior to the start of the pre-meeting. It then displays the start screen of the pre-meeting on a touch panel.
- After the vendors arrive at the server room, they press a start button on the touch panel. Then, the vendors input the necessary information on the touch panel. The information is sent to the network operator and then the network operator checks the information (simple check phase).
- After the input on the touch panel, the vendors start the

video call. The vendors and network operator check the required tools and discuss how to deal with possible risks (deep check phase).
- After the video call, the vendors start the maintenance work. The robot returns to the designated location in Type 1 and 2, or it stays at the place in Type 3.

Compared to the existing pre-meeting in Type 1 (Fig. 2), the network operator can check the required tools with their own eyes and they can discuss possible risks while seeing the actual server and network equipment. Compared to the pre-meeting in Type 2 and 3, the network operator does not have to move to the server room, so it saves time and effort of the network operator.

5.2 Progress Check by Periodical Patrol

This functionality of the robot realizes progress check of the maintenance work especially for Type 1 and 2. In the method of current attendance work explained in Sect. 4, there is no check of the work progress in Type 1 and 2. Thus, this functionality contributes to further human error prevention and safety improvement.

In this functionality, the robot patrols designated server rooms periodically and checks the progress of several works one by one. Ideally, the robot takes photos or videos of the vendor's work and checks whether the work is being conducted properly and safely, and as planned. If the robot detects any problems, it sends a notification to the network operator. However, for such fully automated operation, necessary technologies are not sufficiently developed.

In our approach, the robot patrols designated server rooms periodically, takes photos of the vendor's work, and sends them to the network operator. The network operator can check whether the work is being conducted properly and safely. To relieve some of the burden of the network operator, some image-processing technologies can be utilized. For example, AI-based image recognition functions such as single-shot detector (SSD) [19] and you only look once (YOLO) [20] are installed on either the robot or network side. On receiving photos taken by the robot, the functions first conduct image recognition and then check them by comparing them with registered work plans. If the vendors are working over the scheduled time or working outside of the planned area, a notification is sent to the network operator. As explain in Sect. 4, in the actual field, there is no check of work progress in Type 1 and 2. Through this functionality, the network operator can quickly recognize schedule overruns and wrong working location.

5.3 Remote Monitoring

This functionality is especially for the check of maintenance work in Type 3. By controlling the robot from a remote site, the robot can work as a physical avatar of the network operator. Throughout this functionality, the network operator can monitor the vendor's maintenance work as well as status of
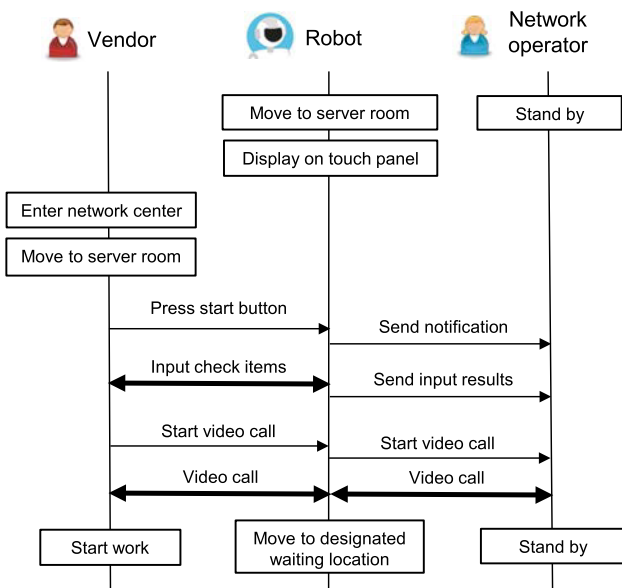

Fig. 3 Flow for delegated attendance at an on-site meetings.

equipment in real time.

Specifically, videos captured by embedded cameras are constantly transmitted to the network operator. The network operator can move the robot to the desired location by remote control while monitoring the videos. During the vendor's work, the network operator can monitor the work and the equipment from the remote site. Moreover, by utilizing the microphone and speaker mounted on the robot, the network operator and the vendors can have a video call in a prompt manner.

There are two ways to remotely control robot movement: manual and autonomous operations. In manual operation, the network operator can move the robot by directly controlling the moving direction, speed, etc. In autonomous operation, the network operator only designates the desired location on the GUI screen. The navigation functions of the ROS [9] execute path planning and lead the robot to the proper location. Both operations are supported in our implementation, and the evaluation results and a discussion of them is presented in Sect. 7.

Moreover, the height of the cameras embedded in the robot is usually unchangeable. However, in our use case, the height of the cameras should be dynamically configured in order to monitor the equipment located on the server rack from the bottom to the top.

6. Implementation

Based on the description in Sect. 5, we developed a prototype of the robot for proof of concept. Both hardware and software implementations are explained below.

6.1 Hardware Implementation

Our developed robot is shown in Fig. 4 and major specifications are shown in Table 3. Utilizing an existing automatic guided vehicle (AGV) product [21], some parts are customized for usage in the network center.

Firstly, in order to take photos or videos of the server racks from the bottom to the top, the height of embedded cameras should be dynamically configured. For this reason, a lifter is embedded over the AGV. By lifting and lowering the lifter in the vertical direction, the cameras can capture from the bottom to the top of the server racks. Secondly, the size of the AGV is reduced from the original. Since the passage in the server rooms is narrow, only about 0.9 [m], the size is customized to run the robot safely. In addition, to support the three functionalities described in Sect. 5, the necessary equipment such as cameras, a touch panel, a microphone, and a speaker is installed. Four cameras are installed front, back, left, and right of the robot, respectively. A Wi-Fi client is also installed to transmit necessary information to the operator's terminal and communicate with the network operator.
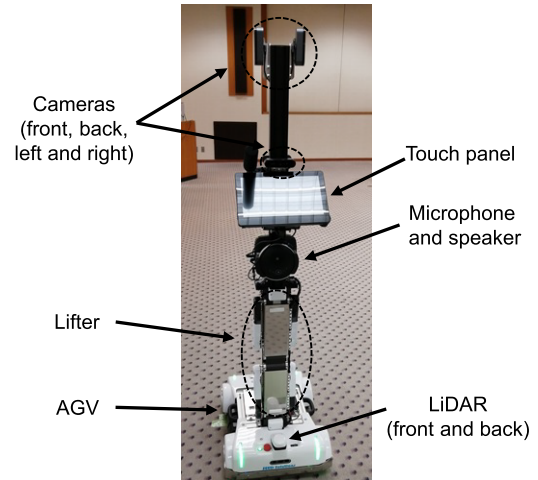

Fig. 4　Developed robot.

Table 3　Major specification of the developed robot.

Item	Value
Maximum translational velocity	0.42 [m/s]
Size (W x D x H)	458 [mm] x 573[mm] x (max.) 1700 [mm]
Weight	48 [kg]
Expected operating time	2 [hour]
LiDAR	HOKUYO UST-20LX x 2
Computing resource	Core i7 based compact PC
Middleware	ROS melodic on Ubuntu 18
Installed equipment	Camera x 4 Touch panel x 1 Microphone x 1 Speaker x 1 Wi-Fi client (11ac) x 1

6.2 Software Implementation

Figure 5 shows the configuration of the developed software on the robot and the operator's terminal. The terminal is located in the network operator's office. The internal interfaces within them are omitted in Fig. 5.

We implemented the software required for the three functionalities. For example, on the robot side, the touch panel interface and video call client are implemented for *delegated attendance at on-site meetings* (A in Fig. 5), and photo capturing is implemented for *progress check by periodical patrol* (B). Furthermore, a video streaming server is implemented for *remote monitoring* (C). The video streaming server supports simultaneous inputs from four cameras and the network operator can select front, back, left, and right videos of the robot. Moreover, master function of ROS is implemented on the robot side. This means that the ROS's major navigation functionalities such as simultaneous localization and mapping (SLAM) [22] and path planning [23] are running on the robot. This implementation can avoid communication delay caused in networks between the robot and the operator's terminal. Meanwhile, the main software components required for the three functionalities are imple-
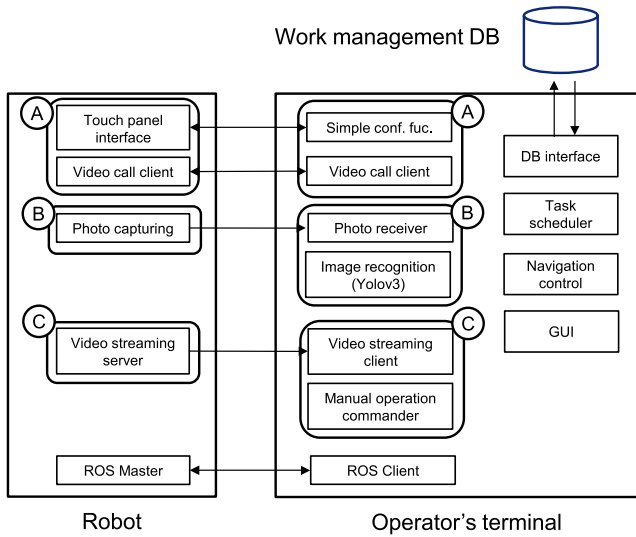
Fig. 5 Configuration of developed software.

Fig. 6 Scene during evaluation.

Table 4 Results of 5-point evaluation of delegated attendance at an on-site meetings.

Evaluation items	Average
Usability of touch panel	4.8
Video quality of video call	4.5
Voice quality of video call	3.8
Overall evaluation	4.0

mented on the operator's terminal. For example, the image recognition module (YOLOv3 [20]) is implemented on the operator's terminal, but not in the robot, because GPU functionality is required.

Regarding common functions, DB interface, task scheduler, high-level navigation control, and GUI are implemented on the operator's terminal. Through the DB interface, the operator's terminal can obtain the contents and schedule of each work from the work management DB. In addition, the results of delegated attendance at on-site meetings and progress check by periodical patrol can be stored in the work management DB. The task scheduler creates a schedule of the robot based on the schedule of each work obtained from the work management DB. The high-level navigation control publishes the necessary ROS commands to the ROS master on the robot and also deals with some errors. For example, when the robot fails to reach a destination for any reason, it decides how to deal with the failure (e.g., retry to the same destination, divert to another destination, abort, etc.). The GUI is a graphical interface to the network operator. The network operator can check the results of delegated attendance at on-site meetings and progress check by periodical patrol. In addition, the current position and status of the robot can be monitored in real time.

In the current implementation, all necessary functions are implemented in a single robot. In the future, when multiple robots are deployed in the network center, some functions can be distributed into multiple robots and cooperatively achieved among them.

7. Evaluations

By using the developed hardware and software, we conducted preliminary evaluations in KDDI's commercial network center. The evaluations were conducted in a single server room approximately 1,000 [m^2] in size. For preparatio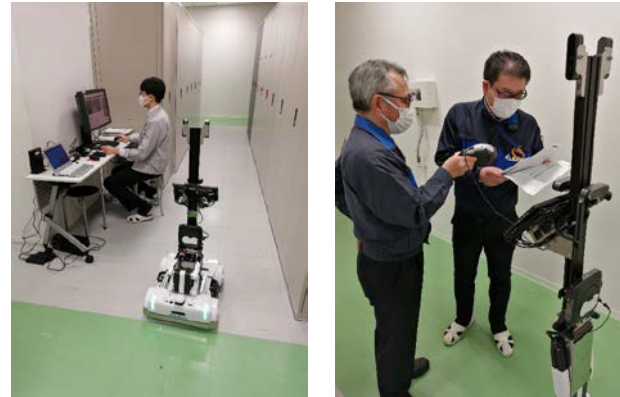n, using the SLAM function of the ROS, we created a digital map of the server room that is used for autonomous operation. In addition, some of the ROS parameters were made suitable for the server room. The scene during the evaluation is shown in Fig. 6 and a demonstration video is available on YouTube's KDDI Research channel [24].

In the following, the outline of the evaluation results of the three functionalities is explained.

7.1 Delegated Attendance at On-Site Meetings

In this functionality, the robot attends the on-site pre-meeting as an avatar of the network operator. The vendors check the pre-determined items displayed on a touch panel and the network operator can check them (simple check phase). After that, the vendors and the network operator directly communicate by video call (deep check phase). Since a key performance of the functionality is how easy it is to use, we conducted a subjective evaluation with the help of four KDDI employees.

Firstly, the results of the 5-point evaluation are shown in Table 4. As shown, the average overall evaluation is 4.0 (5.0 is very good, 3.0 is average, and 1.0 is very bad) and it is a relatively good result. The rating of voice quality of the video call is lower than that of the other evaluation items. In the server room, noise from the server and network equipment is very loud and it degrades voice quality.

Secondly, free comments are collected from the evaluators in order to make further improvements to the system. Some suggestions from the evaluators are introduced below.

- In the simple check phase, it would be good to be able to change check items according to the contents of the work.
- During the video call, it would be good to able to refer to

Table 5 Evaluation result of image recognition using photos taken in the server room.

		Result of image recognition	
		Positive (with person)	Negative (w/o person)
Correct answer	Positive (with person)	238	15
	Negative (w/o person)	2	729

detailed information of the work by a simple operation.
- It would be good to be able to control the direction of cameras remotely. This would allow us to check the surroundings carefully.

7.2 Progress Check by Periodical Patrol

In this functionality, the robot patrols the designated server rooms periodically, takes photos of the vendor's work, and sends them to the operator's terminal. The operator's terminal processes the photos by image recognition technologies and detects if a person is in the aisle or not. The terminal determines abnormality by comparing the results of image recognition with registered work plans. If the terminal decides whether the vendors are working over the scheduled time or working outside of the planned area, it sends a notification to the network operator. We evaluated the accuracy of the image recognition because it is one of the key performance indicators.

In the evaluation, the robot patrols the server room every 30 minutes, acquiring photos in all aisles on each patrol. The evaluation is conducted over two days, and a total of approximately 1,000 images are acquired. The photos are processed by image recognition technology which then determines if a person was included in the photos or not. The module used is YOLOv3 [20], which is one of the major convolutional neural net (CNN)-based image recognition technologies.

The results of processing by image recognition technology are shown in Table 5. In this table, the correct answers are visually confirmed by humans. Regarding accuracy, it is confirmed that recall is 99.2 [%] and precision is 94.1 [%]. In the assumed use case, the recall is an important indicator because the system needs to detect more reliably if a person is in the aisle. In contract, even if the system misdetects a person and sends a notification to the network operator, the network operator can visually check photos for anomalies. The recall performance of 99.2 [%] means that there is a 0.8 [%] chance of missing a person. In order to further improve the accuracy, it is possible to reduce the probability of misjudgment by using multiple photos to judge a single aisle, such as photos from the opposite side of the aisle. Furthermore, in this evaluation a learning model is obtained from the Internet and used as it is. Then, it can be further improved by re-training the model using photos taken in the server room. These verifications are issues for the future.

Table 6 Results of 5-point evaluation of remote monitoring.

Evaluation items	Average
Video streaming quality	4.8
Operability by gaming controller	4.3
Operability by mouse	3.0
Overall evaluation	4.0

Table 7 Results of travelling time for remote control.

Operation method	Average
Gaming controller (Manual operation)	102.6 [sec]
Mouse (Manual operation)	114.5 [sec]
Autonomous operation	70.7 [sec]

7.3 Remote Monitoring

In this functionality, the network operator controls the robot from a remote site and constantly monitors the maintenance work of the vendors. We conducted both subjective and quantitative evaluations.

Firstly, the results of the 5-point evaluation among four evaluators are shown in Table 6. Since the average overall evaluation is 4.0, it is a relatively good result. For manual operation, operations using a gaming controller and a mouse were implemented and evaluated. As shown, the rating of operability by the gaming controller is higher than that of operability by the mouse. This is because the gaming controller allows for more intuitive operation. In addition, some suggestions from the evaluators are introduced below.

- It is difficult to see the distance to obstacles and especially difficult to control turning. It would be good to install a downward-facing camera and/or display a guiding line over a video stream.
- Manual operation is somewhat difficult especially for beginners. Autonomous operation is effective because it is not affected by individual skills.

Secondly, as one of the usability evaluations of manual and autonomous operations, travelling time to a destination about 40 [m] away is evaluated (Table 7). As shown in Table 7, autonomous operation takes about 30 [%] less time than manual operation. This implies that autonomous operation should be used for usual navigation to a certain destination. Meanwhile, manual operation should be used for fine adjustment of direction and location of the robot. It can also be used for error handling of autonomous operation (e.g., when the robot becomes stuck due to a failure of path planning, etc.).

Meanwhile, the travel time of the robot is longer than that of humans. However, this is not critical for practical use of the robot. Because in our system, each work plan (e.g., start and finish time, location of work and work contents) is registered in advance, and then the robot can move to the predetermined location prior to the start time. In this case, the robot's travel time should be taken into account when setting the time to start the movement.

8. Discussion

8.1 Consideration of Safety between Humans and Robots

In this paper, we assume that human operators and robots will coexist for network maintenance works in the next decade and propose the three functionalities necessary for attendance works in network centers. While we demonstrated the effectiveness of the proposals through short-term evaluations, we have not evaluated them over time.

For the practical operation of the robots, we think one of the technical challenges is safety. In particular, safety between humans and robots needs to be thoroughly considered since human operators and robots have to co-work within a narrow workspace and passage. For example, when the robot detects workers (i.e., human operators and/or vendors) in the moving direction, it should pause the movement until the workers passes through or it should find a suitable detour route. Similar problems have been dealt with by other papers [25], [26] and their efforts may be applicable to our use case in the network center. Moreover, when the robot conducts periodical patrol and monitors network maintenance works, it should keep a certain distance from the workers in order not to collide with them and not to disturb their work. Since the suitable distance may vary according to the situation such as type of work and moving speed of the robot, it should be further investigated and evaluated.

8.2 Comparison with Other IT Systems

Although we have been discussing approaches to using robots for network operations, other IT systems can be utilized such as hand carried tablet, fixed camera and smart glass. This section discusses comparison with other IT systems.

The tablet is one of the widespread IT devices and relatively inexpensive to obtain. The tablet has user interfaces such as display, microphone and speaker, and communication means such as Wi-Fi. Since the venders can input necessary information and communicate with the network operators remotely, it may be possible to use the tablet for the function of the delegated attendance at on-site meetings. Meanwhile, it is difficult to achieve the functions of progress check and the remote monitoring because the tablet must be carried around and operated by the vendors. It increases the vendor's workload.

Fixed camera is widely used for surveillance and other purposes in a variety of scenes. It is difficult to achieve the three functions proposed in this paper by using the fixed cameras. In the server room, there are many blind spots from a single camera because tall server racks are set up in rows and rows. Additionally, each aisle is long. To monitor all aisles sufficiently, multiple cameras would need to be installed for each aisle. Consequently, a large number of cameras must be installed to accommodate the large server rooms of the network operator.

Meanwhile, the smart glass is used for network maintenance work [27]. By having the vendor wear smart glass, the smart glass transmits images of the work site and individual pieces of equipment to a remote network operator, who can remotely check on the work being done. However, it is difficult to achieve the progress check and the remote monitoring. In particular, when a network operator wants to check the overall work status or a particular device etc., it requires intervention of the vendor wearing smart glasses based on network operator's instructions. It increases the workload on the vendor. Regarding the robotic approach, since the network operator operates the robot remotely, the network operator can view the part he wants without any intervention of the vender. On the other hand, the robot has to stay a certain distance away from the worker for safety reasons (see Sect. 8.1), making it difficult to see the work at hand. Therefore, a cooperative approach of the robot and the smart glass is also considered effective.

9. Conclusions

This paper focused on robotic assistance for on-site network maintenance works and proposed three methods of robot utilization, namely delegated attendance at on-site meetings, progress check by periodical patrol, and remote monitoring. By utilizing them in combination, most attendance works of network operators can be supported by the robot. Throughout some subjective and quantitative evaluations by using our implemented robot, it was confirmed that the three proposed functionalities worked well. Meanwhile, some issues were identified throughout the evaluations and we will address these issues as future works.

This paper focused on proposing an approach in which robots are used to replace witnessing tasks that are currently performed manually. By giving more authority to the vendor and reconsidering the witnessing tasks itself, the requirements for robots will change. However, the additional burden on the vendors would result in higher fees paid to the vendors. There should be a careful discussion regarding this significant change, taking into account the increased costs and the risk of problems that may arise.

Robot utilization for network management works is just commencing. We will continue to refine our ideas from various perspectives such as safety, usability, performance, etc.

References

[1] ETSI ENI ISG (Experiential Networked Intelligence Industry Specification Group): https://www.etsi.org/technologies/experiential-networked-intelligence

[2] T. Warabino, Y. Suzuki, and M. Miyazawa, "ROS-based robot development toward fully automated network management," Proc. 2019 APNOMS, Sept. 2019.

[3] Report of the Robot Policy Study Group: https://www.jara.jp/various/report/img/robot-houkokusho-set.pdf

[4] National Center for Industrial Property Information and Training, https://www.j-platpat.inpit.go.jp/

[5] C. Mansley, J. Connell, C. Isci, J. Lenchner, J.O. Kephart, S. McIntosh, and M. Schappert, "Robotic mapping and monitoring of data centers," Proc. 2011 IEEE International Conference on Robotics and Automation, May 2011.

[6] J. Lenchner, C. Isci, J.O. Kephart, C. Mansley, J. Connell, and S. McIntosh, "Towards data center self-diagnosis using a mobile robot," Proc. 8th International Conference on Autonomic Computing, June 2011.

[7] Wikipedia, "iRobot Create," https://en.wikipedia.org/wiki/IRobot_Create

[8] S. Yazaki and H. Tsuchiya, "S3R: Automated temperature measurement in small and medium sized server rooms by using a tiny computer and self-driving robot," J. Academic Computing and Networking, vol.19, no.1, pp.114–121, 2015.

[9] J. Boren and S. Cousins, "Exponential growth of ROS," IEEE Robot. Automat. Mag., vol.18, no.1, pp.19–20, March 2011.

[10] S. Rosa, L.O. Russo, and B. Bona, "Towards a ROS-based autonomous cloud robotics platform for data center monitoring," Proc. 2014 IEEE Emerging Technology and Factory Automation (ETFA), Sept. 2014.

[11] L.O. Russo, S. Rosa, S. Primatesta, M. Maggiora, and B. Bona, "Service robotics for data centers monitoring," Proc. IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society, Oct. 2016.

[12] T. Asami and T. Terakado, "The temperature airflow measurement devices, temperature and airflow measurement system and the temperature and airflow image generation method," Patent number in Japan #6494811.

[13] Impress cloud watch (in Japanese): https://cloud.watch.impress.co.jp/docs/news/1179513.html

[14] Impress Internet watch (in Japanese): https://internet.watch.impress.co.jp/docs/event/1296588.html

[15] ALSOK: https://www.alsok.co.jp/corporate/robot/reborg-x/

[16] T. Yoshimura, H. Kazama, and K. Otsuka, "The alarm device, an alarm system and an alarm output method," Patent number in Japan #5530902.

[17] W. Choi, K-W. Park, and K. Park, "SCOUT: Data center monitoring system with multiple mobile robots," Proc. 7th International Conference on Networked Computing and Advanced Information Management, 2011.

[18] G. Otoshi and S. Kobayashi, "State determination device," Patent number in Japan #6912946.

[19] W. Liu, D. Anguelov, D. Erhan, C. Szegedy, S.E. Reed, C-Y. Fu, and A. Berg, "SSD: Single shot MultiBox detector," Proc. 14th European Conference on Computer Visio (ECCV 2016), Oct. 2016.

[20] J. Redmon and A. Farhadi, "YOLOv3: An Incremental Improvement," Technical Report, April 2018.

[21] SEED Solutions: https://www.seed-solutions.net/

[22] ROS.org, "amcl - ROS Wiki": http://wiki.ros.org/amcl

[23] ROS.org, "move_base - ROS Wiki": http://wiki.ros.org/move_base

[24] KDDI Research channel on YouTube: https://youtu.be/dyIIaJKU8Qc

[25] M. Kenk, M. Hassaballah, and J.-F. Brethé, "Human-aware robot navigation in logistics warehouses," Proc. 16th International Conference on Informatics in Control, Automation and Robotics, July 2019.

[26] J. Guzzi, A. Giusti, L.M. Gambardella, and G.A. Di Caro, "Human-friendly robot navigation in dynamic environments," Proc. IEEE International Conference on Robotics and Automation (ICRA), May 2013.

[27] VistaFinder Mx Cloud: https://biz.kddi.com/service/VistaFinderMxCloud/

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