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Can the GestureCam be a Surrogate?

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The GestureCam is a remote-controlled actuator onto which a small camera and laser pointer are mounted The term "GestureCam System" includes other user interfaces which control the GestureCam, such as the master actuator and the touch-sensitive CRT We expect the system to act as the surrogate of a remote person. In order to clarify advantages and problems of the GestureCam system, we conducted some experiments As a result of those experiments, we found that the GestureCam has the ability to support gaze awareness and remote finger pointing We also found, however, that the system has some problems which need to be refined

INTRODUCTION

When we collaborate, we share not only the papers which may be on a desk, but often three-dimensional (3-D) objects dispersed in 3-D space as well. Since 1987, the authors have been working on a video communication system which supports remote collaboration in a 3-D environment (Kuzuoka, 1992 and Kuzuoka et al., 1994). Through our research, we discovered some of the problems of previous video communication systems.

- **Problem of Static Cameras**
  In "The Affordances of Media Spaces for Collaboration," Gaver points out that "camera and microphones are stationary or only moved re-

motely, preventing perceptual exploration (Gaver, 1992)." Remote control cameras seem to be effective in dealing with this problem. We wish to clarify the type of remote control camera that is required for effective video communication.

- **Problem of Gaze Awareness**
  Gaze awareness is known to be an important factor in predicting a person's interest. ClearBoard (Ishii et al., 1992) is one of the most effective systems available which supports gaze awareness for shared drawing tasks. Since the system is static, however, gaze awareness of the objects in the 3-D environment cannot be supported.

- **Problem of Remote Pointing**
  With existing video-mediated communication systems, it is hard to point at an object at a remote site. Gaver (Gaver, 1992) wrote that "we can reach into other peoples' views, almost literally grasping their attention and directing it to oneself or to a relevant direction." In current media space, however, "one can't gesture within a shared space because of the barrier presented by monitor screens."

  VideoDraw (Tang & Minneman, 1990), ClearBoard and Double DigitalDesk (Wellner, 1993) use superimposed real hand images, [1] and this method is known to be very effective. Since the cameras are static, however, only objects on the drawing surface can be pointed at.

We are interested in determining the types of technology which effectively solve the above-mentioned problems. This paper describes what we learned from our experiments using the GestureCam system.

GestureCam System

The GestureCam system was developed to support communication between an instructor and an operator. An instructor is able to give instructions remotely to an operator on how to accomplish a given task. Although the system was described in a previous paper (Kuzuoka et al., 1994), we will briefly describe it again here.

GestureCam

The GestureCam is an actuator with three degrees of freedom of movement. A small finger-sized camera and a laser pointer are mounted on the actuator. The GestureCam is controlled remotely by an instructor, and the instructor can look around a remote site freely. The laser pointer is used to point at a certain object in the same way that a finger points.

[1] In the case of the Double Digital Desk, hand images were projected down onto the desk.

Because the GestureCam moves in front of the operator and is highly visible, operators can involuntarily sense its motion with their peripheral vision. Therefore, it is expected that the GestureCam supports remote gaze awareness, and operators can predict that an instructor may point inside his or her field of view. In this way, the laser pointer helps define the area which is being pointed at. This feature of the GestureCam is expected to support smooth communication in 3D environments.

Interfaces to Control the GestureCam

In this paper, "GestureCam" refers to the remotely-controlled camera actuator. The term "GestureCam system" includes the user interface which controls the GestureCam. Currently two types of user interface have been developed to control the GestureCam.

Master Actuator The master actuator is identical to the GestureCam, but a camera and laser pointer are not mounted onto it. The instructor changes the position of the master actuator with his/her hand; then, the GestureCam mimics the movements of the master actuator until it ends up in the same position as the master actuator.

Touch-Sensitive CRT A touch-sensitive CRT is also used in the system to control the GestureCam and to superimpose annotations on the video image.

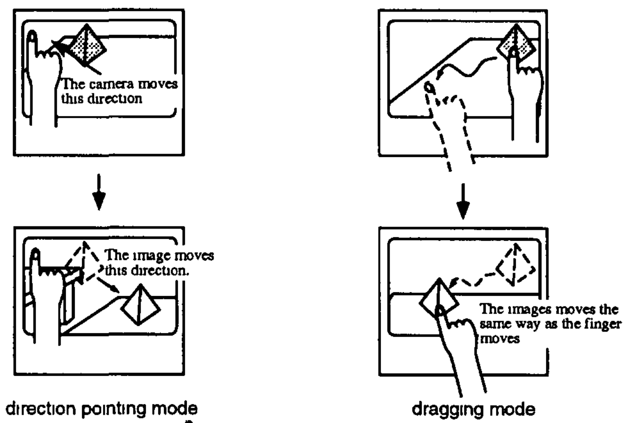

Figure 1. Controlling modes of the touch panel

Two control modes of the GestureCam (e.g. direction pointing mode, and dragging mode) were tested (Fig. 1): the direction pointing mode and the dragging mode. In the direction pointing mode, a user touches the screen and the camera moves toward the spot that was touched. The speed and the direction in which the camera moves is defined by the distance and direction from the center of the display to where the user points to. In the dragging mode, a user changes the image on the display by "dragging" a finger across the display.

Using a touch sensitive CRT, it was also possible to superimpose drawings on a displayed image. Instructors could use their finger to draw lines and write annotations. The superimposed image that is created can then be seen by both the instructor and the operator. Thus, it was possible for the instructor to specify an object or remote position in two ways: either by using the laser pointer on the GestureCam, or by using superimposed drawings(Fig. 2).

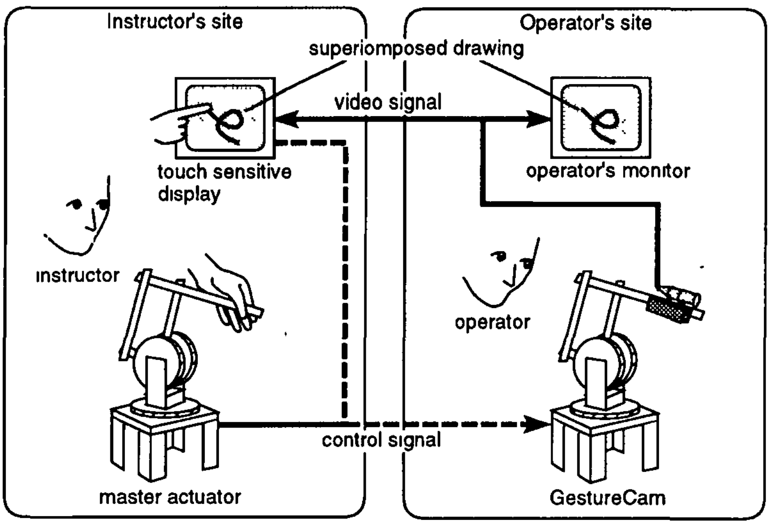

Figure 2 An example configuration of the GestureCam system.

Expected Advantages of the GestureCam System

We anticipate the possibility of the GestureCam acting as a surrogate (Sellen & Buxton, 1992) instructor. That is, we expect the GestureCam to be able to function as the instructor's head, eyes, and finger. In order to evaluate that possibility, we wished to investigate the following points:

- Can the instructor control the GestureCam easily enough so that he/she can look around and point at an object as he/she wishes?

- Can the operator detect the GestureCam's motion and the GestureCam's (e.g. instructor's) gaze naturally?
- Is the laser pointer an effective way to point at an object? How good or bad is the laser pointer compared to the superimposed drawings?

Predictability Experiment Without Communication

By conducting the experiment described in this section, we wished to determine the ability of the GestureCam in supporting gaze awareness.

Task The GestureCam and the small liquid crystal display (LCD) were set in front of the operator. An image from the GestureCam's camera was shown on the LCD. A cross was superimposed at the center of the display (Fig. 3). At first, the operator closed his/her eyes. While he/she was closed his/her eyes, the instructor controlled the GestureCam so that the cross overlapped a pre-defined object in the room. The operator then opened their eyes when the instructor said "yes" to so indicate. Immediately after the operator opened their eyes, he/she tried to find the real object corresponding to the object indicated on the LCD. When the operator found the object, he/she said "yes". The time between the instructor's "yes" and the operator's "yes" was measured.

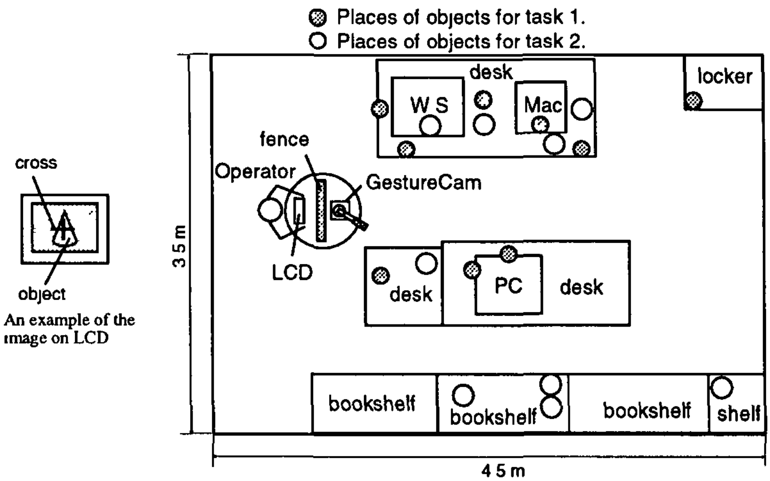

Figure 3 An overview of the predictability experiment.

Fourteen subjects served as operators, and each subject performed two test runs. In the first run (case 1), the operator could see the GestureCam. In the second run (case 2), a small fence was placed between the operator and the GestureCam so that the operator could not see the GestureCam. Two types of tasks (task 1 and 2) were used: seven subjects (group 1) were given task 1 as case 1 and task 2 as case 2. The other seven subjects (group 2) were given the tasks in the reverse order(Table I). We did this to alleviate the effects of the experience.

Table I Visibility of the GestureCam in the predictability experiment.

	task 1	task 2
group 1	visible (case 1)	invisible (case 2)
group 2	invisible (case 2)	visible (case 1)

Result Figure 4 shows the average time and the standard deviation to find an object. It was statistically significant that operators could find objects faster when the GestureCam was visible. (t=4.6).

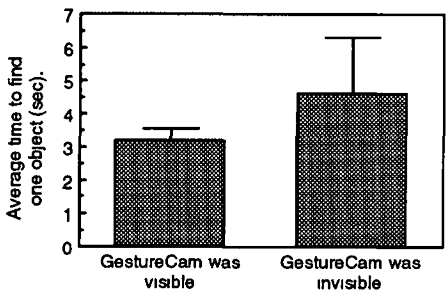

Figure 4 Average time to find one object.

From the results shown, we can assume that the positioning of the GestureCam helped operators find an object faster. According to the interviews with test subjects, the GestureCam was most effective when the object shown was relatively large in proportion to the background in the display to a degree where that background was not seen very well. Also, the GestureCam was most effective when the object was not in the field of view of the operator.

REMOTE INSTRUCTION EXPERIMENTS

In the two experiments described in this section, the instructor gave instructions on some tasks remotely to the operator. The goal of these experiments is to determine the advantages and problems of the current GestureCam system. In order to achieve this, the instructor gave instructions to the operator under various realistic communication conditions.

Experiment 1

In experiment 1, the instructor and the operator were separated by approximately 50 kilometers. The ETS-V communication satellite was used to transmit voice and video and a telephone line was used for computer communication. The transmission delay for the satellite was slightly less than one second. In order to identify as many problems as possible, our research staff acted as instructors and attempted to use GestureCam's functions in an aggressive manner. The operators were university students in the engineering department.

During the test sessions, the instructors asked operators to make an electronic circuit and observe its output with an oscilloscope. Initially, the equipment was placed at various locations and the operators were asked to retrieve them and position them as they wished. The instructors had to instruct the students on such tasks as how to connect the power supply and how to operate the oscilloscope (Fig. 5).

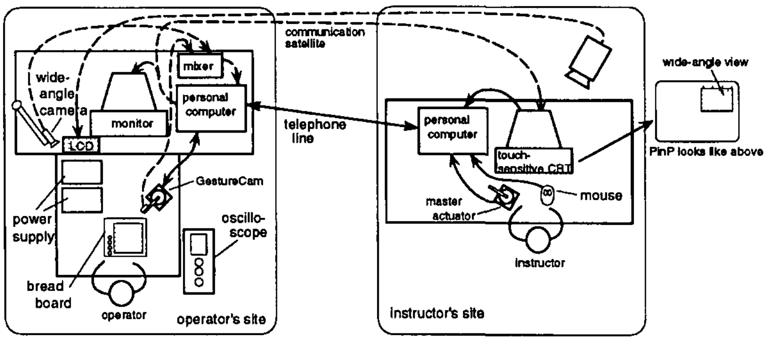

Figure 5. An overview of experiment 1.

There were various parameters for the user interface. To control the GestureCam, either the master actuator or a touch-sensitive CRT could be used. When the touch-sensitive CRT was used, only the dragging mode was available to specify the GestureCam's movement. In addition to the GestureCam, a wide angle camera attached to a cantilevered desk lamp provided an additional view. When the GestureCam was used, an image from the wide-angle camera could be displayed within a smaller area on the monitor. We refer to that image as "picture in picture," or "PinP." When the GestureCam was not used, the image from the wide-angle camera was displayed on the entire screen. Due to limitations of the system, when the master actuator was used to control the GestureCam, only one of either the laser pointer or superimposed mouse cursor could be used to specify positions.

When the touch-sensitive CRT was used, both the laser pointer and superimposed drawings could be used. When only the wide-angle camera was used, only superimposed drawings could be used; in this situation, the instructor could also verbally ask the operator to change the camera's direction during the session. During every session, the instructor's image was also transmitted via satellite and displayed on a small LCD at the operator's site. Table II shows the conditions of communication for each session. The first and the second sessions had identical conditions.

Six subjects served as the operator, and each session lasted between 30 and 50 minutes. After the experiments, the subjects were interviewed and their comments have been compiled as part of the Appendix.

In order to study the subjects' activities, we recorded the number of times the GestureCam was controlled and the number of the times that the operator followed it's motion, i.e. the operator changed his/her head direction or gaze according the motion of the GestureCam. Table III shows the number of GestureCam movements and the number of times that the operator followed those motions. Table IV shows the method instructors used when he/she specified positions. "Verbal" refers to the fact that the instructors did not use one word directions such as "this" or "that" in specifiying positions, but that more descriptive verbal expressions were used.

Table II. The conditions of communication for experiment 1.

session	control method	camera view	pointing method
1-1	master slave	GestureCam+PinP wide	mouse cursor+laser
1-2	master slave	GestureCam+PinP wide	mouse cursor+laser
1-3	master slave	GestureCam	laser
1-4	touch CRT	GestureCam+PinP wide	superimp. drawing+laser
1-5	touch CRT	GestureCam	superimp. drawing+laser
1-6	–	wide camera	superimp. drawing

As table III shows, the instructors moved the GestureCam many times during the sessions. It is worth noting that when the GestureCam was not used in session 6, the instructor of the session stated that he felt it to be an inconvenience.

Experiment 2

In order to study the effectiveness of the GestureCam System on novice users, a further experiment was conducted in which both instructors and operators were not comprised of our research staff. This time, the instructor and the operator

Table III. The number of GestureCam's motions and the number of times that the operator followed those motions in experiment 1.

session	GestureCam's motion	Operator followed GestureCam
1-1	63	32
1-2	62	unknown
1-3	106	45
1-4	37	7
1-5	25	5
1-6	–	–

Table IV Frequency of activities according to methods of pointing for experiment 1.

session	verbal	laser	superimpose
1-1	23	17	0
1-2	29	4	7
1-3	32	15	–
1-4	25	1	45
1-5	17	3	18
1-6	21	–	18

were situated in close enough proximity that the video signals were transmitted through an NTSC video cable. As a result, there were no transmission delays. The task was to connect some video equipment (TV camera and device A, B, and C in Fig. 6) and to operate them. This task was much simpler than that given in experiment 1, and each session lasted between 3 and 9 minutes. The participants also had more flexible communication conditions.

In this experiment, there were also various parameters for the user interface. To control the GestureCam, either the master actuator or the touch-sensitive CRT was used. When the touch-sensitive CRT was used, the instructor could choose from either of these modes: the direction pointing mode or the dragging mode.

Normally, both the laser pointer and superimposed drawings could be used and the instructor could choose either method during instruction. In the case of sessions 1 and 2, however, the operator's monitor was turned off and the instructor could not use superimposed drawings.

Table V shows the parameters of communication for experiment 2. Table VI shows the number of the GestureCam's motions and the number of times that the operator followed those motions. Table VII shows the method instructors used when he/she specified positions. After the experiments, the subjects were interviewed about the usability of the system, and again, these comments are chronicled in the Appendix.

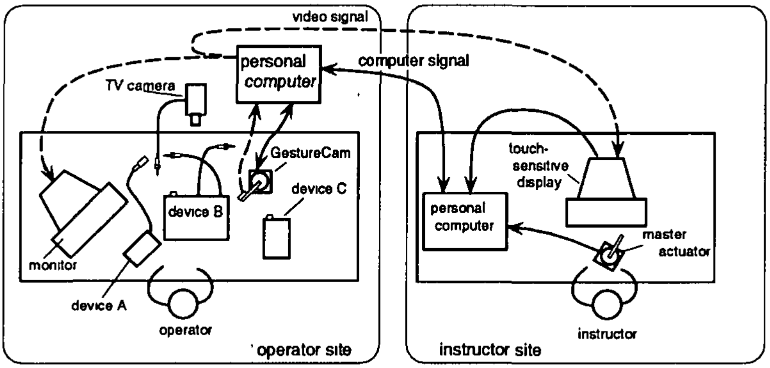

Figure 6. An overview of experiment 2

Table V Conditions of Communication for Experiment 2

session	control method	operator's monitor	pointing method
2-1	master slave	no	laser
2-2	master slave	no	laser
2-3	master slave	yes	superimp. drawing+laser
2-4	master slave	yes	superimp. drawing+laser
2-5	touch CRT	yes	superimp. drawing+laser
2-6	touch CRT	yes	superimp. drawing+laser

As Table VI shows, the instructors moved the GestureCam many times during the sessions of experiment 2. It is clear from the results of both experiments 1 and 2 that the remote-control camera is effective for these kinds of tasks.

DISCUSSION

Controllability of the GestureCam

Although the remote-control camera is useful for both experiments 1 and 2, handling the currently existing master actuator seems to require some skill. This was demonstrated by the fact that when the instructor wanted to turn the GestureCam approximately 180 degrees, or when the instructor wished to look downward or at an object close to the GestureCam, the instructor had to hold the master actuator in an uncomfortable, unnatural way. In order to deal with this problem, the mechanism needs more degrees of freedom to enable it to explore 3D space. Although the master actuator's structure does not

Table VI The number of the GestureCam's motions and the number of times that the operator followed the GestureCam's motions for experiment 2

session	GestureCam's motion	Operator followed GestureCam
2-1	10	8
2-2	17	12
2-3	13	1
2-4	13	4
2-5	11	5
2-6	16	2

Table VII Frequency of activities according to methods of pointing for experiment 2

session	verbal	laser	superimpose
2-1	1	9	–
2-2	4	15	–
2-3	2	11	0
2-4	2	6	4
2-5	0	2	7
2-6	6	7	2

necessarily have to be identical to that of the GestureCam, a new structure that will enable the instructor to conveniently look around him/her approximately 360 degrees is required.

When the instructor controlled the laser pointer with the master actuator, many instructors claimed that the fine control of the pointing position was difficult. Generally, as the instructor of 2-2 stated, the touch-sensitive CRT was preferable for fine control functions such as pointing to an object with the laser pointer, and the master-actuator was preferred for functions requiring less control. When the touch-sensitive CRT was used, however, some instructors often lost sense of which direction the GestureCam was looking at. Therefore, when they wished to look at an object which was not within the field of view of the camera, they did not know which way to look and how much to turn the GestureCam.

From these results, we noticed both the advantages and disadvantages of the current master actuator and the touch-sensitive CRT. We therefore plan to use the master actuator and touch-sensitive CRT simultaneously. If the master actuator were to be equipped with a motor, the GestureCam and the master-actuator would move in unison when the instructor used the touch-sensitive CRT, and the instructor would be able to determine the GestureCam's position by that of the the master actuator.

Position and Direction Specifications

Once the instructor was able to point at a certain object, the operator liked the laser pointer because it can do so directly; it is an especially potentially useful device when an object is relatively small and when one object among similar objects should be specified. TableVII shows that when the superimposed mode was not available (session2-1 and 2-2), instructors used the laser pointer many times and verbal expressions did not increase substantially. This result indicates that the laser pointer was useful to some extent. The problem of the laser pointer, however, lies in the controllability of its positions, which is less than desirable; one instructor also noted that the laser spot was too small to point at a small object. Furthermore, when there was a delay in transmission such as in experiment 1, the instructors tended to use more verbal expressions to express their instructions, rather than relying on the laser pointer(Table IV).

With our prototype, it was faster to point at an object by the use of superimposed drawings than by using the laser pointer. This was one of the main reasons why instructors preferred the superimposed drawing mode. If the control of the laser pointer's position can be fine-tuned to where it becomes much easier and faster to use, it will probably be used more often. Another advantage of superimposed drawings was its expressive ability. For example, by drawing a circle around an object, the instructor could specify the whole equipment and not simply a button on it. Also, the instructor could express directions by drawing arrows.

To incorporate both the expressive ability of the superimposed drawing method, and the direct pointing capability of the laser pointer, one of the solutions may be to employ a laser drawing facility and draw directly onto the object. Small mechanisms for laser drawings, however, would have to be developed.

Different Orientation Towards the Shared Object

When superimposed drawings were used to point at an object or to show direction, some communication problems were observed due to the different orientations toward the shared object.

When the laser pointer was used, since the pointer pointed directly at the real object, this type of problem was not observed. In contrast, however, the laser pointer cannot express directional information; laser drawings would be useful in alleviating this problem.

Predictability

In experiment 2, when the operator's monitor was turned off (session 2-1 and 2-2), the operator often looked at the GestureCam. Furthermore, the operators of session 2-1 and 2-2 said they looked at the GestureCam's motion. Thus, we can assume that the GestureCam was regarded as the surrogate of the instructor's eyes in that it has shown its ability to support gaze awareness. When the operator's monitor was turned on, however, the operator looked mostly at the monitor to ascertain the instructor's view. When the instructor kept the laser pointer turned on, some operators looked at the laser spot but not at the GestureCam while it was moving.

From this observation, the operators apparently preferred a more precise information of the instructor's view, such as that which was obtained from the operator's monitor or the laser spot. We do not feel, however, that the GestureCam is entirely irrelevant. The GestureCam was most likely seen through peripheral vision, and provided some help in locating the real object. Furthermore, the GestureCam was used for confirmation (2-5-ope), especially when it moved a lot (2-4-ope). For the time being, the best solution is to prepare the GestureCam and the operator's monitor at the same time.

If the GestureCam could be controlled faster and more accurately, an operator might look at the GestureCam more, but further studies must be conducted to confirm this. On the other hand, if the monitor can be mounted on the GestureCam in such a way that it does not cause a difference in orientation between the instructor and operator, the monitor would also be an effective way to support gaze awareness. One possibility is to mount a Liquid Crystal Display (LCD) on the GestureCam.

Usefulness of Wide-Angle Cameras

When the wide-angle camera was not used, instructors sometimes faced difficulties in locating an object which was out of the camera's view. In addition, when the master actuator was not used, although the camera moved continuously, the instructor did not know which direction the GestureCam was looking at.

The wide-angle camera seems to be effective in alleviating these problems. However, even though this method can save transmission bandwidth, the PinP is unfortunately obtrusive. If possible, the wide angle view should be displayed on a separate screen. If that is not possible because of insufficient transmission bandwidth, (in experiment 1, only one channel was available for video transmission), the system should allow an instructor to be able to turn the PinP on and off at will. One instructor suggested that the wide-angle view's refresh rate can be lower than the GestureCam's view. If this is true, it may save even more of the video transmission capacity.

Face View

Gaver wrote that tasks such as those presented in this paper do not require a substantial face-to-face view, but he also pointed out that it does not mean that a face-to-face view is entirely unnecessary. In experiment 1, when the instructors did not say anything for a while, many operators looked at the LCD. During these times, the operators did not necessarily want to look at the instructor's face, but they wanted to see what the instructor was doing. Thus, it may be preferable to include the work area of the instructor and not only the instructor in the view.

CONCLUSIONS

For the GestureCam to become a surrogate of the instructor, smooth control of the mechanism appears to be very important in supporting communication. Thus, the user interface should be considered both from instructor's side and the operator's side. The following items should be considered:

- A remote-control camera is more effective than a static camera in supporting 3D tasks. One of the most important factors in improving the effectiveness of the GestureCam, however, is to create a faster and more accurate control of the mechanism. If this factor is not at a satisfactory level, users will tend to rely more on verbal expressions rather than controlling the GestureCam.

- It seems that both the GestureCam's motion and monitor could support gaze awareness. Also, it seems that both the master actuator and touch-sensitive CRT have advantages over controlling the GestureCam and specifying positions; however, even though it is common knowledge to groupware researchers, we recognize that each person has his/her own preference. Thus, we will refine the system so that users can choose and change to any interface as they wish. In other words, we will try to support the seamlessness of tools (Stefik & Brown, 1989).

Appendix

Following are the opinions expressed about the controllability of the GestureCam. Their opinions are numbered in this manner: "1-3-ope". The first number is the experiment number. The Second number is the session number of each experiment. The third word indicates who stated the opinion. "ins" stands for instructor, "ope" stands for operator, and "obs" stands for an observer who is part of our research staff. The observers' opinions are based on their observation of each session.

Controllability of the GestureCam

- **1-3-ins** "Since fine control of the GestureCam was not easy, it was not easy to point at a small object with the laser pointer."

- **1-4-obs** "When I turned the GestureCam almost 180 degrees using the touch-sensitive CRT, it took a longer time than to use the master actuator."
- **1-5-ins** "I sometimes did not know the GestureCam's posture."
- **1-6-ins** "Even though the wide-angle camera was used, the static camera is inconvenient and it is troublesome to ask the operator to move the camera."
- **2-1-ope** *"It was irritating to wait for the laser spot to point at an object."*
- **2-2-ins** "It was hard to point at a place close to the GestureCam, and low places. For controlling the laser pointer, I like the dragging mode of the touch-sensitive CRT the best. To look around, or to look for an object, the master actuator was better."
- **2-4-ins** "There was no problem in controlling the master actuator, but the laser spot was too small to point at a small object "
- **2-6-ins** (He used the master actuator after the session and said,) "I can control the GestureCam easily because I could imagine its posture "

Position and Direction Specifications

- **1-4-ins** "It is easier to use superimposed drawings than the laser pointer to point at an object."
- **1-4-ope** "Both superimposed drawings and the laser pointer have their merits "
- **1-4-obs** "Mostly superimposed drawings were used to show direction "
- **2-1-ope** "The laser pointer is convenient for pointing at small objects "
- **2-2-ins** "The laser pointer is convenient for pointing at one object among similar objects "
- **2-4-ins** "The superimposed drawing was convenient for specifying bigger objects."
- **2-4-ope** "I prefer the laser pointer over superimposed drawings."
- **2-6-ins** "I prefer superimposed drawings because I can point at an object faster."

Different Orientation Towards the Shared Object

- **1-1-ope** "When I compared the object in the monitor to the real object, they looked as if they were different objects "
- **1-6-ope** "When I was told something like 'On the screen, right direction,' it was not easy to understand which direction in the real world "
- **2-6-ins** "Because orientation towards the object was different between the operator and the GestureCam, I sometimes had difficulties in giving instructions."
- **2-6-ope** "When I saw superimposed drawings, I got confused because the orientation towards the object was different In this respect, the laser pointer was better "

Predictability

- **1-2-obs** "When the instructor looked at the oscilloscope with the GestureCam, the operator also looked at it even though the instructor said nothing "
- **2-2-ope** "The GestureCam's motion helped me find a specified object."
- **2-3-ope** "When there was the operator's monitor, I felt like I could look at the work space from the instructor's point of view The combination of the operator's monitor and the laser pointer was good "
- **2-4-ope** "The operator's monitor helped me find a certain position. I only looked at the GestureCam when it moved a lot."
- **2-5-ope** "I seldom looked at the GestureCam, but I was usually looking at the operator's monitor. Even though the laser was pointing at an object, I looked at the monitor first, then I looked at the laser spot. I looked at the GestureCam just to confirm if the position was right."

Usefulness of the Wide-Angle Camera

- **1-3-ins** " Maybe the wide-angle view does not have to be a live video "
- **1-4-ins** "Although the wide-angle view was convenient, PinP screen was too large and become an obstacle "
- **1-5-ins** "When there was no wide-angle view, it was much easier to see the monitor, but I often felt that I needed wide angle view "

Face View

- **1-4-ope** "It is good that I could see the instructor "
- **2-4-ope** "I was irritated when the instructor did not say anything."

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