

Effect of Work Instruction Support Device on Equipment Maintenance and Inspection

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Abstract

For the inspection and maintenance of chemical plants and large-scale machinery and equipment owned by companies, experts from the head offices are required for confirming the situations encountered by the on-site workers and for issuing appropriate instructions or providing apt guidance, as experts performing this work need a real-time grasp of the status of their operations. To this end, through this research, we validate the types of applications that can be carried out with a new work instruction support device developed for the purpose of enabling project supervisors to dispatch instructions and guidance across distances to on-site workers performing maintenance and inspection tasks. In three different cases, namely voice only, voice and on-site video, and the use of the proposed work instruction support device (voice/on-site video/work instruction display), maintenance and inspection tasks of an industrial robot can be performed. The effect of the use of such equipment is clarified through a comparison of the time and the content of the tasks performed.

Keywords

Maintenance/Inspection Tasks, Remote Maintenance, Technology/Skill Transfer, Educational Support

1. Introduction

For the examination and maintenance of chemical plants and large-scale machinery and equipment owned by companies, experts performing this work must have a real-time grasp of the status of their operations. To this end, experts from the head offices are required for confirming the circumstances encountered by the on-site workers and for issuing the appropriate instructions. Accordingly, we have developed a work instruction support device utilizing ICT (Information and Communication Technology) for the purpose of enabling project supervisors to dispatch instructions and provide instruction across distances to on-site workers performing maintenance and inspection tasks. Further, we have confirmed that even in the case of the workers testing this device in connection with operational testing performed by companies under three different conditions (between locations at the same site, between two plants at different locations in Japan, and between a plant located in Japan and one located overseas), who were not satisfied with the support methods used thus far for such inspection or maintenance tasks, the level of satisfaction with the use of the proposed device is high. However, we have been unable to clearly determine the types of tasks that this device is most concretely effective at. We have validated the types of tasks that the work instruction support device is effective for. In three different cases, namely voice only, voice and on-site video, or the use of the proposed work instruction support device (voice/on-site video/work instruction display), maintenance and inspection tasks of an industrial robot can be performed, and the effect of the use of such equipment is clarified through a comparison of the time and content of the tasks performed.

2. Maintenance and Inspection Work Instruction Support Device

2.1 Anticipated Work Circumstances

In this research, we anticipate situations involving the distance between off-site experts or head offices (hereafter, expert bases) and the locations lacking expert support. Further, with the exception of crisis or disaster situations, these devices can transmit and receive information for routine inspection and maintenance tasks via the Internet.

2.2 Device Specifications

The technical specifications of the Maintenance/Inspection Work Instruction Support Device are given in Figure 1. On-site workers using this device are equipped with a camera for capturing the video of the work site, a microphone and headset for transmitting and receiving audio communications, a handheld work instruction display (Personal Digital Assistant) for receiving instructions and video guidance, and a portable compact notebook PC. Back at the expert bases, experts can guide and instruct on-site workers and transmit audio using the onboard notebook PC and the equipped microphone and headset. On the base end, experts can use on-site workers' PCs to remotely issue task instructions, view worker positions, display video media, and transmit, receive, record, and verify audio. On-site workers and expert bases may also use the Internet for information exchange, and workers can set up several wireless LAN routers enabling them to transmit and receive online data both inside and outside the project site.

In contrast to the audio communication tools and methods used thus far, this device can gather and store not only audio information but also videos, location data, and other information that cannot be obtained using audio communications through the use of an onboard camera, a microphone and headset, and a task support monitor. Through this functionality, the experts back at the expert base can confirm on-site conditions, improve their degree of understanding of such conditions, and reduce the time required to do so, thereby making it possible to provide appropriate guidance and issue the corresponding instructions.

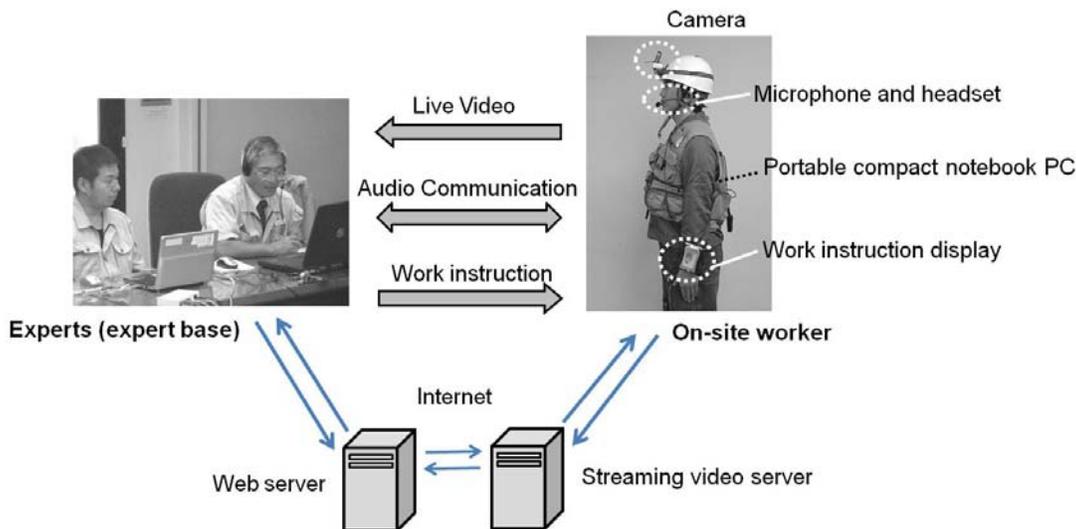


Figure 1: Maintenance and inspection work instruction support device

2.3 Device Functionality

The device that we have developed will enable experts to remotely grasp and confirm the status of operations performed at a work site and contains the following features designed to facilitate an understanding of the details of the on-site operations performed by workers.

- Display of Live Video of On-Site Conditions

Through the use of the onboard camera, those back at the expert base will be able to remotely confirm on-site working conditions via a real-time video feed. Further, by using the device's microphone and headset, workers will be able to dynamically transmit and receive information, as well as continue working with both hands using the hands-free function.

This function takes into account the video captured by the onboard camera while the on-site worker is in motion because of walking or otherwise. Prior to this study, teleconferencing systems available in the market only anticipated the video capture to be performed while the meeting participants were seated. As a result, when the workers were in motion, the camera was jostled and the video function would suddenly be cut out or be disconnected entirely. There was also no way for workers to capture detailed or real-time video feeds. In order to improve upon this, the tool used in this study utilizes a streaming video server (Adobe © Flash Media Server 3.0) as well as a Web server (Apache 2.2.4), which prevents bitrate reductions caused by the server burden exerted by the processing and transmission of video files.

- **Work Instruction**

The text and diagrams of work instruction sent from the base office to the on-site workers, combined with the status of the progress made on a project, are shown on the device's onboard task support display (Figure 2). Experts stay connected to the project site via the work instruction display's connection to the Internet. The work instruction issued by experts covers both anticipated and unanticipated issues. Therefore, all necessary information (explanations of instructions for workers, diagrams of the project site, facility inspection items, etc.) based on the extent to which the experts can anticipate the circumstances is uploaded to a PC at the expert base beforehand. The "work instruction" and "images" in the diagram shown in Figure 2 illustrate how the anticipated task circumstances can be presented to workers in an on-demand format. The "work instruction" section displays the anticipated content of the work in text, and the "images" display maps or facility schematics or diagrams in detail. On the other hand, in the event that unexpected circumstances arise, the "manual input" function allows workers to type a description of the situation using the PC to send to the expert base. Based on experience, with the work instruction display, in contrast to the head-mounted display, there is no need to adjust the line of sight while walking and performing works. Thus, we adopted this design, as there was no impact on performance.

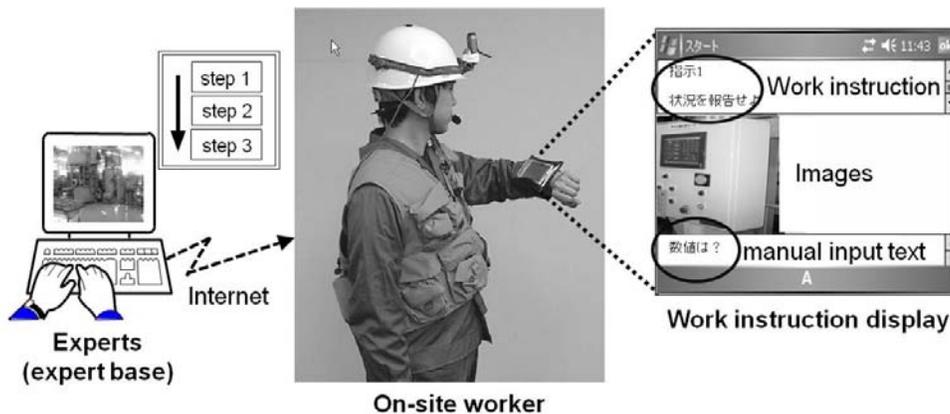


Figure 2: Sending work instruction from experts to on-site workers

- **Communicative history and auto-transcription: Recording of live video**

The proposed device confirms and saves all information and audio used in the course of works. This recorded audio can also be converted to text. It is also possible for the base side to receive information on the project site status as well as record video.

3. Experiment Methodology

In this section, we will outline the methodology used in the study in order to clarify the effectiveness of the work instruction support device with respect to the maintenance and inspection works.

The maintenance or inspection works were performed at a project site in the absence of experts. However, these works were performed on the basis of the instructions sent by experts located elsewhere.

3.1 Work Contents

As a maintenance or inspection work, we replaced the battery of the industrial 6-axis vertical articulated robot shown in Figure 3 (Mitsubishi Electric Co. RV-E3), and ordered the robot to initialize its position and confirm its operation. The details of the robot's operation are as follows:

- Changing the battery
 - We replaced each of the five battery units installed in the main body socket of the robot (Figure 4). We utilized tools (Philips head screwdriver and Allen wrench) for opening and closing the battery cover.
 - Step 1: Check the screws on the battery cover of the robot as well as the new battery.
 - Step 2: Remove the battery cover.
 - Step 3: Remove the five batteries.
 - Step 4: Replace the five batteries with new ones.
 - Step 5: Replace the battery cover.
 - Step 6: Remove all items not required by the robot to function.

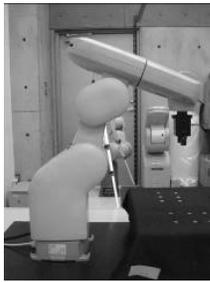


Figure 3: Industrial robot

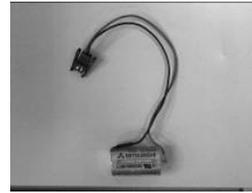


Figure 4: Socket-equipped battery

- Initialization/operation confirmation
 - Expert operators can order the robot to initialize at a starting point, and confirm whether the robot is performing its operations appropriately, by using a controller.
 - Step 7: The robot will return to a starting position to initialize. However, if an on-site worker controls the robot via a remote controller, a supporting worker will need to manually reposition the robot.
 - Step 8: Switch the robot's servomotors on in order to reset the robot's initial calibration settings.
 - Step 9: Inspect the robot's movements to confirm that each of the robot's joints are actually functioning.

3.2 Data Transmission

In order to evaluate the effectiveness of this device, we conducted tests under the following three conditions under which experts at the base would attempt to transmit data to on-site workers.

- Condition 1: Audio Only
 - Testers transmitted real-time audio information without the use of on-site video or the work instruction display. This is the closest-range condition for the use of the hands free cellular telephone.
- Condition 2: Audio and Live Video Function
 - Testers transmitted real-time audio information and on-site video without the use of the work instruction display. This was the closest-range condition with respect to the quality of the video signal reception for TV and telephonic use.
- Condition 3: Inspection and Maintenance Work Instruction Support Device (Audio, Live Video, and Work Instruction Display)
 - Users of the work instruction display may transmit information based on their line of sight. This information is not limited to only basic audio but includes real-time audio and on-site video as well.

3.3 Test Subjects

The on-site test subjects were engineering students (aged 21–26) who had no prior experience of performing maintenance or inspection tasks with robots. The distribution of participants across different transmission conditions was as follows. Audio only: 10, audio and live video: 10, and use of maintenance and inspection work instruction support device: 11.

During initialization tasks, the robot was rotated manually by an assistant (expert), and on-site tasks were performed using only the controller.

Further, in consideration of the individual differences in the instructions given by experts on the base side, one person will provide such guidance, as opposed to many. There was also no impact from having a single expert perform a task multiple times in the actual training exercises, as the three transmission conditions (audio only,

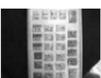
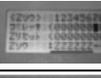
audio and live video, and use of maintenance and inspection work instruction support device) were randomized.

3.4 Content of Instruction Data Transmitted to Work Instruction Display

When the work instruction display was used, the anticipated working conditions were pre-uploaded to the device, and the experts were able to issue instructions without a delay period. The content of the instruction from the expert base shown on the work instruction display (images and text) is presented in Table 1. These data were prepared on the basis of trial experience and were determined to require images in the relevant descriptions.

Moreover, rather than performing each exercise mentioned in Table 1, only the works deemed necessary to progress were continued and the required information was transmitted to test subjects via the work instruction display.

Table 1: Content of instructions transmitted to work instruction display

	Images	Text
1		Switch the remote controller on.
2		Push an emergency stop button.
3		Remove the battery cover.
4		Remove four screws.
5		Condition inside robot after the battery cover was removed.
6		Condition inside robot after batteries were removed.
7		Insert the plug in with the metal exposing.
8		Remote control buttons.
9		Push the "run" button after input six "z" in the bottom step.
10		Repeat the following order; Step 1: Input "1" in the upper "brake" step one by one. Step 2: Push the "stop" and "run" buttons at the same
11		Switch the remote controller on after six "z" were shown in the bottom step.
12		The origin of the coordinate axes is not set.
13		Confirm "the origin of the coordinate axes was set" on the display.
14		Starting position of the robot.

3.5 Work Measurement

We compiled metrics related to the maintenance and inspection works performed by the industrial robot during use. We also recorded the robot performing its works and used these videos during our analysis.

4. Test Results and Discussion

4.1 Operating Time

The conditions under which subjects used the Inspection and Maintenance Work Instruction Support Device are displayed in Figure 5. An expert (Figure 5 Left) issues instructions while observing the project site, and the subject (Figure 5 Right) performs the work.

The average time taken by each subject with respect to each transmission condition is displayed in Table 2 and Figure 6.

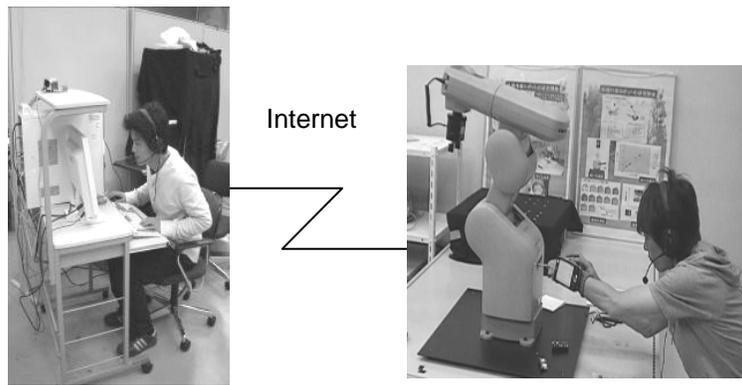


Figure 5: Actual testing conditions (using the maintenance/inspection work instruction support device)

Table 2: Operation time under each transmission condition

	Changing Battery (s)	Initialization/Op. Confirmation (s)	Total Operation Time (s)
Condition 1: Audio Only	726.9	577.2	1304.1
Condition 2: Audio and Live Video Function	710	525.4	1235.4
Condition 3: Inspection and Maintenance Work Instruction Support Device (Audio, Live Video, and work instruction display)	751.8	459.5	1211.3

We observed no statistically significant difference between the different transmission conditions with respect to the average time taken by each subject to complete the works. Further, with respect to the use of the device, when subjects checked their performance of changing the robot batteries after work completion, two subjects made errors under audio only conditions, one under audio and on-site video, and zero when using the device. The reason for this was that the work of removing the robot's battery cover using the Philips screwdriver and Allen wrench were comparatively simple tasks, not necessitating any instruction, and we believe that having engineering knowledge or prior experience or skill would not cause a statistically significant difference in performance.

On the other hand, with respect to the average time taken for subjects to complete the works, between the use of the device and the audio only conditions, the meaningful level of difference was 5% when the t-value was 2.92, which led to a t-boundary value (both sides) of 2.22, and we observed a statistically significant degree of difference with the use of the device. Even between the conditions where the device was used, and with audio and on-site video, the meaningful level of difference was 5% when the t-value was 3.59, which became a t-boundary value (both sides) of

2.16, and we observed a statistically significant degree of difference with the use of the device. Accordingly, for complex tasks requiring experience such as initialization and confirmation, we can conclude that the use of the device is effective.

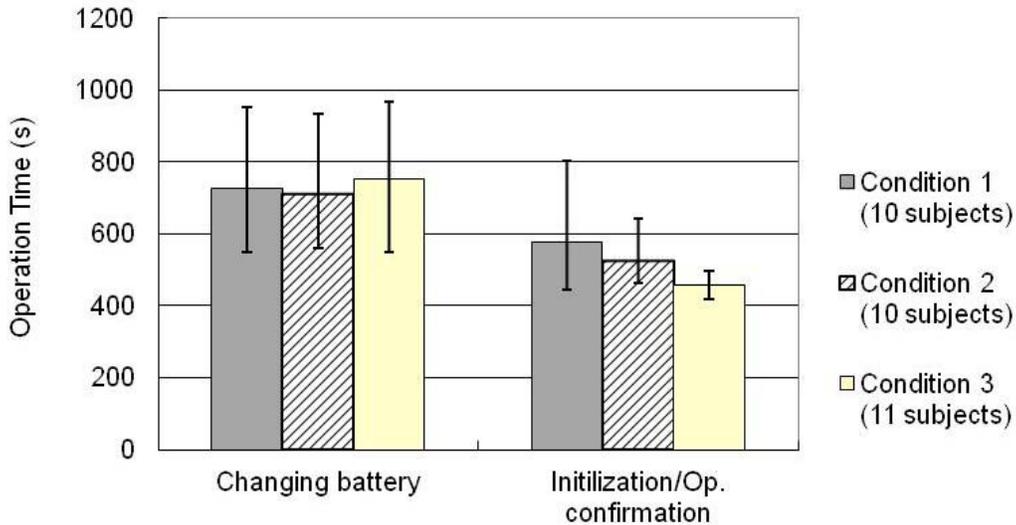


Figure 6: Average operation time under each transmission condition

4.2 Motion Analysis

During the study, we recorded a video to analyze the statistically significant difference observed for the initialization and operation confirmation tasks, in order to clarify the effect exhibited by the content of the work (composite tasks). The investigation and analysis software used was Operation Research Software (OTRS) Version 3.22 by JASI. We selected five test subjects who had the smallest difference between the average time taken to complete the works and analyzed their motions in order to better clarify the distinctions between each of the different circumstances, as there were large individual differences between each of the test subjects.

The results for the average times taken to complete the works under the established conditions for each of the five subjects are displayed in Figure 7.

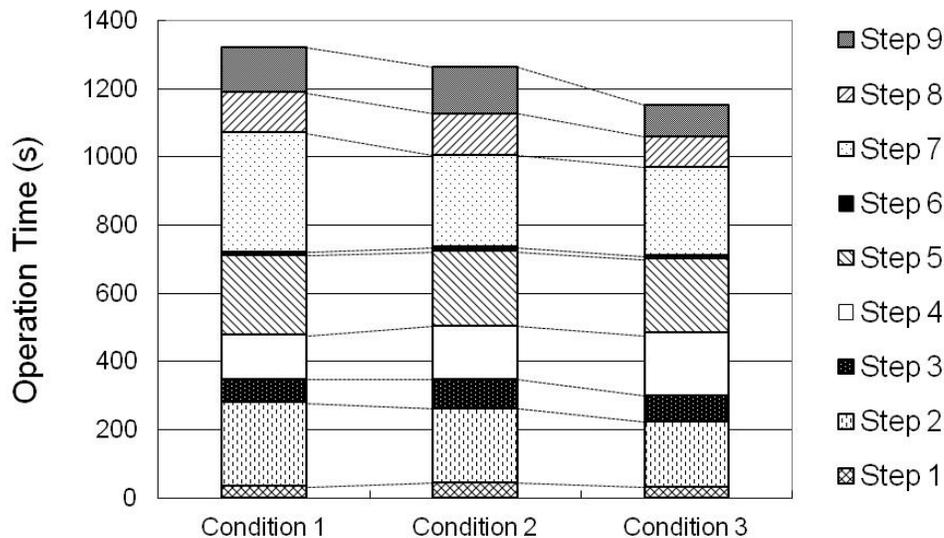


Figure 7: Average operation time under each transmission condition (avg. for each of the five subjects)

According to our analysis, the statistically significant differences observed beforehand with respect to the average times taken by each of the five subjects to complete the initialization or confirmation works, particularly in the case of the “configure origin point, servo ON” tasks, were as follows: a meaningful level of difference under the audio only conditions was 5% when the t-value was 3.27, which led to a t-boundary value (both sides) of 2.57. Even between the conditions where the device was used and with on-site video, the meaningful level of difference was 5% when the t-value was 3.55, which led to a t-boundary value (both sides) of 2.57. Moreover, when subjects used only the remote controller (to configure the origin point, and turn the servos ON) and when experience was necessary to perform complex tasks, the use of the proposed device’s work instruction display was more effective than the use of simple audio or on-site video only.

Furthermore, through an analysis of the works performed, we can clarify more detailed work content for subjects, such as operational errors and repeated operations. Through the initialization and confirmation of robot motions performed, we attempted to eliminate actions that did not meet the target time for the performance of a task, and achieved an operation time proportional to such task. Our results are displayed in Figure 8. The proportion of initialization and confirmation tasks that took more time than the predicted time was as follows: 15.9% under audio only conditions, 3.0% under audio and video conditions, and 3.0% when the proposed device was used. Excluding tasks that took longer than expected, we found that the time taken to complete the tasks (in seconds) was approximately 60 s shorter when the proposed device was used, compared with the other conditions. Because of this fact, and in the interest of reducing minor errors in performance, we believe that the use of the proposed device is more effective than that of the other methods. In fact, the delay in the completion of the tasks could be attributed to mistakes made while using the remote control or by misreading images shown on the remote. Under the audio only condition, we observed numerous errors caused by a failure to convey the instructions appropriately.

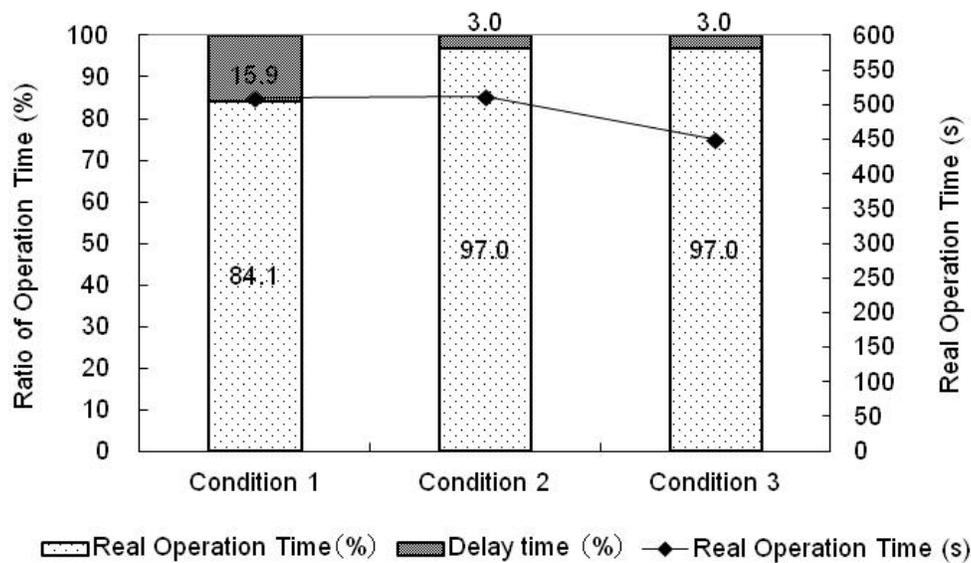


Figure 8: Real operation time under each condition

5. Conclusion

Through this study, we aimed to validate the effectiveness of a work instruction support device developed to facilitate communication between on-site workers and those at an administrating base issuing instructions regarding maintenance or inspection works over long distances. We analyzed the effectiveness of the device in connection with the maintenance and inspection tasks performed by an industrial robot under three different circumstances, namely voice only, voice and on-site video, or the use of the work instruction support device (voice/on-site video/operational instruction display). Further, we analyzed the time and content of the works performed and presented a discussion of our results in this paper.

From the results of the study, with respect to initialization and operation confirmation, we observed a statistically significant difference in the average time taken by subjects on works using the device under the other two conditions, and it was clear that the device was effective in its function. Further, the results of our analysis revealed

that with respect to the initialization and operational confirmations, we realized the effectiveness of the device in observing the necessity for experience in configuring the settings for the robot's origin point and other complex tasks, particularly through the use of a remote controller for the robot. Moreover, the amount of time taken to complete works was reduced through the use of the proposed device.

Future issues include considering the actual feasibility of implementation and making the improvements necessary for marketing purposes to the proposed device.

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Biography

Seiko TAKI is an Associate Professor in Management Information Science at Chiba Institute of Technology, Japan. She earned Masters and PhD in Engineering from Okayama University, Japan. She was an Assistant Professor in Management Systems Engineering at Tokyo Metropolitan University until March 2013. Her research interests include Industrial Management, Industrial Engineering, Support of Work Training, Support to Transfer Skills, Plant Maintenance, Management in the home, Child Care.