

Robot-Augmented Communication: A Remote-collaboration System based on a Shared Field of View in Real Space

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Abstract - To create a more efficient environment in which to perform remote maintenance, the authors propose a novel collaboration concept, called robot-augmented communication (RAC). In RAC a maintenance robot and an on-site human worker are assisted by another skilled human operator at a remote support center. By emphasizing the intentions of the remote supporter through robot functions that cannot be imitated by humans, RAC can provide effective support for the on-site worker. In the present study, as the first manifestation of RAC, featuring the projection capability of a maintenance robot, a prototype remote-collaboration system named SCOPE (sight collaboration by projection effect) was developed. This system consists of a projector unit with a camera, a multiple control unit (MCU) for video/voice communications, and PCs connected via a network. It has three key functions: creating a shared field of view between a remote supporter and an on-site worker, keeping meta-information related to objects in real space, and projecting meta-information onto the objects. The effectiveness of these functions was evaluated by experiments on two fundamental tasks—"comprehending a target object" and "transmission of instruction details"—involved in a typical maintenance operation. The experimental results show that each function is effective in shortening the time taken to perform the maintenance operation.

Index Terms - Remote collaboration, Shared field of view, Meta-information, Information projection

I. INTRODUCTION

In recent years, the number of experienced workers in manufacturing industries has been declining; thus, how to perform swift and efficient maintenance with a small number of experienced workers in a factory has become a serious problem. Under these circumstances, development of a "remote-maintenance" environment utilizing networks and information technology (IT) become more and important from now onwards. As regards this problem, the following two approaches have been conventionally taken.

- Perform on-site maintenance operations by dispatching autonomous robots to the site or by utilizing remote-control operation technology [1] [2]
- Dispatch an unskilled worker to the site and assist the worker in performing maintenance operations by another skilled supporter in a remote support center [3][4][9]

As regards the first approach, a robot is an effective tool for working in limited spaces in which people cannot enter. However, in consideration of problems such as time lags in network communication and the current level of autonomous operability of robots, it is clear that this robot approach cannot reach the level of operability possible by dispatching a human worker to perform on-site maintenance. As regards the second approach, various attempts to assist an unskilled worker using video transmission and IT methods are being performed. However, such attempts have found that the on-site worker not only has to carry heavy IT devices like wearable PCs but also the intentions of the remote supporter are often not sufficiently transmitted. Under these circumstances, the mental as well as the physical burden on the on-site worker becomes a serious problem.

In recent times, application of robot technology has not stopped at industrial fields; it has also spread to the home and office. At the same time, research on communication and cooperative working under the assumption of harmonious coexistence of humans and robots is continuing apace. As regards this research, the roles and tasks of humans and robots are clearly defined, each other's weak points are interpolated, and relationships between them are formulated. In the current report, attention is focused on this interpolation relationship between humans and robots, and the role and necessary functions of a robot for remote maintenance are discussed.

In section 2, the advantages and disadvantages of the two approaches mentioned above are compared, and then section 3 introduces a new concept called "robot-augmented communication"—namely, a way of redeeming these advantages and disadvantages by extending the skills of a distant skilled worker to a work site through on-site communication between an unskilled worker and a robot. After that, section 3 explains the hypothesis concerning the essential requirements for robot-augmented communication, and then describes a test system—called SCOPE (sight collaboration by projection effect)—for providing a shared field of view in real space. Section 4 then presents the results from experiments with the SCOPE system, and Section 5 wraps up this report with our conclusions and future study direction.

II. ROBOT-AUGMENTED COMMUNICATION

As mentioned above, in the case that a skilled worker is not present at a work site, there are two ways of handling maintenance: either remotely operate a robot and devices at the site (see Fig. 1(a) below) or dispatch an unskilled worker to the site and remotely instruct him to perform maintenance operations from a distance (see Fig. 1(b)). In the case of Fig. 1(a), the robot and a person (i.e., the skilled operator) cooperate through a network in such a way that the robot interacts with the outside world. On the other hand, in the case of Fig. 1(b), two people (the skilled operator and the unskilled worker) cooperate through a network, and the unskilled worker interacts with the outside world. Each of these two cases—namely, the robot or the person handling the on-site operation—has its own advantages and disadvantages as explained below.

1.(a) Remote-controlled-robot type: Robot operation (e.g., in terms of power and information-processing capability) can surpass that of a human operator, but the present level of autonomy of current robots is low and cannot match the operation skill of the remote skilled worker.

1.(b) Remote-supported-human type: Generally decision capability of a person in response to site conditions is much better than that of a robot, but under the present state of communication between a on-site work's side and a supporter's side, it is difficult to sufficiently convey the intentions of the remote supporter (skilled operator) without putting undue stress on the unskilled worker. For example, due to the time-delay of a network, the supporter's intention often cannot be transmitted rapidly and smoothly.

With the drawbacks of the above two approaches in mind, and aiming at extending the skill and ideas of a remote supporter to cover work sites, where specialized robot functions such as high-level information processing are particularly applicable, we are proposing a new form of collaboration between a robot and an on-site worker (who

has a high decision capability). Since we have extended communication by means of a robot's functions, we call this collaboration set-up "robot augmented communication" hereafter. As shown in Fig. 1(c), by actively utilizing interaction between an on-site worker and robot functions that cannot be imitated by humans, robot-augmented communication provides effective support by emphasizing the intentions of the remote supporter through the robot.

In the case of a remote support for on-site worker, two examples utilizing robots are GestureMan [5] developed by Kuzuoka et al. and C-term [6] developed by Mikawa et al. These systems, in which robots with mechanisms of some kind or other mediate between remote supporters and on-site workers, aim to smooth communication between these parties, and share the same fundamental research goals. However, the main point of these systems is to get the robot to re-create the behavior of the remote supporter; they have not been developed from the viewpoint of actively utilizing the functions of robots that humans cannot imitate.

Furthermore, as regards applications in fields apart from remote maintenance, such as InterRobot [7] developed by Watanabe et al. and Alter Ego Interface [8] developed by Hiraiwa et al., although experiments are being performed on attaining smooth communication through robots in distant places, the main thrust of these researches—namely, as in [7] and [8] directly recreating the behavior of humans—is different from our principle aim.

III. SCOPE: A SYSTEM FOR SUPPORTING A SHARED FIELD OF VIEW IN REAL SPACE

A. Functions required by robots

As robot functions that seek to surpass the ability of humans, mechanical support by power assistance and intellectual support by high-level information processing are two good examples. These functions must be selected in response to the target operation. As regards the current work, we are aiming at remote maintenance work as the target operation, and with realizing our goal of "robot-augmented communication" in mind, we are focusing on precise transmission of the intentions of a remote supporter to an on-site worker. In our previous work, we developed a remote-supported-human-type system called Field-AID [3]—which has the collaboration function utilizing multi-point video and voice communication. According to the experimental results on remote collaboration operations using Field-AID, the following key issues must be addressed in order to make remote collaboration more effective.

(A) Whether the object indicated by the remote supporter is within the field of view of the on-site worker or what is in the field of view are unclear.

(B) The relationship between the information presented by the remote supporter and physical objects at the on-site worker's side is undefined.

(C) Devices worn by the on-site worker (i.e., a head-mounted display and a wearable PC) exert a heavy load.

As regards tackling issues (A) and (B), we set up a particularly effective hypothesis called a "real-space

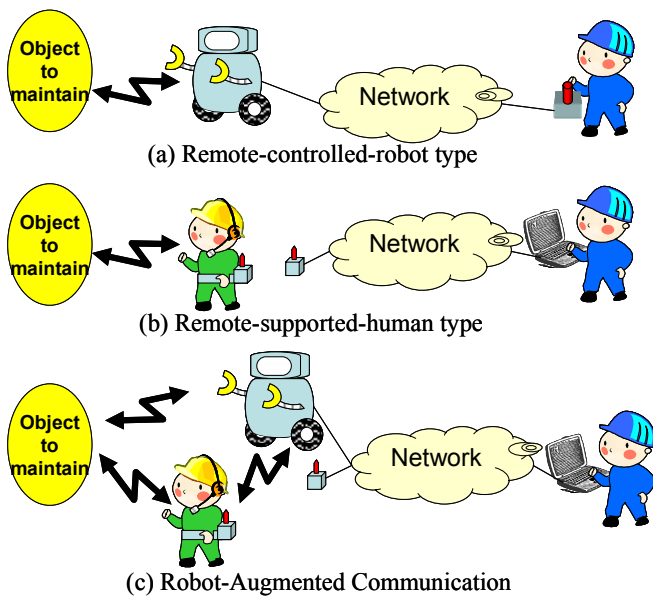


Fig. 1 Set ups for remote maintenance.

information presentation function,” as explained in the following key points and shown schematically in Fig. 2.

(1) Shared-field-of-view function: Share a target object perceived in the field of view of an on-site worker with a remote supporter.

(2) Indexing function: From a remote place, affix information to objects in on-site real space or in specified locations.

(3) Superimposed-information function: Information is presented directly in real space, where it can be selected and manipulated.

As regards the solution to issue (C) stated above, by fitting a projector and a camera to a mobile robot, and turning over the function of presenting information in real space to the robot itself, we are able to realize the functions stated above. That is to say, the functions that a person cannot perform themselves—such as presenting information in real space—are given to the robot. In addition, as for operations in the real world, since the working space is not always spatially fixed, so a projector fixed in one place is inadequate. By having the robot move in real space, we can expect that the on-site worker will not have to wear information devices and spatial limitations in the working space will be eliminated.

With realizing the above-mentioned functions in mind, we considered a method using a head-mounted display (HMD)—often used in the fields of mixed reality (MR) and augmented reality (AR)—for superimposing meta-information onto a target object. However, in the case of using a current HMD, issue (C) remains unsolved; therefore, we consider that the method proposed here—namely, utilizing a projector—is more effective.

B. System for hypothesis testing

1) System configurations

To test the hypothesis outlines in the previous section, we developed a remote-support system called SCOPE (sight collaboration by projection effect) for providing a shared field of view in real space. Fig. 3 shows the configuration of this system schematically.

Under this configuration, a multi-point video/voice transmission server is connected via an IP network with client PCs set up respectively on the supporter’s side and the on-site worker’s side. The server can also function as a database server for managing attribute information (mentioned

hereafter). The video/voice transmission unit utilizes NTT-IT’s teleconferencing service called Meeting Plaza.

On the on-site worker’s side, a camera and a projector are integrated as one, and an incorporated stepping motor enables the camera’s viewing field and the projected images to rotate around the vertical axis. To attain the capability of a “shared viewing field” as explained later, the domains of the viewing fields of the camera and the projector are adjusted so that they line up as one. Furthermore, in this study, major emphasis is placed on verifying the function of presenting information in real space, and it is assumed that the number of degrees of freedom of the robot is only one.

Since the on-site worker is not wearing a “wearable” PC, operating the client PC while working is difficult. Accordingly, a laser pointer is set up as an input interface. By means of image-recognition processing on the position of the laser pointer, we experimentally implemented a manipulation function equivalent to the mouse on the client PC.

2) Shared-field-of-view function

During remote collaborative operations, one scene that often occurs is the remote supporter giving instructions to the on-site worker verbally. As long as the remote supporter and on-site worker share common information about the targeted object, specifying the targeted object and giving manipulation instructions are relatively easy. However, if that is not the case, indicating relative directions like “on the right” is frequently used. At such times, the remote supporter’s viewing field becomes essential information from the viewpoint of the on-site worker.

In the SCOPE system, by unifying the camera’s viewing field and projector’s projection area and displaying a frame on the projected images, it is possible to present the remote supporter’s viewing field to the on-site worker.

3) Indexing function

Information needed for carrying out operations (referred to as “attribute information” hereafter), is affixed to the target object in terms of position coordinates in the working space, controlled, and displayed as occasion demands. In the developed system, five kinds of fool-proof information are conveyed: text, still images, video, sound, and program administration. Programs are looked upon as attributed

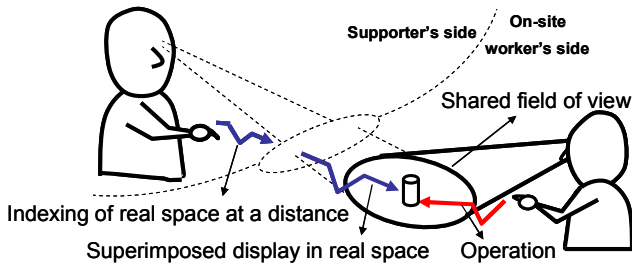


Fig. 2 Image of remote support to provide a shared field of view in real space.

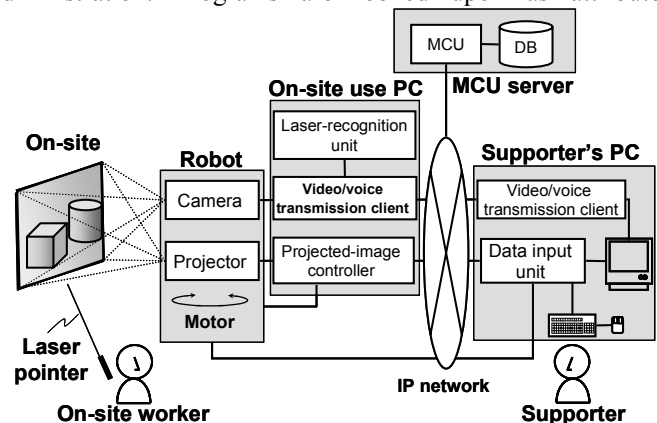


Fig. 3 Schematic configuration of SCOPE system.

information and foolproof, so they can be executed and terminated on the on-site worker's side. The location of related attributed information affixed to the target object is marked as a graphical image with a circular form (known as a "projected object"). For example, in a scene in which a chemical solution is selected from a shelf of items, attribute information is recorded as its characteristic properties and appropriate handling procedures, and a projected object is displayed at the location of the bottle containing that chemical. By manipulating the projected object, the display status of attribute information can also be manipulated. On the on-site worker's side, the laser pointer is used to manipulate the projected object; on the supporter's side, the projected object is shown on a communication screen displaying images transmitted from the on-site worker's side and manipulated by PC mouse (see Fig. 4). Records of the attribute information can then be processed and analyzed by various GUIs on the supporter's side communication display.

4) Superimposed-information function

As regards the SCOPE system, the camera and projector on the on-site worker's side can be manipulated from the supporter's side, and the domains of the viewing field and the information presentation can be changed. In this case, the movement of the motor and the projected image plane of the connected projector are compensated, and the projected object and the attribute information can be presented in real space in a stationary manner. This function enables the on-site worker to intuitively recognize the relationship between a stationary object in real space and its attribute information.

5) Other functions

By projection of images to the on-site work's side by moving the mouse of the remote supporter's client PC, an action referred to as "pseudo-finger pointing" is performed. The mouse-cursor mode can be selected to show or hide the track of the cursor. Accordingly, by choosing to show the cursor tracks, it is possible to write simple text and draw signs in real space. Moving the operation target object in this way is exploited when the operation instructions involve directions.

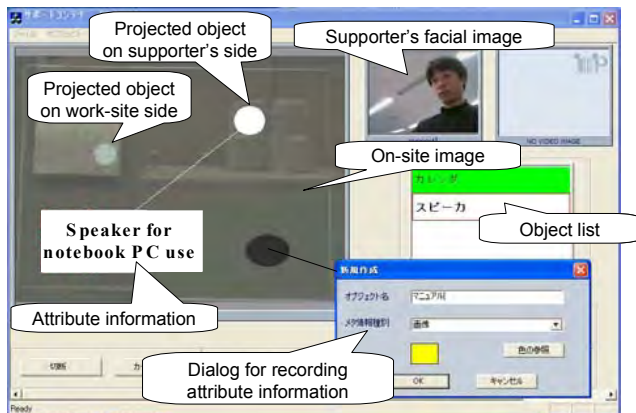


Fig. 4 View of a support screen.

IV. VERIFICATION EXPERIMENTS

A. Verification of shared-field-of-view function

1) Experimental aims

In the most cases of receiving instructions regarding equipment maintenance work from a skilled worker at a remote support center, first, "comprehending the target object"—namely, mutually recognizing the place to be the target of instructions—is carried out. After that, "transmission of instruction details" is performed. In this section, taking up the "comprehending the target object" phase just mentioned, we aimed at verifying the effectiveness of the shared-viewing-field function experimentally. Accordingly, by means of remote indication utilizing the shared-field-of-view function of SCOPE, we measured the time taken for the on-site worker to comprehend the indicated target object and, thus, estimated the worker's efficiency.

2) Experimental method

The experiments consist of one person as the on-site worker and another person as the remote supporter. The task of the worker is to pick out a target object stuck to a wall by following instructions from the remote supporter, and then stick that object in a different place. As target objects, 20 cards painted with various graphical forms were stuck to a wall on the worker's side; the same cards were also laid out on the supporter's side. The supporter arbitrarily chose five cards from the 20 and then instructed the worker to pick out these cards in sequence. The graphics on the cards were framed by random free-form curves. A scene from one of the experiments is shown in Fig. 5.

Table I lists the four sets of conditions set up for the experiments. Under conditions 1 and 2, the shared-field-of-view function of SCOPE is used to indicate the target object. Under condition 1, by displaying the PC mouse cursor, specified points within the shared viewing field can be pointed out. Under condition 3, only conventional video and voice communication is used to give instructions. And under condition 4, instructions are given by voice—via telephone—



Fig. 5 Scenes of verification experiments.

TABLE I
EXPERIMENTAL CONDITIONS FOR VERIFYING SHARED VIEWING FIELD

	Voice	Image	Viewing field display	Cursor display
Condition 1	Yes	Yes	Yes	Yes
Condition 2	Yes	Yes	Yes	No
Condition 3	Yes	Yes	No	No
Condition 4	Yes	No	No	No

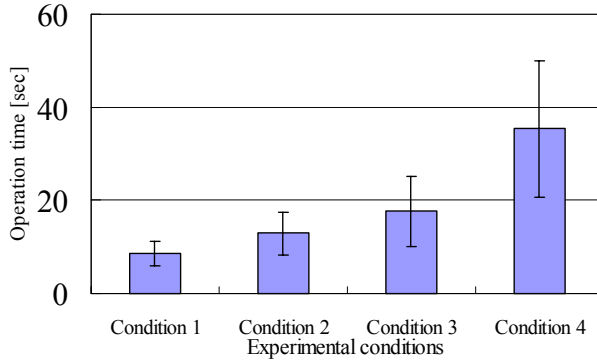


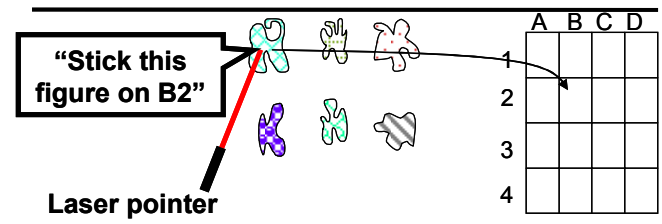
Fig. 6 Experimental results on shared viewing field.

only. A group of four people were used as subjects in experiments under all four conditions.

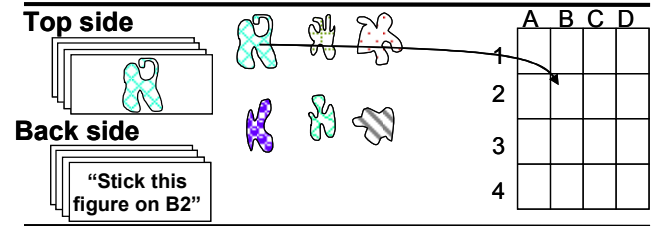
3) Experimental results and discussion

The time taken from the beginning of the supporter's explanation about the target object until the worker sticks that object at the specified point is taken as the "operation time." The mean values and standard deviations of the measured operation times under the four test conditions are plotted as bar graphs in Fig. 6. It is clear that compared to the operation time for the voice-only condition 4, the times get shorter and variation gets lower as more functions are added (i.e., conditions 3 to 1). Moreover, the results confirm that utilizing the shared-field-of-view function of SCOPE (i.e., conditions 1 and 2) shortens the time required to identify the target object.

Furthermore, as for the result under condition 4—which shows a large variation—even with voice instructions only, some short operation times are shown. This is because in some cases the graphic symbols framed by random curved lines remind both the worker and the supporter of familiar shapes (e.g., the shape of a prefecture boundary or an animal). That is to say, it is sometimes the case that an operation can be sufficiently carried out by listening to voice instructions alone. This means that, as regards remote collaboration operations, in the case that both the worker and supporter are skilled workers, they both understand common technical jargon, and voice communication only is sufficient. On the other hand, under the noise of a factory environment, it is difficult to hear voice instructions, and language barriers can sometimes arise during interactions with overseas locations. In these problematic cases, we consider that the shared-field-of-view function will demonstrate its effectiveness.



(a) Superimposed display of instruction details



(b) Look up instruction details in booklet of cards

Fig. 7 Method used for Test 1.

B. Verification experiments for indexing and superimposed-information functions

1) Experimental aims

The aim of these experiments was to verify the effectiveness of the indexing and superimposed-information functions under the assumptions described in section 3. Accordingly, taking up the phase "transmission of instruction details" mentioned previously, we set out two tasks for testing. In experiment 1, the "ease of transmission" of the instruction details within the time taken to understand them was evaluated. In experiment 2, the "memory retainability" of the instruction details (i.e., how easily they are retained) within the time required to perform the operation was evaluated.

2) Experiment 1: Ease of transmission of instruction details

As target objects, 16 cards each drawn with a different graphic figure are stuck to a wall, and each card is fixed with corresponding instructions. The worker thus performs operations according to these 16 sets of instructions. As shown in Fig. 7, the worker transfers each card to a specified position on a four-by-four matrix, and by following the two different instruction methods only, the worker correlates the cards on the matrix. In method (a), the indexing function of SCOPE is used beforehand to record the instructions on the cards in text. When the card is pointed out by laser pointer, the recorded instructions are superimposed onto the card. In method (b), a booklet (or "manual") of cards, each drawn with the same graphic figures as the cards stuck to the wall, is used, and the instructions for each card are written on its back face. By looking through the manual, the worker can search for the instructions corresponding to a certain figure. In the experiments, three subjects performed the tasks using method (a) and method (b).

3) Experiment 1 results and discussion

In the two cases—either (a) superimposing the instructions on the cards or (b) looking up the instructions in

TABLE II
RESULTS OF EXPERIMENT 1

Test subject	(a) Superimposition display method (operation time in sec)	(b) Card booklet (manual) look-up method (operation time in sec)
1	157	380
2	175	295
3	159	290

the booklet—the time taken to lay out all 16 correctly is taken as the “operation time,” and the measured operation times for the three subjects using each method are listed in Table II. For all subjects, it is clear that the operation time is shorter when they use method (a). Moreover, the time required to record the instructions by using the SCOPE indexing function is 640 seconds (i.e., an average of 40 seconds per card). In regards to the instruction recording, although the time required to record the instructions can be reduced by improving the user interface, the time that goes with an increased number of recordings is thought to be considerable. From the viewpoint of the worker, it is necessary to take into account not only the operation time but also the time required for preparation. Nevertheless, in the case that instructions recorded once are used any number of times or in the case that the operation time should be shortened even a little under a poor factory environment, the indexing function is effective.

4) Experiment 2: Memory remnants of instruction details

In this experiment 2, 48 cards are stuck to a wall, and a memory game is played. One of the 24 letters of the alphabet is stuck to each card, creating 24 pairs of cards with the same letter. The worker chooses two cards at a time, and using either method (c) or (d) below, verifies the details associated with each card, and performs operations created by the pairs.

(c) Cards are selected by laser pointer, and their descriptions (letters of the alphabet) are superimposed on them. In the case that the selected cards are not a matching pair, the description of those cards are not displayed.

(d) Cards are selected by laser pointer, and their descriptions (letters of the alphabet) are given by voice. Each of three subjects performed the task once using method (c) and once by (d).

5) Experiment 2 results and discussion

The time to complete matching of all the cards is taken as the operation time, and the measurement times are listed in Table III. In the case of all the subjects, the operation times are shorter when they perform the task using the superimposition method (see (c) above). According to the post-experiment impressions of the subjects, using the voice-only method (see (d) above) was often stressful. In the case of a memory game like this, if a card flipped over once does not form a pair, that card has to be kept in mind. The experimental results suggest that the superimposition method makes it easier for the subject to memorize the cards. In the case that support is given from a skilled worker at a distant location, if a problem can be handled only once, it is sufficient

TABLE III
RESULTS OF EXPERIMENT 2

	Subject	Operation time
Superimposed display (method (c))	1	10 min 41 sec
	2	24 min 38 sec
	3	13 min 01 sec
Voice presentation (method (d))	1	15 min 36 sec
	2	30 min 31 sec
	3	17 min 35 sec

to give instructions and guidance by voice. However, in the case that an on-site worker has to repeat the same operation at a later date, if the superimposition method was used, the on-site worker gets a deeper understanding of the operation details and will find it easier to remember them for future operations. This intriguing result thus shows the advantage of the superimposition method.

C. Discussion on multiplying the number of degrees of freedom of the robot and related future work

In the current study, we took up the function of displaying information in real space as a robot function for extending communication, and we verified the effectiveness of this method in the previous sections. As for the robot’s motion mechanism, only one degree of freedom (i.e., rotation about the vertical axis) was dealt with. However, as mentioned in section 3, if we assume operations in the real world, to achieve unrestricted operation in free space, it is necessary to increase the robot’s number of degrees of freedom, especially concerning its mobility. Accordingly, in the following discussion, we examine the challenges concerning equipping a mobile robot with the capability of displaying information in real space.

As regards our SCOPE system, to achieve the capability of a shared field of view, as shown previously in Figure 3, a camera and projector are unified as one in order to bring together the camera’s viewing field and the projector’s projection field. In the case of this method, the distance to the projected image is assumed to be constant. However, in the case of a mobile robot, this distance is variable. This means that, in accordance with the degree of this variation, calibration must be performed to match up the camera’s viewing field and the projector’s projection field. By skillfully aligning the optical axes of the camera and projector mechanically, as shown in the set up in Fig. 8(a), even if the distance to the target object varies, the viewing field and projection field are kept together. An external view of our prototype camera/projector with a combined optical axis is shown in Fig. 8(b). In our future work, we plan to mount this camera/projector on a mobile robot and investigate its effectiveness.

In regards to SCOPE, by realizing the functions for information indexing and superimposition, and correcting the projected image plane in accordance with the variation of the camera’s orientation, projected objects and attribute information can be presented as still images in real space. With this method, it is assumed that the camera’s orientation is

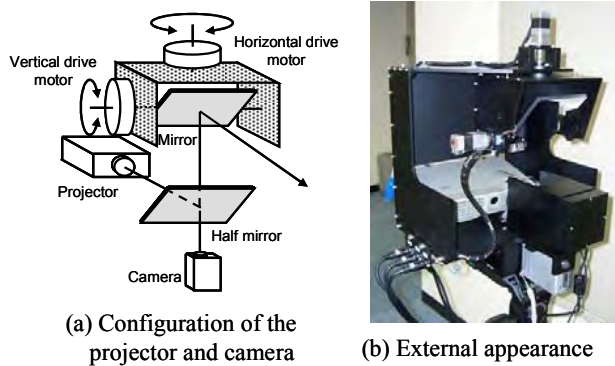


Fig. 8 Projector and camera with unified optical axis.

known. In the case of mounting the camera on a mobile robot, the location of the robot itself must be obtained, and the projected image plane must be corrected according to that location. In the system targeted in the current study, since it is expected that a human worker can do corrections (for example, adjustments by a remotely located skilled worker on the position of the projected object), there is a good chance that the accurate position of the robot itself cannot be acquired. From now onwards, firstly, we plan to establish the capability of correcting the projected image by utilizing existing identification methods for acquiring a robot's own location, and then verify these methods experimentally.

V. CONCLUSIONS

The concept of "robot-augmented communication" was introduced in this study. Involving cooperation between an unskilled worker and a robot on-site, this concept aims at a collaboration set up in which a skilled worker remotely located from a work site supports an on-site worker by communicating his intentions through a robot. Incorporating three essential functions that a robot must be fitted with, namely, shared field of view, information indexing, and

superimposed presentation, the constructed SCOPE (sight collaboration by projection effect) system demonstrated that these functions shorten the on-site operation time. Furthermore, we discussed problems in regard to equipping a mobile robot with the function for presenting information in real-space. From now on, we plan to mount such a real-space-information-presentation function—which combines the optical axes of a camera and projector—on a mobile robot, and while verifying this function, we will examine ways of handling the challenge of identifying the robot's own location.

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