Comparison of Co-located and Remote Collaborative Work using a Stereoscopic Image on Path Steering Task

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ABSTRACT

We compared two types of 3D collaborative work, co-located and remote, on a tabletop display with stereoscopic images on collaborative path steering task with two users. We used IllusionHole, an interactive stereoscopic display for multiple users, that enables each of the users to directly reach out to and point at a particular position on the stereoscopic image. The 3D workspace is simultaneously shared by all users. We carried out a comparative experiment on the path steering task presented on IllusionHole in which two participants cooperatively manipulated a virtual object along a wire. Experimental results show that there was significant difference in favor of co-located situation, and the performance was affected by synchronization difficulties between participants appeared for remote situation. Based on the results, we discuss supporting remote collaborative work with stereoscopic image.

KEYWORDS: virtual reality, stereoscopic display, 3D user interface, direct pointing, steering law, awareness information, evaluation

INDEX TERMS: H.5.2 [Information Systems]: User Interfaces—Evaluation/methodology, I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality, K.4.3 [Computers and Society]: Organizational Impacts—Computer-supported Collaborative Work

1   INTRODUCTION

Recently, the advance of virtual reality technologies provides simplifying the acquisition and the use of more complicated and higher quality 3D environments in real time. In medical field, for example, 3D volume data of human bodies are visualized in a moment and shared by multiple persons such as doctors and patients. Since more and more 3D televisions and 3D content are widely developed, the use of 3D environment is getting familiar to many people. For example, a 3D telecopier that we recently proposed allows multiple groups of users at remote locations to share a stereoscopic image of real object [15]. Technology progress expands possibilities for collaborative work in a 3D environment. When users adequately share 3D environment with others, they can efficiently perform cooperative tasks with good common mutual understandings [26].

Tabletop displays offer users the opportunity of face-to-face communications with verbal/nonverbal communications and awareness information. If such displays can present a sharable stereoscopic image, the collaborative work will be conducted smoothly by sharing the awareness information of other participants' physical actions, such as hands that reach out to a particular point on the stereoscopic image.

Much research on object manipulation in VR is conducted for various tasks such as path following task [6], or collaborative assembly tasks on co-located environment [3][26]. In addition, a network is spread and its speed is becoming faster today, a collaborative workspace is enough to be used on remote environments. For remote diagnosis, surgical operation, industry design, and 3D telecopier, remote collaborative work with object manipulation is expected. Especially for remote medical applications, such systems are widely explored (e.g., [10][12][29]). To perform remote collaborative work with object manipulation effectively, what information to be transmitted to remote places and the environmental difference between co-located and remote situation is should be investigated.

In this paper, we compare two types of 3D collaborative work, co-located and remote, on a tabletop display with stereoscopic images on collaborative steering task with two users. The task is designed based on steering law [1], which is the quantitative performance model on trajectory tracing in 2D GUI and 3D environment [6]. Through the quantitative investigation of the differences between co-located and remote collaborative work, we explore the difficulties in remote collaborative work. A comparative experiment is conducted with IllusionHole [16], an interactive stereoscopic tabletop display for multiple users that enables each of the participants to directly reach out to and point at a particular position on stereoscopic images. In co-located work, two participants in the co-located situation cooperatively manipulate a virtual object to perform steering tasks on one IllusionHole. In contrast, two IllusionHoles are connected by a network in the remote situation, and two participants at individual locations perform the task without seeing their partner. The experiment also includes the investigation of the effect of conversation on object manipulation.

2   RELATED WORK

In this section we discuss previous work on collaborative and tabletop display systems using stereoscopic images.

2.1   Interactive Stereoscopic Display

One reasonable medical-use, multi-user interactive stereoscopic display system has been installed in a table in which a horizontal monitor has been placed [2]. This is the most effective way to view stereoscopic images from the vantage point of each user standing around a table, as is the case during surgical procedures. Multiple users must also maintain cooperative work environments to communicate effectively by eye contact and facial expressions during the procedure. Optical equipment, which includes a parallax barrier, mirror [4], and a revolving screen [8], must be used that allows multiple users to observe the stereoscopic images with motion parallax in any direction. It is, however, impossible

to naturally interact with the stereoscopic images since image formation is located in the optical device.

An IllusionHole [16] multi-user stereoscopic display consists of a display device and a display mask with a hole in its center. With its simple configuration, this system provides intelligible stereoscopic images free of flicker and distortion. In this theory, the display regions for users are smaller, but they can naturally reach out to and point at the stereoscopic image and share the direct pointing information. These characteristics offer natural interactions.

2.2 Co-located and Remote Collaborative Work

Collaborative work with a tabletop display enables users to share not only the information shown on the display but also the awareness of such information as their partner's facial expressions or gestures. For example, DiamondTouch [7] enables several users to directly manipulate and simultaneously touch and share direct pointing information. Kruger et al. concluded that the direction of the information objects could be a clue for establishing communication channels, better understanding of the content, and mediating collaborative work [20].

One type of system has already been proposed that supports collaborative work between distant places connected by computers. This type of system electrically provides such additional awareness information as a partner's facial expressions and gestures so that the remote situation is similar to a co-located situation. Ishii et al. proposed Clearboard [14], which displays the other users by a camera. This enables users to get awareness information as if they are working in the same place. Using the DiamondTouch system, Pauchet et al. confirmed that remote situations, which provide overlaid information of a partner's arms and gestures on a table, give equal task performance to co-located situations [23][24].

A system that supports collaborative work in 3D virtual space has also been proposed, and the evaluation of user actions in that environment has also been conducted. Kiyokawa et al. explored a collaborative design task using HMD and found that users exhibit many of the same behaviors using a HMD condition as in face-to-face unmediated collaboration. Moreover, if using the three different types of HMD, the difference of view angle affected the non-verbal information by comparing the task performance, the utterance process, and subjective evaluations [19]. Salzmann et al. investigated the utility of co-located collaborative work based on projector and HMD [26]. They confirmed that perspective correct view of virtual world is a basic requirement. Prop-based two-user interaction provides a mutual understanding and improves task performance. Grossman et al. proposed 3D interaction for collaborative task on volumetric displays [11]. They proposed two users manipulating 3D object simultaneously. Basdogan et al. set a remote situation for a path following task that used a stylus with a force feedback function. They researched the influence of the force feedback and found that feedback improved the task performance [5]. Similarly, Eva et al. showed that force feedback does not affect the task completion time but does decrease the number of errors [25]. Moreover, Takemura et al. proposed a distributed situation that allows two users to share a 3D working space with direct pointing [27]. In one immersive telecommunication system, users at different places felt as if they were having a meeting at the same place. This system transmits facial expressions and gestures [30]. Many systems support collaborative work, and most choose a factor to conform remote collaborative work to the co-located collaborative work. The difference of user performance between co-located and remote collaborative work should be quantitatively evaluated.
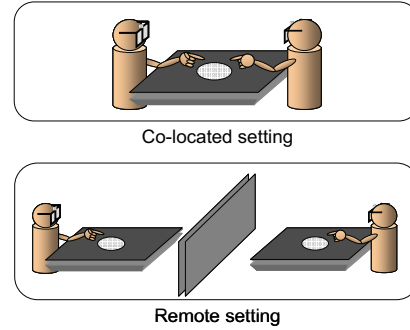

Fig. 1: Experimental settings: co-located (above) and remote-located (below).

2.3 The Steering Law

The steering law is a performance model for producing trajectories, such as drawing, tracing pull-down menus, and writing in human-computer interaction [1]. In the steering task, a user moves a pointer through a trajectory with a certain width. For trajectory C with a certain length and width, the steering law is expressed in the following form:

$$TCT = a + b \times ID, \; ID = \int_C \frac{ds}{W(s)} \qquad (1)$$

Here TCT is the task completion time for path C, ID is the index of difficulty, $W(s)$ is the width of path C at the point of abscissas, and a and b are empirically determined constants. The steering law is useful in situations with various control devices and different movement scales. For example, Bluteau et al. carried out 3D-pass steering task in immersive virtual reality environment [6].

Naito et al. conducted a task conversion from the original steering task [21]. They found that a width of path ($W(s)$) was equivalent to a pointer size. When a trajectory is narrow and pointer is certain size, steering task is converted in the following form:

$$TCT = a + b \times ID, \; ID = \frac{A + D}{D} \qquad (2)$$

D is the diameter of pointer, and A is length of trajectory.

3 COMPARING COLLABORATIVE WORK

Our purpose is to clarify the difference between two types of collaborative work, co-located and remote, with stereoscopic image presented on a tabletop display and discuss supporting remote collaborative work. To investigate the difference quantitatively, we designed and used a collaborative steering task in a shared 3D workspace based on the original steering law [1], which is a standard performance model in GUI by a single user. We also investigated the effect of conversation during the task because we considered that important information that should be transmitted to the partner for synchronizing manipulations between users.

3.1 Experimental Aparatuses

Fig. 1 shows the two experimental settings. One was for the co-located situation in which two participants share the same virtual objects on one IllusionHole. The other was for the remote situation using two IllusionHoles. Two participants see virtual objects in different places with networked IllusionHoles. One was an active type of stereoscopic view with a DLP projector and liquid crystal shutter glasses (called IH-A) [17], and the other was a passive type IllusionHole (called IH-P) [18] using a polarization
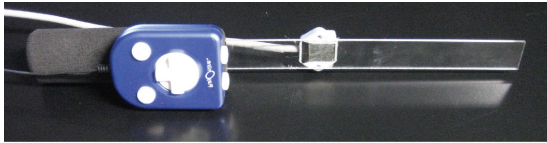
Fig. 2: Transparent stick device.

filter. IH-A (1,388 x 1,110 mm, 1,280 x 1,024 pixels) showed stereoscopic images in an active time-sequential manner. Its refresh frequency was 85 Hz. IH-P (1,219 x 914 mm, 1,024 x 768 pixels) showed stereoscopic parallax images with a circular polarizing filter. Its refresh frequency was 60 Hz. Although the mask hole radius of IH-A is different from IH-P, we adjusted the displays of both IH contents sizes so that both showed the same virtual object sizes. We also used IH-A in a co-located setting because we could easily set the experimental condition.

To get the participants' head positions, we used two types of 3D ultrasonic trackers (ZPS-VK, Furukawa Co., Ltd., and IS-600 Mark2 SoniDisc, InterSense Inc.) that have practically the same precision levels. These tracker systems can detect the three-dimensional positions of two or more tags (with a precision of 20 mm). The tags were attached to the glasses to measure participant head positions and directions. Two ZPS-VK tags at a sampling frequency of 10 Hz were used to measure the two participants' head positions and directions at the co-located setting. In the remote setting, one ZPS-VK tag at 20 Hz was used for one participant, while an IS-600 tag at 150 Hz was used for the remotely placed participant. The sampling frequency difference between ZPS-VK and IS-600 was no problem in our task.

There are various existing 3D interaction techniques for the purpose of 3D object manipulation [3]. In our experiment, we carried out experiments with most simple way to directly manipulate objects. The participants used transparent input tools called stick devices to point directly at the stereoscopic images on the IllusionHole (Fig. 2). The stick device is made with an acrylic plate (30 x 2 cm), a sponge grip, a controller, and a Fastrak receiver (6 degrees of freedom sensor, Polhemus Inc.). Fastrak was used to get the three-dimensional positions and directions of each participant's stick device. Its sampling rate was set to 60 Hz. A transparent acrylic plate was used so that participants can point directly at the stereoscopic images without any occlusion. The virtual cursor was displayed at the tip of the acrylic plate, and its radius is 4 mm (Fig. 3). In the remote situation, the cursor information is shared by both users.

The refresh rate of the display was around 10 Hz, depending on the measured participant head positions and their stick device's positions and directions in the co-located setting. In the remote setting, the refresh rates of IH-A and IH-P were 20 and 30 Hz. Although two types of IllusionHoles, IH-A and IH-P, were used, no differences occurred in our experimental task because the task did not ask participants to move their heads or the stick devices rapidly (described below). In the remote setting, the network delay was about 11 ms, which can be ignored in actual use. Thus, the co-located and remote settings were almost equal for the experimental situations.

3.2 Steering Task Design

We designed a collaborative steering task for two participants on a tabletop display based on the original steering law [1]. In the task, a pair of participants collaboratively held a virtual ring with their stick devices and moved the virtual ring from side to side along a wire. The ring was not allowed to touch the wire during the
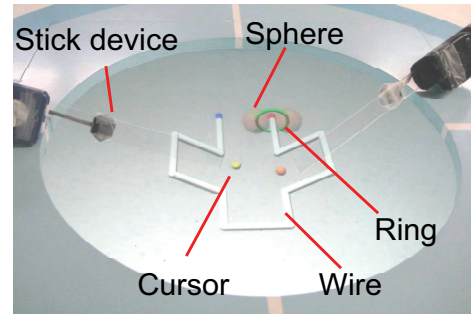

Fig. 3: Wire, rings, spheres, and cursors in 3D environment.

movements (Fig. 3). The task was designed to simulate operation training such as supporting remote diagnosis by doctors.

In the original steering task, a single user moved a pointer through a trajectory with a certain width without touching the trajectory's wall during the task. The steering law states that as the trajectory length increases or the trajectory width decreases, the task completion time increases. An equivalent task transformation regarding trajectory width was proposed by Naito [21]. When the pointer has a certain width and is moved along a line without getting away from the line, the pointer width can be converted to the trajectory width of the steering law. We extend the original steering task to two user object manipulations following Naito's task conversion. A similar task was used by Basdogan et al. [5].

We selected a steering task for the following reason. Moving an object cooperatively by two users can be considered one of the most basic collaborative works, because physical synchronization and continuous concentration are needed between users during the task.

Basically participants stood and moved freely around the IllusionHole. But during the experiment, they were instructed to stand face-to-face around the IllusionHole so that they could talk with each other and easily get nonverbal information. In the remote situation, the participant positions were identical as in the co-located situation. The participants could tilt their heads and bodies, but they were instructed not to move from their initial positions during the experiments.

The virtual cursor followed the device's movements in both situations. Note that only the partner's cursor was shared in the remote situation. During the task, the participants pointed directly at one of two spheres attached to the side of the ring to indicate a possible area for holding the ring. When they pushed the button on the stick device, they could hold the ring. If both participants simultaneously held the ring, they could move it. The participants had to move it along a wire from one side to the other as fast and accurately as possible. To do so, the ring's center had to be at the midpoint of the tip of both stick devices. The ring always stood straight against the display surface, and if the stick devices were horizontally moved to the counter by another, the ring could be rotated. When the ring touched the wire, it stopped and could not move to the same direction any more. In addition, if one of the participants moved the top of the stick device out from the sphere, the ring could not be manipulated until the ring was again held by the participants.

As visual feedback to the participants, the yellow spheres changed to a deeper color when the tip of stick device entered the sphere, and when the ring was held by pushing the buttons, the sphere's color became blue. The ring became blue when it could move. If the ring touched the wire, it changed to red.

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(a) ring radius 12 mm, wire length 300 mm.
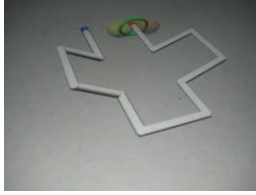
(b) ring radius 18mm, wire length 600 mm.
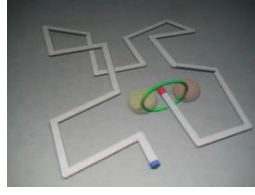
(c) ring radius 27 mm, wire length 1,200 mm.

Fig. 4: Wire length and ring radius.

3.3 Experimental Design

We used a within-subjects design with planned comparisons. The independent factors were situation (co-located, remote), wire length (300, 600, 1,200 mm), and ring radius (12, 18, 27 mm), and talking condition (talking, silence). The wire length and ring radius were selected to control the task difficulty based on the steering law on collaborative work and to explore the difference between situations. All parameters (levels of factors) were turned based on pilot study. The wire's shape was designed by considering the display area of the IH and the pilot study. Talking was selected because we considered that it could affect participant performance such as synchronization between participants. The condition of remote with talking was done in the same room, so that participants could easily have a conversation without such special settings as microphones and speakers. Fig. 4 shows all wire length and ring radius conditions. The ring is moved in x-y plane and z-axis direction. Using all combinations, participants did 36 trials three times in each condition for a total of 108 trials. Participants had a 5-minute break and a 5-minute practice session in each situational condition per experiment. Accordingly, the total time was about 30 minutes for one situational condition. The presented orders of wire length and ring radius were completely random and balanced with a pre-defined order among participants to reduce the order and the learning effects. Participants included 16 graduate students (15 men) ranging from 21 to 25 who were divided into eight groups of acquaintances to facilitate conversation. We measured their interocular distance to present stereoscopic images at accurate positions. All participants were right handed.

Before starting the task, participants put their stick devices on the mask of the IllusionHole. The task started when a bell rang. The participants collaboratively and carefully manipulated the ring to avoid touching the wire as much as possible from one side of the wire to the other with the stick device on the IllusionHole. When the ring reached the other side, the participants had to put their stick devices back on the IllusionHole. This was the process for one task, and they repeated it until they attained the prescribed number of trials. We defined the task completion time as the time from the task starting bell until the ring reached the other side. We counted the number of wire touches as errors. Even if error occurred, the participants continued to finish the task without stopping. Throughout the experiments, we filmed the participant actions and distributed questionnaires when the situational
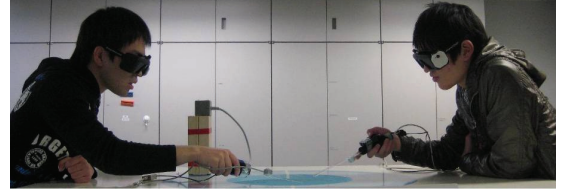

Fig. 5: Participants collaborating in co-located environment.

condition changed. All trials were analyzed to compare the participant conversations and actions on the IllusionHole. Fig. 5 shows the collaborative task in co-located situation.

4 RESULTS

4.1 Task Completion Time

We conducted the task conversion, as well as Naito et al. did [21]. The width of path ($W(s)$) could be converted to twice the ring radius ($2R$). The path length was also fixed, so path length (C) was equivalent to wire length (L). Thus the steering law for our task was expressed in the following form:

$$TCT = a + b \times ID, \; ID = L/2R \qquad (3)$$

In this experiment, lengths (L) were 300, 600, and 1,200 mm, and radiuses (R) were 12, 18, and 24 mm. Applying Eq. (3), the index of task difficulty (ID) was 5.56, 8.33, 11.11, 12.50, 16.67, 22.22, 25.00, 33.33, and 50.00 bits. For each condition, the regression analysis for the task completion time (TCT) and the index of difficulty (ID) gave:

CT: $TCT = 2.556 + 1.434 \times ID \, (R^2 = 0.966)$ (4)

CS: $TCT = 0.171 + 1.657 \times ID \, (R^2 = 0.977)$ (5)

RT: $TCT = 8.333 + 1.523 \times ID \, (R^2 = 0.928)$ (6)

RS: $TCT = 7.417 + 1.496 \times ID \, (R^2 = 0.947)$ (7)

CT is co-located with talking. CS is co-located with silence. RT is remote with talking. RS is remote with silence. Figs. 6 and 7 show each completion time and the index of difficulty. We see a linear relationship with high correction values ($R^2 > 0.9$) for all four conditions. We found a difference in y-intercept (a) between the co-located and remote situations, but all slopes of line ($1/b$) were almost the same.

A four-way ANOVA by situation, wire length, ring radius, and talking was carried out on the task completion time. Fig. 8 shows the task completion time relative to the situation, wire length, and talking. Fig. 9 also shows the task completion time relative to the situation, ring radius, and talking. We found a main effect of situation ($F(1,7)=30.092$, $p<0.01$), wire length ($F(2,14)=576.720$, $p<0.01$), and ring radius ($F(2,14)=154.895$, $p<0.01$). No main effect of talking was revealed ($F(1,7)=0.123$, $p=0.726$). We found interactions between situation and wire length ($F(2.14)=3.204$, $p<0.05$) and wire length and ring radius ($F(4, 28)=8.890$, $p<0.01$). The average completion time in the co-located and remote situations was 31.8 and 37.1 sec, and 34.1 and 34.6 sec in the talking and silence conditions.

A multiple comparison of Tukey's HSD test shows significant differences between situations at wire lengths of 600 ($p<0.01$) and 1,200 mm ($p<0.05$) (Fig. 8). There are significant differences between situations at ring radiuses of 12 ($p<0.01$), 18 ($p<0.05$), and 27 mm ($p<0.01$) (Fig. 9). When the ring radius gets smaller, it takes a longer time to complete the task, and participants experienced difficulty maintaining good performance when detailed control is demanded in any situational conditions.
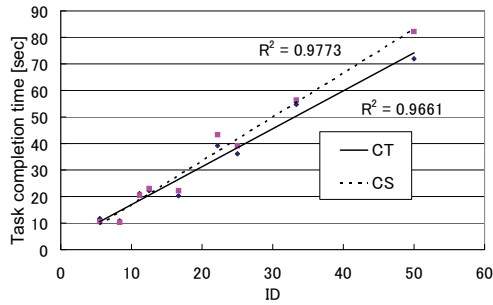
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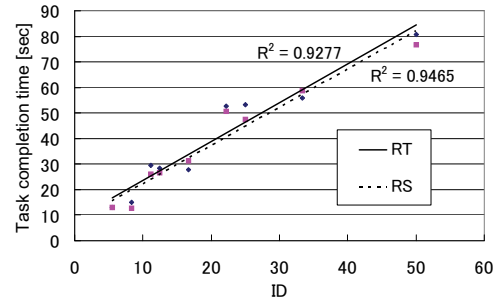Fig. 6: Relationship between ID and TCT in co-located situation.

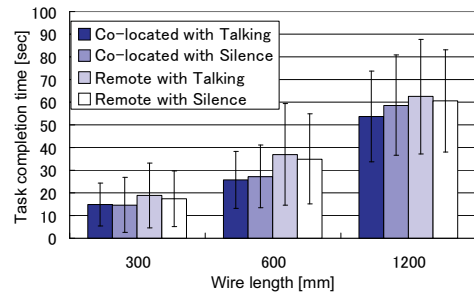Fig. 7: Relationship between ID and TCT in remote situation.

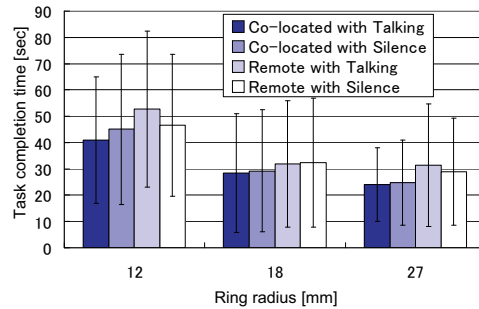Fig. 8: Task completion time relative to environment, wire length, and talking.

Fig. 9: Task completion time relative to environment, ring radius, and talking.

4.2 Number of Errors

A four-way ANOVA by situation, wire length, ring radius, and talking was carried out on the number of errors. We counted the number of wire touches as errors. Fig. 10 shows the number of errors relative to situation, wire length, and talking. Fig. 11 shows the number of errors relative to situation, ring radius, and talking. We found a main effect of situation ($F(1, 7)=37.908$, $p<0.01$), wire length ($F(2, 14)=502.910$), and ring radius ($F(2, 14)=1029.717$). No main effect of talking was revealed ($F(1, 7)=0.546$, $p=0.460$). We found interaction between situation and talking ($F(1,7)=6.414$, $p<0.05$), situation and wire length ($F(2, 14)=4.817$, $p<0.01$), and situation and ring radius ($F(2, 14)=11.987$, $p<0.01$). The average number of errors in the co-located and remote situations was 8.30 and 10.60, and 9.47 and 9.40 in the talking and silence conditions.

Fig. 10 shows the number of errors relative to wire length. A Tukey's HSD test for interaction revealed a significant difference between situations at wire lengths of 600 ($p<0.01$) and 1,200 mm ($p<0.05$). Fig. 11 shows the number of errors relative to ring radius. The Tukey's HSD test for interaction revealed significant differences between situations at ring radiuses of 12 and 18 mm ($p<0.1$). The Tukey's HSD test for interaction revealed significant differences in talking in the co-located situation ($p<0.05$).

These observations show that the number of errors in the co-located situation is less than the remote situation. When the task difficulty is low, like a wire length of 300 mm or a ring radius of 27 mm, there is no significant difference in situations. There is no significant difference in talking, except in the co-located situation.

4.3 Video Analysis

We analyzed the conversations among users because we considered conversation necessary for synchronization between participants. Table 1 shows the average number of utterances and their frequency in the co-located and remote situations. The

average number of utterances divided by the number of trials is their frequency.

We expected co-located with talking to have fewer utterances than the remote condition with talking because participants were face-to-face in co-located with talking and they needed to have conversation to transfer their intention in remote situation. However, a two-way factorial ANOVA showed that environment did not affect the number of utterances ($p=0.654$). We observed such utterances during the second half of the task. The participants achieved understanding of the direction and the positional relation from each other, and they found the point to tell their idea and intention.

4.4 Subjective Evaluation

After finishing the task on each situation and talking condition, the participants answered questionnaires based on NASA-TLX [13]. Six scale items were evaluated: mental demand, physical demand, time pressure, degree of work achievement, efforts, and dissatisfaction. We calculated the total points of the average of the Weighted Work Load (WWL) from the results of a pair of comparisons between indicators. All participant WWL results are shown in Table 2. From the ANOVA with situation and talking conditions, no significant difference about the scale items was found among any conditions, but co-located with talking and remote with talking had high workload and dissatisfaction; in our task, conversation increased workload and caused stress. The work achievement scale item was higher in the co-located environment, so this effect reflects whether the participants can see each other.
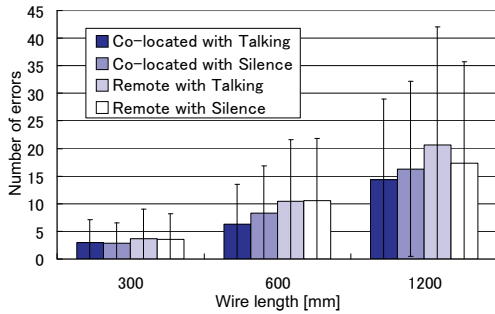
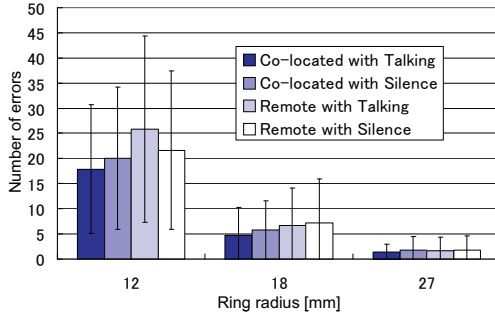Fig. 10: Number of errors relative to environment, talking, and wire length.

Fig. 11: Number of errors relative to environment, talking, and ring radius.

Table 1: Average number of utterances and frequency.

	Number of average utterances (Standard Deviation)	Utterance frequency per task
CT	120.3 (73.0)	4.45
RT	146.0 (81.0)	5.40

Table 2: NASA-TLX results.

	CT	CS	RT	RS
Mental demand	64.8	52.7	69.0	61.5
Physical demand	59.3	52.7	65.5	44.0
Time pressure	41.8	50.5	53.6	40.7
Work achievement	75.8	72.5	52.4	63.7
Effort	75.8	64.8	73.8	69.2
Dissatisfaction	57.1	45.0	72.6	56.0
Total workload	62.5	56.4	64.5	55.9

5 DISCUSSION

5.1 Differences between Co-located and Remote situation

Applying the steering law, we found that it is suitable for our designed task with high correction values (R^2). This indicated that our experiment and task difficulty were well controlled. From the results of converted steering law, the difference between co-located and remote situations does not appear in the slope of the lines, but in the y-interceptions (Eq. 4, 5, 6, and 7). This result means the difference between situation, whether a participant can see the partner face-to-face, does not affect the index of performance ($1/b$) using a virtual object. 1/b indicates that user's performance with the device, and its value is often used for discussion on Fitt's or steering study [9] [22]. On the other hand, it affects the y-interceptions as bias. From observations, the bias might be caused by the synchronization difficulties between participants when simultaneously holding the ring and starting the movement. In the initial stages, users cannot clearly predict their partner's movement due to the poor awareness information in the remote situation. After synchronization and starting the task, users have the same performance in both situations. Because the task is rather simple, current position and wire shape indicate the user's next movements, and so users can easily predict their partner's next movement. The synchronization delay simply and clearly explains the difference in the y-intercept.

From the video, we could observe participants conducted a collaborative work in a complementary style; when they turned the corner, inside user stop and the other move. This type of movement was often seen in co-located situation. We believe that mutual assistant action is affected by their awareness information. They could turn the corner more smoothly and avoid errors.

We expected conversation to help participants avoid errors and turn corners well. Unfortunately no significant difference was revealed by conversation. From observation of participant behaviour with the video, it can be explained by the following factors. The first is the task type. Our task was rather simple, so users could easily predict their partner's intention without conversation. The second is sharing cursors. In this experiment, both cursors were always visible and shared in each situation. Since partner cursor movements clearly revealed intention in this task, conversation could not be key information to predict and comprehend partner movements. Participants sometimes avoided error by effectively using conversation. We believe conversation may work better in other tasks, for example, the tasks in which the motion direction is not visually indicated to both participants.

5.2 Supporting Remote Collaborative Work using Stereoscopic Image with Direct Pointing

From the above results and discussion, we summarize the effect of situational differences and conversation to support remote collaborative work, in which two participants simultaneously manipulate a 3D object.

The bigger difference between co-located and remote is described that user cannot acquire awareness information from other user's behaviour. Not seeing a partner's physical action affects synchronization for 3D manipulations. To make rich remotely collaborative work, we should consider a system that allows users to easily synchronize and predict each other's movements. In the early stages of a collaborative work, we believe that conversation is inadequate for effective synchronization because they need too many detailed directions among users, increases workload, and causes dissatisfaction from the NASA-TLX [13]. We should not rely on user conversation skills; we must study new elements to effectively transmit user intentions instead of conversations. Conversation might not be needed when the moving direction is obvious. In this study, a partner's cursor was presented even for remote situation. Only the cursor behavior indicated how the partner's intention was related to object manipulation. A previous work, VideoArms [28], shows that remotely presenting user's arms successfully creates natural communication. Thus, additional awareness information such as arms, bodies, or head movements of remote users may increase synchronization. Since there may sometimes be too much information in both users' recognition and network configurations, further investigated is required under various task settings.

In this paper we put a collaborative work with/without awareness information into co-located and remote situations on a stereoscopic tabletop display. We will investigate the effect of a

network delay, which is typical difference between co-located and remote situations, and compare the impact on a collaborative work with this experimental result.

6 CONCLUSION

In this paper we compared two types of 3D collaborative work, co-located and remote, on a tabletop display with stereoscopic images on collaborative path steering task. The task was designed based on the steering law, that multi-user simultaneously manipulate a 3D object on stereoscopic display for multi-user. We conducted a comparative experiment on the path steering task presented on IllusionHole. Experimental results showed that there was significant difference in favor of co-located situation, and synchronization difficulties between users occurred for remote situation. The participants intention is implicitly indicated, participants tend to reduce the need of conversation.

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