GestureMan: A Mobile Robot that Embodies a Remote Instructor's Actions

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ABSTRACT
When designing systems that support remote instruction on physical tasks, one must consider four requirements: 1) participants should be able to use non-verbal expressions, 2) they must be able to take an appropriate body arrangement to see and show gestures, 3) the instructor should be able to monitor operators and objects, 4) they must be able to organize the arrangement of bodies and tools and gestural expression sequentially and interactively. GestureMan was developed to satisfy these four requirements by using a mobile robot that embodies a remote instructor's actions. The mobile robot mounts a camera and a remote control laser pointer on it. Based on the experiments with the system we discuss the advantage and disadvantage of the current implementation. Also, some implications to improve the system are described.

Keywords
CSCW, remote instruction, mobile robot, embodiment, video mediated communication.

INTRODUCTION
The authors have been developing systems that support remote instruction on how to use machinery. One of the characteristics of this kind of interaction is that participants' activities are inseparable from artifacts of the physical environment [7,14]. A system should consider not only human-to-human interaction but also consider human to artifact interaction.

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According to Goodwin [3], when instruction is given face-to-face, operators move their bodies into appropriate positions, which allow them to see the shared artifact. The instructor likewise moves in such a way that his view of the shared object is not obstructed by the operators and makes sure that the operators are watching his/her gestures while they are given instructions. The operators in turn express their understanding using words and gestures while they are performing their tasks. During such sequences an instructor and operators not only use words, but also gestures, and body arrangement. It should be noted that body arrangement is not static, but changes dynamically during collaboration.

Gestures and body arrangements can be monitored naturally when participants are talking face-to-face. When they have to collaborate via video-mediated communication systems, however, these acts easily become disembodied [4]. In other words because a remote participant's gestures are displayed on static two-dimensional display, such gestures cannot be shown at a place where local participants can easily be aware of them while he/she is oriented towards artifacts to work with.

In the Robotics field, many researchers have started work on robot-human interaction. We are especially interested in robot mediated human-to-human interaction systems such as ProP [16], Tel-E-Merge [15], and CYBERSCOPE [9]. PRoP (surface cruiser version) is a remote-controlled vehicle and a 1.5 meter vertical pole on which a color video camera, microphone, speaker and color LCD screen are mounted. A remote user can control the robot using a user interface on a

PC. As Paulos et. al., described, this kind of robot is expected to embody a remote participant's actions.

Influenced by these studies, we have been developing a robot-mediated communication system called GestureMan. We are especially interested in supporting remote instruction using the robot. Thus our main interest in our research is to derive the design implications for a mobile robot to support remote instruction.

The main difference between our research versus PRoP, Tel-E-Merge, and CYBERSCOPE is that we are especially interested in focused interaction that require precise pointing, precise body arrangement, and frequent mutual monitoring with minimal time delay.

We begin by first describing several basic requirements for robot design that we had derived from our earlier studies. We then will introduce the GestureMan system. Finally, based on our preliminary experiments, we discuss the advantages and disadvantages of our current system, and describe additional requirements for improvement of our robot.

REQUIREMENTS FOR THE ROBOT

We have been developing robot-mediated communication systems that can embody participants' behavior e.g. the GestureCam[13] and the GestureLaser[19]. GestureCam consists of a camera and a laser pointer mounted on a remote controlled manipulator with three degrees of freedom of movement. A simple pointing gesture was possible with a laser pointer. Since the robot was placed close to an operator, he/she could involuntarily notice where the robot (instructor) was looking (Fig. 1).

The GestureLaser is a remote-control laser spot actuator that aims to enhance the gesturing capability of the GestureCam. GestureLaser reflects the laser emitter's ray off two orthogonal mirrors into the workspace.

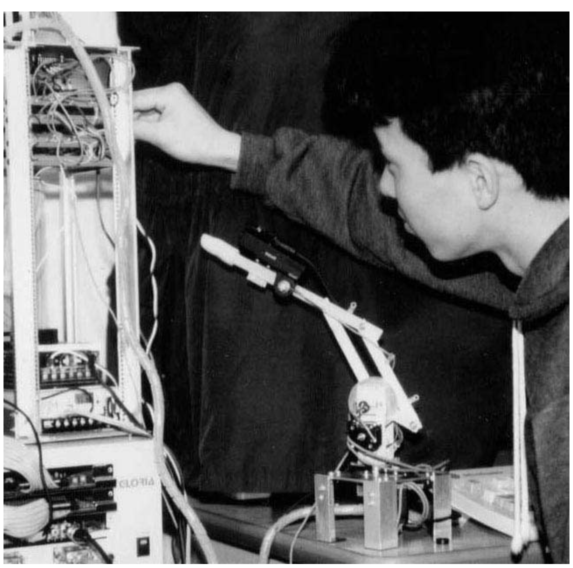


Figure 1. GestureCam and an operator.

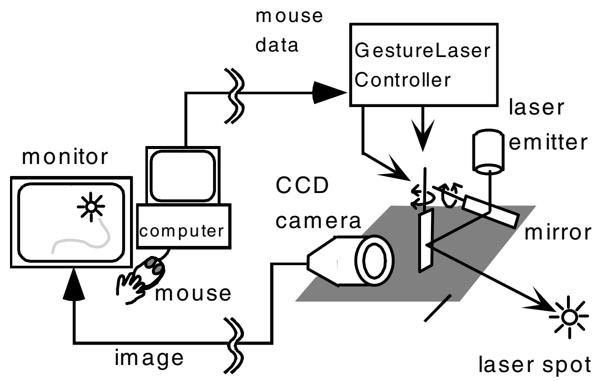


Figure 2. Schematic diagram of the GestureLaser system.

The laser spot can be moved like a mouse cursor. The instructor controls the location of the laser spot with a mouse. Input from the mouse is sent through the instructor's computer to the GestureLaser Controller, where it is translated into mirror movement. The instructor can monitor the position of the laser spot as well as objects and operators on an image from a camera unit. It is thus possible for the instructor to treat the laser spot as if it were a mouse cursor (Fig. 2). In this way, the instructor can show various expressions such as rotation and direction by a movement of the laser spot. The smallest step angle of a motor is 0.036°, which allows movement of the laser spot with a precision of about 1 mm at a distance of 2 m, making it appear continuous.

From the experiments with the system, we found that mere laser spot movement can communicate a variety of meanings when it was used with verbal explanations.

Based on the ethnomethodological studies and our own studies with GestureCam, GestureLaser, and other video mediated communication systems [11], we formulated the following requirements for a system.

(1) ***Gestural expression requirement***: The instructor must be able to freely use not only verbal expressions, but also body movements and bodily expressions (gestures).

(2) ***Observability requirement***: Participants should be able to mutually observe each other's activities. In particular, (i) the operator should be able to see where the instructor is pointing and how the robot (instructor) is oriented; (ii) the instructor should be able to see how the operator is orienting himself/herself towards the indicated object as well as the pointer, when he/she is observing the instructor's pointing; (iii) the instructor should be able to reassure the operator by words and actions that the instructor is aware of the operator's orientation.

(3) ***Arrangement of bodies and tools requirement***: One of the major factors to support the *observability requirement* is to allow for the appropriate arrangement of bodies and tools.

For instance, an instructor may position the robot so that he or she can easily see an operator and tools. Also, the robot should be positioned so that an operator is able to see its actions without conscious effort.

(4) ***Sequential organization requirement***: The communication delay could disrupt the timing relations between the participants' actions [17, 18]. Thus sequential and interactive organization of the arrangement of bodies, tools and gestural expression must be possible without serious time delay due to poor system response or communication latency.

In terms of these requirements, one of the major problems of the GestureCam and the GestureLaser is their low mobility. When tools are dispersed in the environment, an instructor should be able to move around in the space while he/she is giving instructions. Thus in such cases our previous systems cannot always support the *arrangement of bodies and tools requirement*.

Therefore, in order to mitigate this problem e.g. to enable dynamical body arrangement and to support the above four requirements, we decided to design a mobile robot that mounts the functions of the GestureCam and the GestureLaser. We named this new robot 'GestureMan'.

Although the system is still under development, we have been conducting experiments with this system. The goal of these experiments is not only to verify the effectiveness of our ideas, but to find out what kind of resources participants use and how they organize their bodies for participation as they interact in this new situation [1,5,6,14]. We also want to elicit problems of the current system and discover any design implications that could help improve it.

GESTUREMAN

GestureMan is a mobile robot (Fig. 3). We are using the ActivMedia Robotics LLC's Pioneer 2-CE as the mobile robot base [21]. A camera unit and the GestureLaser are mounted on a tilting mechanism atop a vertical pole. GestureMan's total height is about 1.2 meters.

The camera's horizontal field of view is about 90 degrees which is relatively wide. Thus the camera captures not only the intended object, but also participants as they stand close to the object.

The tilting mechanism allows both the GestureLaser and the camera unit to tilt to back and forth together.

The remote instructor can control the base unit using a joystick (Fig. 4). Forward, backward, right turn, and left turn motions of the base unit can be controlled by leaning the joystick forward, backward, right and left respectively. The speed of GestureMan's motion is proportional to the leaning angle of the joystick.

Tilting can be controlled by pressing two buttons of the joystick, as shown in Figure 4.

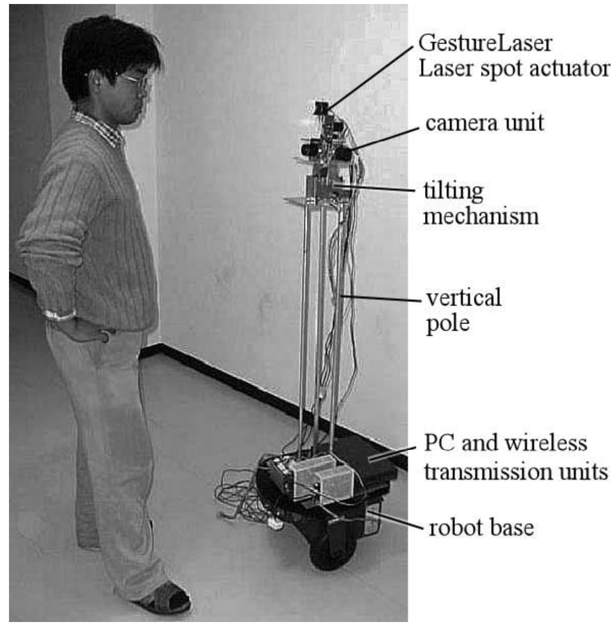


Figure 3. GestureMan

Figure 4. Joystick Controller.

Finally, GestureMan can be controlled wirelessly. We do this by mounting on the robot's base the batteries, a notebook PC, a 2Mbps wireless LAN unit, and a wireless video transmitter. Because the video transmitter uses the 1.2GHz band, we can maintain a high quality image in the transmitted image. With the current setup, batteries last 30 to 40 minutes.

EXPERIMENTS

We conducted several remote instruction experiments to investigate the advantages and disadvantages of the current GestureMan system.

Remote Instruction Experiment

An instructor at the University of Tsukuba gave instructions on how to use the machinery to an operator in the workshop at the University of Tokyo. The distance between both universities is about 50 km. Video and voice were transmitted using a satellite communication system called SCS (Space Collaboration System). SCS is an inter-university satellite network designed for transmitting sounds and images amongst universities, colleges, and national institutes. Because the transmission bandwidth of the SCS is 1.5Mbps, the video signal is compressed. Due to the compression time and traveling time, the transmission delay of SCS is about 0.3 seconds in total.

An instructor who was at the University of Tsukuba controlled the robot (Fig. 5). Computer data for robot control was transmitted via the Internet. However, transmission delay for this computer communication was negligible compared to the video/audio transmission delay.

Figure 5. Instructor's site.

GestureMan's camera was projected onto a 100-inch projection screen in front of the instructor, as illustrated in Figure 5.

An overview of the workshop at the University of Tokyo is shown in figure 6. The instructor gave instructions on how to use the MC (Machining Center) that is depicted as MC1 in the figure. An MC is a numerically controlled machine tool that has the ability to perform milling and drilling automatically. The MC in the workshop could be controlled using a user interface on a PC that was placed right next to it.

At the beginning of each session both an operator and the GestureMan were placed in the initial position shown in fig. 6. Soon after the session was started, an instructor took the operator to the power switch of the MC1. After an instructor made the operator turn the switch on, the instructor took the operator in front of the PC and the control panel. Then, the instructor told the operator to push and turn some switches on the control panel. After that an operator was told to control a user interface on the PC to start the previously prepared milling program and then the MC started to cut the work piece. Finally after milling was done, the operator was told to take a work piece out of the MC and show it to the instructor.

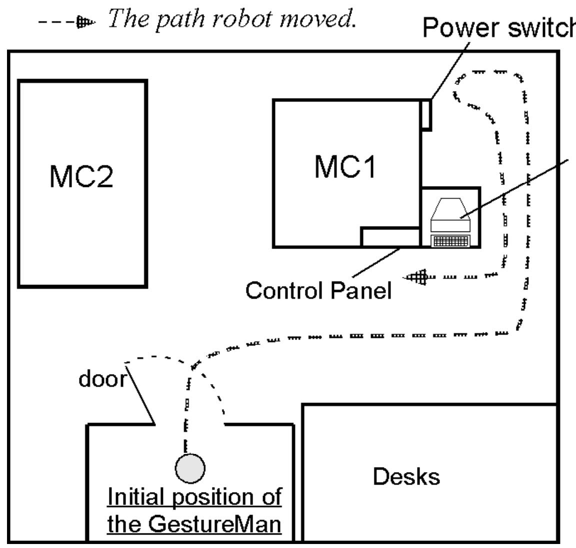


Figure 6. Overview of the workshop at the Univ. of Tokyo. For verbal communication, the operator used a wireless microphone and wireless headphones.

Four university students from the Engineering department served as operators. All of them had never seen the MC before.

Only one graduate student served as the instructor. He was quite familiar with both the MC and the user interface on the PC. Because the instructor had never controlled the GestureMan before, we had him practice using the system by actually performing remote instruction to one of the authors.

Face-to-Face Instruction

For comparison, we did exactly the same instruction task in a face-to-face setting. Only one session was conducted. The instructor was the same student as the remote instruction experiment. The operator was an undergraduate student who had never used the MC before. While the instructor could do most anything he wished, we did not allow him to control the MC and the PC directly as we wished to mimic the constraints of the remote situation.

ANALYSIS OF THE EXPERIMENT

We analyzed the interaction in an attempt to clarify how the operator and the instructor interacted each other. We were especially interested in seeing if the mobile robot could support the previously stated requirements: 1) The gestural expression, 2) The arrangement of bodies and tools, 3) The observability, and 4) The sequential organization requirement. In this way, we tried to identify the advantages and disadvantages of the system.

Controllability of the GestureMan

In order to satisfy the requirement concerning the arrangement of bodies and tools, the instructor should be able to control the robot without excessive frustration: in the worst case, the instructor would simply stop controlling it.

During the experiment, in spite of the transmission delay, the robot was moved more often than we expected. We observed the instructor move the robot for several reasons:

- to guide the operator to certain positions,
- to observe an artifact to work with,
- and to observe an operator's manipulation.

For example, in order to guide the operator to the power switch, the robot had to pass through a narrow path where only one person could get through. It seemed that the instructor did not hesitate to go into the path. We suspect it was because the instructor used the affordance of himself to judge if the robot can get through or not. Thus we postulate that it is better to design a robot with almost the same width as a human body.

During the session the instructor had to change the robot's orientation between the PC and the control panel. It seemed that he could do so within a reasonable time. This was clearly possible because the robot was designed so that it could change its orientation at the same spot without moving back and forth.

However, we also noticed that the frequency that the instructor moved the robot's body was much less than what he did during the face-to-face instruction. One of the reasons may be the transmission delay of the video image. Because of this delay, the image from the robot's camera moved a little bit after the instructor moved the joystick. Because of this inexact control/display compatibility, the instructor had to move the robot little by little. We also saw that the instructor sometimes moved the robot much too close to an object or overturned the robot so he could no longer see the intended object. In such cases he had to fix the robot's position or direction. This problem is one of the major reasons why remote instruction took more time than face-to-face instruction.

This problem happened since the instructor could not specify the exact position/direction to move/turn to, but he could only specify direction and speed of movement. In order to alleviate this problem, we are planning to employ a virtual reality technique i.e. an omni-directional treadmill. The omni-directional treadmill was developed by Virtual Reality Lab. at the Univ. of Tsukuba [10, 20]. It enables a user with a head mounted display (HMD) to walk around any direction in the virtual world. Using this technology, the robot can be controlled to move in exactly the same direction as a user walks. The video image from the robot's camera will be displayed on the HMD. In this way, we are expecting that an instructor can use his/her own sense of distance/direction to decide how far/much the robot should move/turn. Currently this method is still under development. Since an HMD will have problems of narrow field of view and low resolution, it will be necessary for us to carefully evaluate if the system is really effective or not.

Observability for the Instructor

During face-to-face instruction, the instructor turned his head toward the operator very frequently (sometimes less than every five seconds) as he was explaining about certain artifacts. He did this to observe the operator's reaction such as facial expressions, orientation, and facial expressions.

In this experiment, the GestureMan was mounted with one camera with a 90 degrees horizontal field of view. With this wide field of view, the camera could often capture both object and the operator within one screen (Fig. 7). Thus the video could be used to observe the operator's orientation with respect to the object.

Figure 7. A screenshot from the GestureMan's camera.

When the robot and the operator were positioned side by side, however, the camera's field of view was too narrow to capture the operator.

Another problem was a trade-off between width of field of view and image resolution per object [2]. That is, the field of view of the camera was too wide to capture an image of each object with a satisfactory quality. In our experiment, this mean that the instructor could not read the characters on the PC screen or the control panel.

In order to satisfy the *observability requirement*, we are testing a zoomable camera. Although the results are not yet analyzed, it seems that the instructor was generally comfortable with the zooming function. Since the field of view of a camera becomes narrower as it zoomed, however, we have to further analyze how this function affected the interaction.

A more radical approach is to employ a three-camera unit. A three-camera unit is a combination of three cameras, each of which has a narrower field of view. Three cameras are aligned radially and close to each other to make the blind areas between cameras as narrow as possible. In this way the unit achieve not only a wider field of view but also a higher resolution (Fig. 8). Of course this method requires much more bandwidth for video transmission. It is worth studying this kind of system, however, because such high bandwidth networks will be widely available in the future.

Because of this, we are starting to test three-camera unit. Video images of three cameras were transmitted from the Univ. of Tsukuba to CRL (Communications Research Laboratory) in Koganei City using a 135Mbps ATM network and displayed on the three-screen system named the UNIVERSE [22] (Fig. 9).

Laser Pointer

As we have reported on our previous paper [19], the GestureLaser is effective because it can project a pointing gesture (a laser spot) directly on an object.

During this experiment, the laser was constantly used to point at switches on the control panel, buttons on the user interface of the PC, and tools placed somewhere in the environment (Fig. 10). The laser spot was conspicuous enough for the operator, and also small enough so that it can be projected on a small button. Surprisingly, in spite of the transmission delay, the instructor could point at buttons precisely enough for effective instruction. Perhaps the most telling moment came when the instructor said that it would be impossible to give instruction without this kind of pointing device.

The instructor complained, however, about a transmission delay because sometimes he had to adjust the position of the laser spot a few times to correctly point to an intended object. In order to satisfy the fourth requirement of *sequential organization requirement* we have to minimize the time delay due to the system. To alleviate this problem, we are considering employing a touch panel display so that the laser spot automatically points at the place corresponding to an instructor touches on a screen.

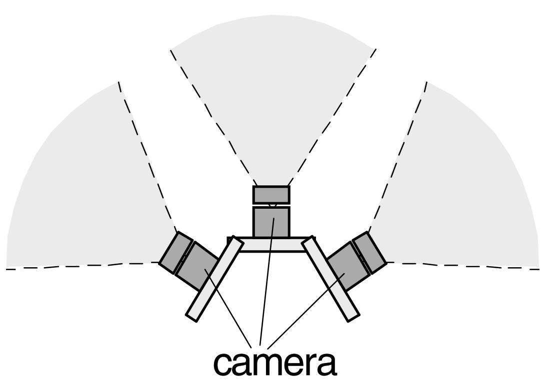


Figure 8. Top view of the Three-camera unit.

Figure 9. Three-screen system at CRL.

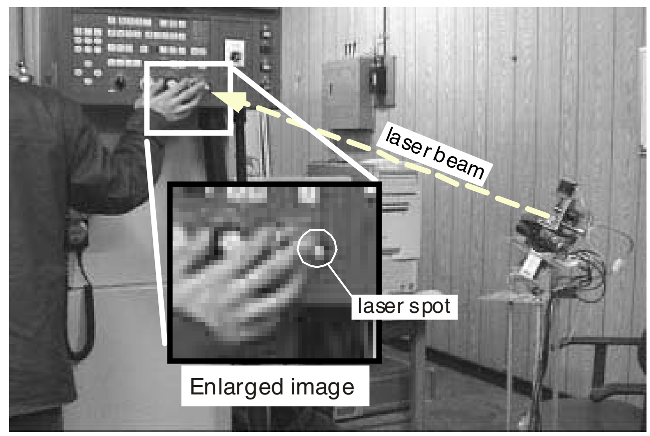


Figure 10. Using a laser beam to point at a button.

Robot Awareness

We are interested in analyzing if a mobile robot can satisfy the second and third requirements of *arrangement of bodies and tools* and of *observability*. For instance, we want to know if the operator could be aware of the robot's orientation.

Awareness to Orientation

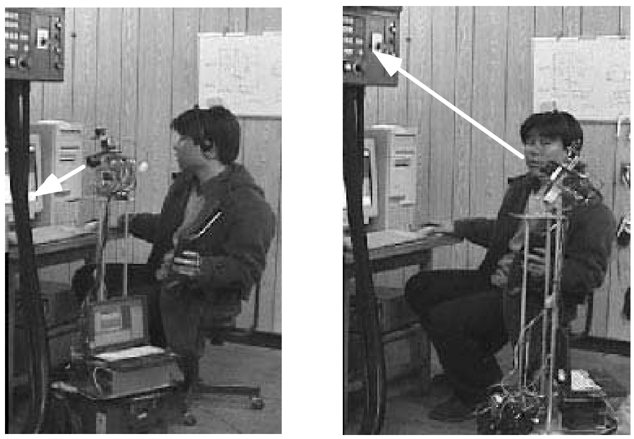
In our previous experiments, when a static camera was used to mediate remote instruction, the instructor's verbal expressions such as "right" and "left" often caused misunderstandings because the operator could not be aware of the direction of the instructor's gaze through the camera.

Most of the time during this experiment, the robot and the operator placed their bodies close to each other and oriented themselves in the same direction. Also, the instructor often used verbal expressions such as "right" and "left" but no misunderstanding by the operator was observed. We believe that the operator could be aware of the robot's orientation intuitively during the course of interaction.

Predictability

During face-to-face instruction the instructor often looked at the object to explain something before he pointed at it. Very often the operator was aware that the direction of the instructor's gaze had changed and the operator looked in the same direction before the instructor actually performed the pointing gesture [12]. Thus the operator could involuntarily predict the location of the next object to be explained.

During the session of this experiment, the instructor changed the orientation of the robot between the PC and the control panel several times. In such cases, most typically the instructor first turned the body of the robot and then tilted the camera to capture the image of the object on which instruction is given. Finally, the instructor started to say things such as "Please look at this control panel."



(a) **(b)**

(c)

Figure 11. An example that the operator was aware that the robot changed its gaze direction. Solid line show the robot's gaze direction and the dotted line show the operator's gaze direction.

According to our video analysis, we could observe several cases where the operator was aware of the change of robot's orientation and looked at the same direction before the instructor uttered a word. Figure 11 shows a typical example of such a case. At first both the robot and the operator were looking at the PC (a). Soon afterwards, the robot started to change the direction of its gaze toward the control panel. While it was moving, the operator noticed that the robot was moving thus he looked at the camera (b). Two seconds later, the operator changed his gaze direction toward the control panel (c). Again the instructor did not utter any word during this period. It can be assumed that this prediction was possible because the robot could position its body close enough to the operator so that he could easily be aware of its movement.

Different operators, however, used other resources to notice the robot's motion and to predict the next place to be explained. One operator, for example, said that he noticed that the robot changed its orientation because the laser spot moved out from the PC screen. Then he kept on following the laser spot until it reached the control panel. It was an interesting discovery that the laser spot can show not only gestures, but also the focal point of the remote instructor.

In order to support our third requirement of observability, perhaps it is better to equip the robot with redundant resources that indicate its orientation. Thus we are considering mounting a flashlight on the camera to brighten the field of view of the camera. Mounting a dummy head on the camera may also help the operator intuitively notice the instructor's gaze direction.

CONCLUSIONS

In order to support remote instruction on how to use machinery, we developed a mobile robot-mediated communication system named the GestureMan. GestureMan was designed so that it partially enables 1) the instructor to use pointing gestures and body movements, 2) both the operator and the robot to take an appropriate body arrangement to see and show gestures, 3) the instructor to monitor operators and objects, and 4) participants to organize the arrangement of bodies and tools and gestural expressions sequentially and interactively.

From our experiments, we believe that a remote control mobile robot has the ability to embody a remote instructor's actions. In other words, because the robot can position its body close to the operator, its actions can be easily noticed by that operator.

Ruhleder and Jordan pointed out that time delay breaks down the distributed interaction [17]. Consequently, we need further study on the effect of the time delay on remote instruction. It was interesting to note, however, that the remote instruction was effectively performed with a relatively low bandwidth for a video/audio communication line and 0.3 seconds transmission delay. This means that the next generation cell phone system such as IMT-2000 (that will have 2Mbps bandwidth) will be sufficient to be used as communication line for the GestureMan. It means this kind of system can be used anywhere in the world in the near future.

ACKNOWLEDGMENTS

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