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GestureLaser and GestureLaser Car

Development of an Embodied Space to Support Remote Instruction

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Abstract. When designing systems that support remote instruction on physical tasks in the real world, one must consider four requirements· 1) participants must be able to take appropriate positions, 2) they must be able to see and show gestures, 3) they must be able to organize the arrangement of bodies and tools and gestural expression sequentially and interactively 4) the instructor must be able to give instructions to more than one operator at a time GestureLaser and GestureLaser Car are systems we have developed in an attempt to satisfy these requirements GestureLaser is a remote controlled laser pointer that allows an instructor to show gestural expressions referring to real world objects from a distance GestureLaser Car is a remote controlled vehicle on which the GestureLaser can be mounted. Experiments with this combination indicate that it satisfies the four requirements reasonably well and can be used effectively to give remote instruction. Following the comparison of the GestureLaser system with existing systems, some implications to the design of embodied spaces are described

Introduction

We propose a new system, the 'GestureLaser system', which allows us to instruct multiple operators at a remote site. The goal of this system is to facilitate remote instruction on physical tasks in the real world, such as repair and maintenance of mechanical devices, laboratory classes, medical treatment, etc. At the same time, we want to clarify the requirements and problems in the design of remote instruction systems for multiple operators in the real world.

In this paper, we consider the basic elements required to support instruction on physical tasks in the real world by reviewing conversational analysis and ethnomethodological studies of work places. We then introduce GestureLaser and GestureLaser Car. Based on observation of remote collaboration experiments, we show that GestureLaser and GestureLaser Car are effective in supporting remote instruction on physical tasks in the real world By comparing GestureLaser system with other systems that have been proposed up to now, we clarify factors that should be considered when designing a system that supports collaborations by multiple operators in the real world.

Collaboration in the Real World

Most current groupware uses fixed computers and fixed TV monitors to mediate communication This means that shared objects have to appear on such monitors. In other words, the work area is confined to what can be captured by a stationary camera, and displayed on a flat screen Other shared objects are usually limited to computer data such as drawings and texts, which are stored in a common database.

On the other hand, there are many tasks that require operators to share physical objects and their disposition in the real world. In fact most of our tasks such as laboratory classes, machinery assembly, furniture repair, etc., require us to collaborate using the human body and physical tools. In this paper, we consider a system that can support an instructor to direct multiple operators at remote sites, as required in remote medicine, remote education and so on.

What, then, is necessary to support remote instruction on physical tasks in the real world? In order to get an answer to this question, we would like to review some ethnomethodological studies.

Conversational analysis and ethnomethodological studies of workplaces (Heritage, 1997; Goodwin, 1994) are strongly interested in problems of instruction and collaborative work in the real world. Their main interest is to explain how participants organize human actions interactively and sequentially For example, when B answers A' s question, B displays how B understood A's question Through this sequential understanding mechanism, conversation is organized interactively and sequentially (Heritage, 1997).

According to Heath these mechanisms are also relevant in bodily interaction. Heath says that "The emergent and sequential organization of interaction is also relevant to how we might consider the contextual or in situ significance of visual conduct and the physical properties of human environment" (Heath, 1997)

For example, A says to B 'take this' and at the same time points to an object (perhaps a book on the table). A's pointing connects with A's utterance 'take this' At the same time pointing is organized not only by A's utterance but also by B's utterance and bodily movements. A's pointing is done at the time and space when and where B can see A's pointing to the book. When B sees A's pointing to the book, B turns his body to the direction of the book and says 'okay'. B's body movement and utterance display his understanding of A's utterance and gesture After that A draws away A's hand which pointed to the book By withdrawing the hand, A displays A's understanding of B's understanding to all participants, including B (Goodwin, 1994; Goodwin, 1998). Gestures, including pointing, are connected with utterances They are performed and monitored in an arrangement of bodies and tools. In collaborative work, participants maintain and reorganize arrangements of bodies and tools interactively to monitor their pointing and other work (Kendon, 1990).

According to Goodwin (Goodwin, 1994), 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.

These resources can be monitored naturally when participants are talking face-to-face When they have to collaborate via video-mediated communication systems, however, such resources easily become disembodied (Heath et al., 1991)

In order to alleviate this problem, we must design new video-mediated communication systems that can embody participants behavior (Kato et al., 1997) How is it possible to embody participant's interactions via video communication? Based on the above mentioned ethnomethodological studies and our own studies on video mediated communication, we formulate the following four requirements for a system intended to support remote instruction in the real world.

(1) ***Arrangement of bodies and tools requirement***: The arrangement of bodies and tools should be appropriate for monitoring other participants behavior for both instructor and operator. In particular, (i) the operator should be able to see where the instructor is pointing; (ii) the instructor should be able to see that the

operator is orienting himself/herself towards the indicated object as well as the pointer, when he/she 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.

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

(3) ***Sequential organization requirement*** Sequential and interactive organization of the arrangement of bodies and tools and gestural expression must be possible.

(4) ***Multiple operators requirement*** All the above should work even when several operators are present.

We named virtual spaces that satisfy these requirements "embodied spaces" By satisfying these requirements, we believe, a system can embody the behavior of the participants.

We used these four requirements to design a video mediated system and developed our own embodied space system which we call GestureLaser system. We have conducted some experiments with the system

The analysis of the experiments shown in this paper aims not just to show the effectiveness of our system By developing a system and conducting experiments with it, we want to find out what kind of resources participants use and how they organize their bodies for participation in interaction in this particular video mediated communication system (Heath et al , 1992; Heath et al , 1995; Dourish et al , 1992; Nardi et al., 1993). By doing so we will be able to compare our system with other systems and design an improved system

GestureLaser and GestureLaser Car

Laser Pointers are convenient devices and quite popular tools for presentations at scientific conferences. A speaker can precisely indicate positions and spaces to a large audience. Sometimes he/she can show motions and directions by its movement. Although these expressions are not as good as real hand gestures, when used with verbal explanations, a laser spot can communicate a variety of meanings. Since the laser emitter is very small nowadays, a system can be implemented small and light enough so that it can be mounted on a mobile mechanism and thus permits a large work area. Based on these ideas, we have developed a remotely controlled laser pointing system named GestureLaser and GestureLaser Car.

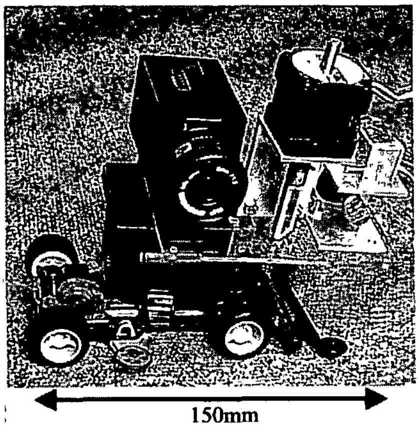


Figure 1. GestureLaser and GestureLaser Car.

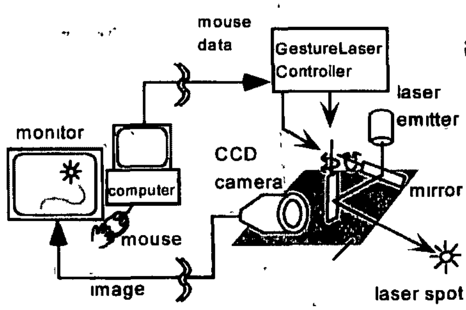


Figure 2. Overview of GestureLaser system.

GestureLaser

The GestureLaser is a remote controlled laser spot actuator developed by the authors (Kuzuoka et al., 1998). GestureLaser reflects the laser emitter's ray off two orthogonal mirrors into the workspace.

One of the authors had previously developed a system for support of remote collaboration called GestureCam (Kuzouka et al., 1994). This system consisted of a camera and laser pointer mounted on a remote controlled manipulator with three degrees of freedom of movement. Since camera and laser pointer were mounted on the same manipulator, the pointer could not be moved independent of the camera. Although the instructor could move the laser spot, because of technical limitations, this could not be done with the precision and ease of GestureLaser, while the quality of the camera picture also deteriorated.

In contrast to this, GestureLaser's pointer is independent of the camera, so that the instructor can move the pointer even while the camera remains fixed (Fig.1, Fig.2). Because of this, the instructor is able to transmit a variety of expressions through movements of the laser pointer.

We give a short description of the main characteristics of the GestureLaser System.

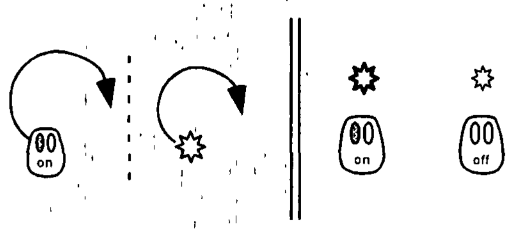
(1) The laser spot can be moved like a mouse cursor. The instructor controls the location of the laser spot with a mouse. Input from the mouse is sent through the instructor's computer to the GestureLaser Controller, where it is translated into mirror movement. As shown in Fig. 2, the instructor can monitor the position of the laser spot as well as objects and operators on an image from a CCD camera. It is thus possible for the instructor to treat the laser spot as if it were a mouse cursor (Fig. 3a). In this way, the instructor can show various expressions such as rotation and direction by a movement of the laser spot. To allow precise pointing even at a

distance of 2-3m a stepping motor (Oriental Motor. PMC33BHV2) is used to control the mirrors. The smallest step angle is 0.036°, which allows movement of the laser spot with a precision of about 1 mm at a distance 2 m, making it appear continuous

(2) The laser pointer is able to follow fast movements By using a high performance stepping motor, and by appropriately adjusting the correspondence ratio between mouse motion and laser spot motion, we were able to avoid delays in pointer movement.

(3) One characteristic of the system is that the instructor can increase the brightness of the laser spot by pressing the left mouse button to give emphasis. When the instructor presses the left mouse button, the laser spot becomes brighter. When the mouse button is not pressed the laser spot is dim, but remains visible (cf. Fig. 3b). This feature enables the laser spot to show richer expressions For example, the instructor can emphasize an expression by making the laser spot blink by repeatedly pressing the left mouse button.

(4) One important aspect of GestureLaser is the fact that it is light and portable It can easily be mounted on a transport device that moves it into appropriate positions



(a) Laser spot moves corresponding to the mouse motion

(b) Brightness of the laser spot changes corresponding to a left mouse button

Figure3 Control of a laser spot

GestureLaser Car

By conducting numerous preliminary experiments we realized that in order to actually use the GestureLaser for instruction in the real world, it is necessary to solve the following problems. (1) Sometimes certain areas cannot be viewed by the camera either because they are hidden behind objects or because of a restricted field of vision. (2) It may be impossible to point at a desired location because the laser beam is obstructed by objects or operators.

When we tried to use GestureLaser in the real world we thus ran into problems, because the instructor could not see the object of instruction sufficiently well or because the operator could not see the laser spot. We therefore decided to take advantage of GestureLaser's lightness and portability and constructed a system where it can be moved by remote control. More specifically, we mounted GestureLaser on a four-wheeled conveyance, which we call GestureLaser Car. This car can move horizontally on rails, controlled by the instructor's keyboard. Fig.4 gives an idea of the working space. A rail, comprising a straight part and rounded corners at the ends with an overall length of 140 cm is installed at a height of approximately 150 cm. It thus becomes possible to change the position and angle of the GestureLaser. Operators work and receive instructions in front of the rail, while the instructor can watch them on his monitor and give instructions.

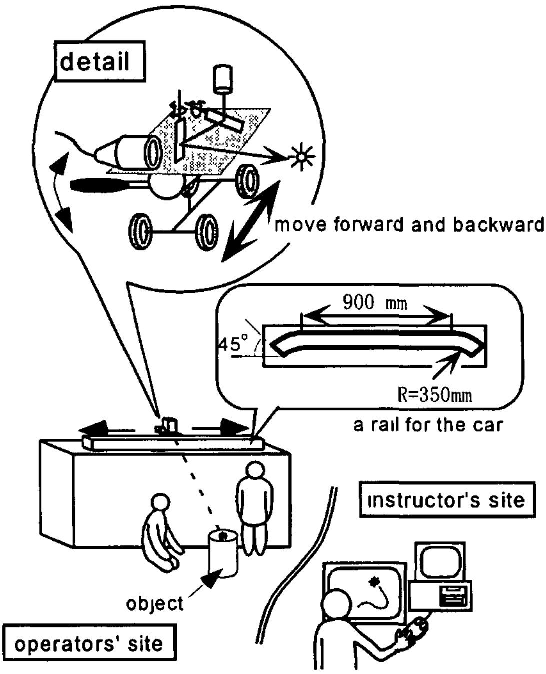


Figure 4 GestureLaser Car and experimental environment.

Experiments

We performed experiments to see how subjects performed under remote instruction in the real, three-dimensional world using a GestureLaser and a GestureLaser Car.

Experimental Tasks

As instructors we used 2 students who had practiced the basic use of the setup to some extent. The 7 students who worked as operators had no prior knowledge of the tasks required.

There were two kinds of tasks Task 1 was the installation of a PCI board in a PCI slot of a personal computer. Task 2 was the assembly of furniture Task 1 was performed twice with one instructor and one operator (one-on-one) and three sessions were conducted Task 2 was performed in a one-on-one session as well as in two sessions with two operators (one-on-two). For each session the combination of instructor and operator was changed. Instructor and operators were placed in separate rooms, but allowed to communicate freely through a sound system The instructor could thus accompany pointing with verbal instruction. Each session took about 30 to 40 minutes. Several VCRs were used to record participants' activities and recorded videos were used for later analysis.

In the following we would like to demonstrate how instructors and operators communicated during remote instructions on physical tasks in the real world We perform a detailed analysis of video data from instruction as it occurred during our experiments

First, we analyze the arrangement of bodies and tools when the GestureLaser system was used Second, gestural expressions with a remote controlled laser spot are analyzed Finally, using a transcript, we analyze how interaction was sequentially organized between the instructor and the multiple operators

Analysis of Experiments (1) — Arrangement of Bodies and Tools —

We first asked in which position the instructor and operators gave and listened to directions and performed tasks. We also analyzed under which circumstances the instructor moved the GestureLaser Car.

The Basic Arrangement

Fig. 5 shows an example of the position of operator and instructor during experiments. The GestureLaser is off to the side behind the operator while the object of instruction is in front.

It is thus not only possible for the operator to see the laser pointer and the indicated object, the arrangement of bodies and tools also allows the instructor to recognize that the operator is looking at the object It is realized because pointing is projected directly onto an object where it can be seen by a camera.

This natural body arrangement is not realized with existing video mediated communication systems, where it is thus often not easy to determine "what a co-participant is referring to" (Hindmarsh, 1998).

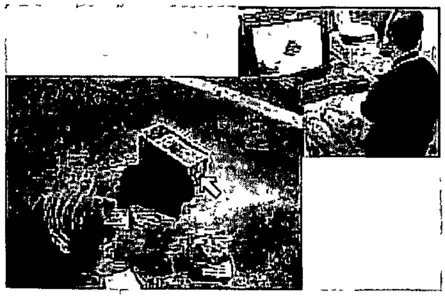


Figure 5. Basic arrangement. The instructor (upper right) and the operator (lower left).

Movement of GestureLaser Car

The instructor moved the GestureLaser Car when he was trying to capture an object outside of the camera's angle of vision or when it was impossible to point at an object with the laser, because the operator was in the way.

In the example shown in Fig. 6, the instructor began instruction only after having moved the laser on its conveyance into a position that avoided the operator and made pointing possible.

By moving the GestureLaser the instructor was able to see objects in a large region of three dimensional space and point at these objects with the laser. The operators, on the other hand, also moved when the GestureLaser moved and a new spot was indicated, in order to better be able to see the laser beam and the object pointed at, creating again the previously mentioned basic arrangement. In this way the GestureLaser Car mounted GestureLaser was able to satisfy the 'arrangement of bodies and tools' requirement.

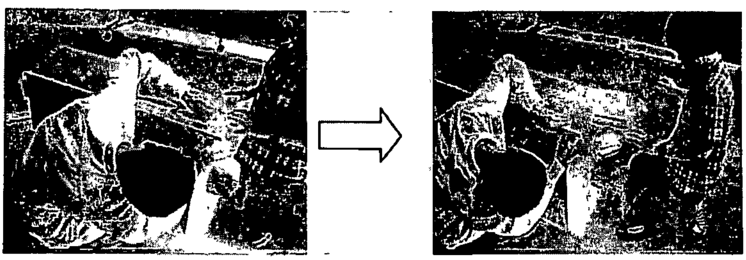


Figure 6. Movement of GestureLaser Car to change angle.

Analysis of Experiments (2) — Expressions with a Laser Spot —

The GestureLaser is designed not only to accurately indicate a location in the real world, but also to convey instructions by blinking and movement controlled by a mouse.

By studying the scenes occurring during actual experiments one realizes that there are numerous cases where the dynamic features of the laser pointer, motion and blinking, are employed. There are also cases where motion and blinking are used at the same time. We call the expressions made possible by use of these dynamic features of the laser 'gestural expressions'.

Use of GestureLaser's gestural expressions can be roughly divided into two categories: Instances where the instructor is using motion of the laser or blinking to achieve movement of the object or operators, and instances where the instructor is trying to indicate an object or a particular property of the object by tracing with the laser spot or by blinking.

Directing Motion

i) Using pointer movement

In Fig. 7 the operator was being asked to turn the object, which had been placed parallel to the angle of the camera, sideways. The instructor indicated this by moving the laser spot in an arc on the floor, as shown by the arrow in the picture. The concrete indication of the direction of rotation facilitated the operator's comprehension of the instructor's intent, and easily accomplished its aim. We also observed cases where the laser moved around at a spot visible to the operator to tell the operator to do something there.

Figure 7. Requesting rotation.

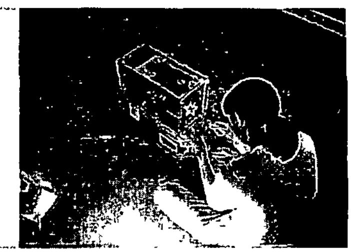


Figure 8. Use of blinking.

ii) Use of blinking

Tasks involving movement of the object are not limited to moving the object up, left, etc., but also include things like pushing buttons, making a hole, and screwing in a screw. Indicating such actions through laser motion only is difficult. In these cases blinking was used. Fig. 8 shows an example where blinking was used to indicate when a screw was to be turned.

iii) Use of blinking and motion at the same time

When the object is to be moved, the direction may be up, down, left, or right.

However, if the instructor simply moves the pointer in the desired direction, the problem is how to return it to its initial position if the gesture must be repeated. The operator will also observe the return movement and may get confused. Consequently, except in the case of rotation, there were cases where the intended direction of movement was not communicated well. In these cases it helped, when the instructor indicated the starting point of the movement by blinking before moving the pointer.

Indicating Objects

Indicating objects in the real world does not simply mean placing the pointer precisely on a certain spot. The same spot on an object may have different aspects depending on how it is perceived: there may be an indentation, or a long groove, or the spot may be part of a surface, all at once. In everyday situations we use gestures such as waving our hands, etc., and utter demonstratives such as 'this' or 'that one', while tracing the shape of it, or pointing repeatedly while moving our finger, when referring to an object. With GestureLaser the instructors referred to the various objects in the workspace during instruction with demonstratives, while tracing the object with movements of the laser spot or making it blink at a certain point. Instructions making use of this capacity of the GestureLaser were well understood by operators.

i) Indicating a line by tracing

In Fig. 9 the laser spot is moved in the direction of the arrow following a groove in the board. The instructor traces the groove many times while giving verbal explanations.

ii) Indicating a surface by tracing

Fig. 10 shows an example where the same method of tracing is used to indicate a surface. The instructor shows that he is referring to this surface by moving the laser spot around on it while saying 'This side of the board...'

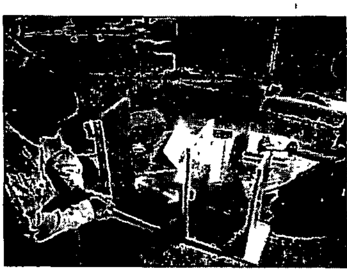


Figure 9. Following a groove.

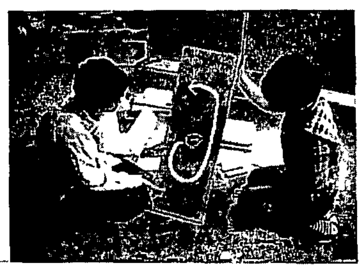
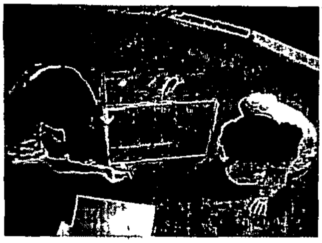


Figure10. Indicating a surface.



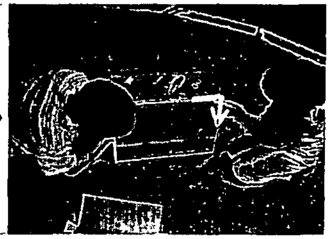


Figure 11. Tracing the left corner. Figure 12. Then the right corner.

iii) Reference to an object by tracing of its shape

The instructors were able to refer to objects or tools of a certain shape by tracing and by drawing the shape with the laser spot. In Fig. 11 and Fig. 12 one can see how this was done by tracing, but there were also cases where the instructor drew the shape of a tool, that was not at hand, on the floor to help the operators search for it.

iv) Indicating small objects

Small objects, such as screws, were indicated by blinking. There were also cases where a small object was indicated by tracing with the pointer around it.

Analysis of Experiments (3) —Interaction with Multiple Operators—

Here we would like to consider an example of instruction with more than one operator in somewhat more detail. In particular we are interested in how the operators indicate their understanding of the instructor's gestural expressions, and how in turn the instructor recognizes this.

Fig. 13 shows an exchange between an instructor and two operators. The physical setting of the scene is shown in Fig.11 and Fig.12. In this scene, the instructor was trying to instruct the operators as to where a small triangular pieces were to be attached. At (1) in the transcript the instructor, while saying "here", pointed at the upper left corner of the object with the laser spot. However, at this very moment only O2 was watching the spot and O1 who was bending his body toward the other side of the cupboard is not ready to see the spot. Soon the instructor restarted his instruction. At (2) in the transcript the instructor pointed at the same corner of the cupboard again with the word 'here'. Immediate after this restarted instruction, O1 set his body toward the laser spot. By his body movement O1's recipiency was socially indicated and thus a shared space where instruction could be done was mutually constructed. However, the instructor moved the laser spot from left to right and began tracing the right corner with the word "here"(3). It is presumed that this was because the laser spot was blocked by the head of O1 who moved his body.

I kokoni sukıma arimasu yone koko koko koko
(Guess you can see an opening here) (here) (here) (here)
TR------------------ M(R to L) TL TL M(LtoR) TR
O1 Ah-
B---L---------In -------------P--
O2 Ah-
L---T--
↑ (1) ↑ (2) ↑ (3) ↑ (4)

I kokoto kokoni ireruyouna katatidesune
(here and here, you may insert the pieces)
TR------------
O1

O2

I : Instructor
O1 : Operator1(left),
O2 : Operator2(right)
TL : Tracıng Left corner TR : Tracıng Right corner
M(L to R) : Move the laser spot (from Left to Right)
B : Movement of body (does not see the laser spot)
L : Look at the laser spot In : Operator's body interrupt the laser spot
P : Put object to the corner T : Touch the corner
--- : Contınuing of action

Fıgure 13 Transcrıpt

Right after that both of the operators said 'ah' (4) simultaneously, indicating that they had understood the instruction. This indication of understanding was followed by the instructor's quickly uttered summary, i. e., "here and here, you may insert the pieces" and he traced the right corner again, which displayed the instructor's understandıng that the operators had understood his instruction.

As shown at (1), (2), and (3) in transcript 1, the instructor's instruction used movement of the laser spot accompanied by verbal expressions. Then, the operators' understandıng was shown by moving their hands to the indicated places (as shown at (4) in the transcrıpt). Furthermore, the instructor's understanding of the operators' understanding was expressed by tracing the corner again with verbal expressions (as shown at (5) in the transcript) Thus motion of the laser spot was one of the important resources to mediate interaction and reciprocal understanding between the instructor and the operators.

When guidıng the work of more than one operator performing a task ın the real world under everyday circumstances, it often happens that instructions are not directed at all operators at once. Instead 'individual instruction' is used to make operators perform different subtasks at the same time. GestureLaser allows the instructor to direct each operator to perform an independent task or to make operators perform different tasks at the same time. There were several instances of this in our experiments.

Evaluation of the Experiments

The analysis of the experiments in which GestureLaser Car was used shows that the system satisfies the four requirements set out for support of remote collaboration in the real world

In particular, the 'arrangement of bodies and tools' requirement is satisfied, as indicated in Analysis of Experiments (1) because of GestureLaser's wide range and the mobility contributed by GestureLaser Car.

Analysis of Experiments (2) shows that GestureLaser with GestureLaser Car also meets the 'gesture expression' requirement through a variety of gestural expressions using movement and blinking

One may think that GestureLaser is inferior to other remote collaboration systems in that it has only the laser spot to express actions and reference. However, when one looks at the actual experiments, one sees that the instructors were able to use their knowledge of particular aspects of the work object (a corner, point, side, or surface, a distinctive shape or property) to create effective gestural expressions with the limited repertoire of laser spot movements and blinking. A line can be indicated by 'following' it with the laser spot, a surface by 'circular movement' of the spot, a point of interest by 'keeping steady and blinking'.

The 'multiple operators' requirement is fulfilled because GestureLaser and GestureLaser Car are able to point at each operator in his/her work area In order to give different instructions to individual operators, it must be possible for the instructor to give instructions to each operator in the space where s/he is working (his/her work area) and the instructor and each operator together must be able to observe how the instructions are given. This must furthermore be transparent to the other operators. If this is not the case, discrepancies in the process of instruction will occur. As shown in Analysis of Experiments (3), GestureLaser solves this problem.

Also this analysis showed that the GestureLaser system could support sequential organization requirement. By controlling a laser spot with a mouse the instructor could show gestures directly on each object. The instructor could also observe the operators' activities and orientation. Furthermore, by moving the laser spot in response to the operators' behaviors, the instructor could sequentially show understanding, approval, or disapproval regarding the operators' actions.

In this way GestureLaser is able to seamlessly fuse actions occurring in the world of the computer (mouse moves) and work in the real world, using the practice and knowledge of body movements and body language as a guide, and is thus able to support work in the real world.

Comparison with Other Systems

Although we could show some advantages of the GestureLaser, it also has some limitations. In this section, by comparing the GestureLaser with existing systems, we try to describe some factors that we must pay attention; when we design improved systems .

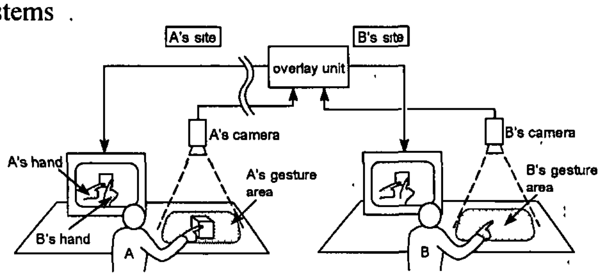


Figure 14. TeamWorkStation type configuration.

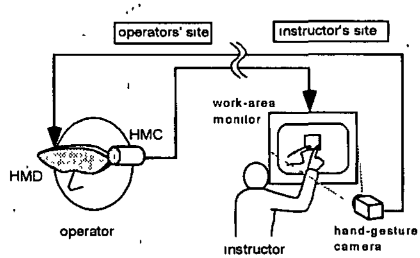


Figure 15 Remote instruction system using HMD + Head Mounted Camera

At first, we briefly explain some existing remote collaboration systems that enabled the use of gestures. VideoDraw (Tang et al., 1990) and TeamWorkStation (Ishii et al., 1991) (Fig.14) are pioneering systems that overlay participants' hand images over shared desktop surfaces. ClearBoard (Ishii et al., 1992) is an improved system that additionally overlays participants' upper body images over the shared drawing surfaces and effectively supports eye contact and gaze awareness. Double DigitalDesk uses a unique mechanism to overlay hand images (Wellner, 1993). A video projector and a camera is mounted above each desk. The camera grabs images from its local desktop and the projector projects down the image from a remote desktop. In this way, artifacts and hand gestures on the local desk are projected onto a remote desk and vice versa. Finally, some systems used combinations of Head Mounted Display (HMD) and Head Mounted Camera (similar to Fig. 15) to give remote instructions (Kraut et al., 1996; Kuzuoka, 1992).

In the following, GestureLaser and the above mentioned systems are compared in terms of expressiveness of gestures, visibility of gestures, width of work area, possible number of participants, and safety.

Expressiveness

When a person wants to express complicated three-dimensional motions or hand posture, a mere laser spot is not good enough In such cases, to use real hand images like previously mentioned existing systems may be better As mentioned in the following chapter, however, there are some problems to use such technologies for remote instruction on physical tasks in the real world.

Also, as already described in this paper, it should be remembered that assistance of verbal expressions and context of interaction make an instructor possible to communicate various expressions by moving and changing the brightness of a laser spot.

Visibility of Gestures

In order to support remote instruction of real world tasks, it is necessary that a system can show gestural expressions so that operators can easily recognize them.

Although VideoDraw and ClearBoard basically allow participants to do their tasks only on desktops, when a technique like TeamWorkStation is employed, it is possible to give remote instructions on real world tasks Since objects are specified on a monitor, however, a worker has to find the real physical object in the real environment. When there are similar objects close to an intended object, it is hard to determine the correct one (Kuzuoka et al., 1995).

Systems using video projection work well as long as the work area is flat, as is the case with DigitalDesk, but when they are to be used for instruction in using machinery, problems arise. The reasons for this have to do with the fact that normal projectors are not very bright, which requires the workspace to be relatively dark. When the workspace is bigger than a table surface, when the work objects are widely distributed in space, or when they have complicated shapes, it becomes difficult to use projection. There are 3 reasons for this: 1) the projected image blurs when it is not in the focus area, 2) when the projection surface is not almost perpendicular to the direction of projection, the image will get distorted, 3) when operators enter between the projector and the object, shadows will appear.

In the case of the GestureLaser, since only a laser spot is projected, problem 1 and 2 are alleviated. Also GestureLaser Car alleviates problem 3 since it can change the position of the GestureLaser when an operator obstructs the laser beam. If a small, light weight and bright video projector is developed in the future, however, some problems of the video projector can be alleviated by mounting it on a mechanical rover.

HMD + Head Mounted Camera may be the best way to show an operator hand gestures because hand images appears right in front of an operator's eyes. Based on our experiences, however, many operators complained that such hand images obstructed their view

Work Area

The extent of work areas of systems other than HMD + Head Mounted Camera are limited because cameras and displays are settled in fixed positions. HMD + Head Mounted Camera, on the other hand, can turn any space into a shared work area as long as a worker can look at it. Because of the narrow field of vision and low resolution of cameras and HMDs, however, visibility of most of the HMDs is much lower than that of the naked eye.

In the case of GestureLaser, because it was designed light and small, the work area could be enlarged by using GestureLaser Car. The current implementation, however, allows the system to move only along rails and it cannot point at an object from behind Currently, we are planning to mount the system on a movable robot like the PRoP (Paulos et al., 1998).

Support of Collaborative Work with More than One Operator

When it comes to complicated tasks such as assembly, repair, emergency medicine, etc, it will often be the case that several operators are needed The system must therefore provide effective support for instruction in such situations as well.

In HMD systems, even if all operators are equipped the same way, each operator's angle of view will be different and thus the pointing device can be overlaid on only one view at a time Of course one might attempt to give each operator a camera and the instructor a monitor for each operator, but then the task of mapping each operator's position and viewpoint in the work space becomes a burden for the instructor

As for video projection systems, the problem of obstruction by operators becomes all the more severe as the number of operators increases.

GestureLaser, on the other hand, can point directly at objects independent of the operator's angle of view, and can give precise instructions to several operators at the same time. There remains of course the problem of obstruction, but this can be alleviated by switching to GestureLaser Car.

Safety

One of the big problems of using a laser pointer is that it is dangerous if a strong laser beam gets directly into an eye. Although, our laser emitter is not strong and we have never experienced such an accident, we have to consider using a low power laser or normal light beam.

HMD also has some problems. Since it limits the field of vision and the resolution of a worker's sight, it can be dangerous for him/her to walk around.

Summary of Comparison

In summary, GestureLaser system can simultaneously support four aspects (expressiveness, visibility, work area, number of operators) reasonably well. Therefore, in order to support remote instruction on physical tasks in the real world with multiple operators, the GestureLaser system has advantages over other systems.

We also realize, however, that there are many other kinds of remote collaboration for which the GestureLaser may not be the best solution. Number of participants, kinds of tasks, and physical and social environment of tasks change the utility of a systems. For example, for a task that requires only one operator, HMD may be better than the GestureLaser. On the other hand, for desktop tasks, Double DigitalDesk maybe the best. The purpose of this paper is not to claim that the current GestureLaser is the best system for all the situations but to clarify factors that should be considered and functions to be improved when designing a system Thus this comparison is important to design a next system. So far, we are planning to add a laser drawing function to improve expressiveness and mounting the GestureLaser on a mobile robot to further enlarge the work area. We also have to think seriously about increasing the safety of the system.

Conclusions and Implications

In this paper, we have shown that GestureLaser and GestureLaser Car can reasonably satisfy the requirements for support of remote instruction on physical tasks in the real world. We do not mean to claim that the system we designed is more effective for various tasks across various settings compared to existing systems. But by observing the interaction of participants while they were using the system, we tried to clarify how participants use their bodies and the tools afforded by the system for achieving their tasks. Understanding of these processes is essential for designing and elaborating systems for remote instruction in the real world, such as remote education, tele-medicine and so on.

We were able to delineate some implications to the design of embodied spaces, i.e. virtual environments that can embody participants' behavior. The main point is that the system should not support gestures as individual iconic expressions (Luff, 1999). That is when a remote collaboration system is designed, it is important not only to enable the system to show gestural expressions well, but also to consider how such expressions can be used as parts of the resources of sequentially organized interactions To allow efficient use of these resources, the system must be designed in such a way that participants can use gestures and arrange and orient their bodies without time delay, and such resources must be simultaneously observable.

With GestureLaser, since it allows the instructor to project a laser spot directly onto an object, operators can monitor gestural expressions easily. Furthermore, because the camera is placed so that the laser spot and operators can be monitored simultaneously, an instructor can observe operators' actions and orientations in response to instructions Furthermore, by employing a mouse to control the position of the laser spot, an instructor can use various gestural expressions with minimum time delay. These sequential gestures also help the instructor to show understanding, approval, and disapproval to operators.

Although GestureLaser cannot show gestural expressions as clearly as real hands, we realized that it is important not only to improve the expressiveness of the laser spot itself, but also to consider how the system can support participants to use and monitor various resources sequentially

In addition to GestureLaser, we have developed and studied other embodied space systems, which support other kinds of collaboration (Kuzuoka, 1992; Kuzuoka et al , 1994, Kato et al , 1997; Kuzuoka et al , 1999) By continuing improvements and experiments in various kinds of remote instruction situations, we hope to build more effective systems and elucidate the mechanism of collaboration in the real world

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