Zoom Cameras and Movable Displays Enhance Social Telepresence

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ABSTRACT

This paper shows that the augmentation of a remote person's positional movement enhances social telepresence. There are three possible ways of representing a remote person's movement toward the user in visual communication: a) the remote person's movement toward the remote camera, b) the remote camera's zooming in to enlarge the remote person's picture, and c) a forward movement of the display that is displaying the remote person. We conducted an experiment to see the relationship among these three ways and the effects of a remote camera's zooming and a display's movement on social telepresence. In the experiment, we observed that the remote person's movement lowered the reality of conversations, and the remote camera's zooming lowered the visual quality. However, social telepresence was enhanced when both the person's movement and the camera's zooming occurred simultaneously. We also observed that a 6-centimeter movement of the display enhanced social telepresence, whether the remote person moved or not.

Author Keywords

Telepresence, videoconferencing, telerobotics.

ACM Classification Keywords

H5.3. Information interfaces and presentation (e.g., HCI): Group and Organization Interfaces -Computer-supported cooperative work.

General Terms

Design, Experimentation, Human Factors.

INTRODUCTION

The role of live video in videoconferencing has traditionally been regarded as the presentation of eye movements, facial expressions, gestures, and postures. Additionally, the

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CHI 2011, May 7-12, 2011, Vancouver, BC, Canada.

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presentation of positional movement has recently started to attract a lot of attention [10,15,21,22,25]. This paper shows that the presentation of augmented positional movement enhances social telepresence, that is the degree of resembling face-to-face interaction [4]. This paper especially focuses on short movements that can occur even in formal meetings, e.g., a seated person sliding the chair.

It is currently common to use a single display to see multiple people in videoconferencing. But, since the price of large flat-panel displays is becoming lower and lower, it becomes more and more feasible to assign one display to each remote person. This study supposes that each user can use a dedicated display to show the user's picture at the remote site. A dedicated display makes it easy to show the remote person's life-size picture and also the person's positional movement as described below.

Figure 1 shows three possible ways of representing a remote person's movement toward the user in visual communication: a) the remote person's movement toward the remote camera, b) the remote camera's zooming in to enlarge the remote person's picture, and c) a forward movement of the display that is displaying the remote person. This paper clarifies the relationship among these three ways and demonstrates how they contribute to social telepresence.

The first way, i.e., the remote person's movement toward the remote camera, is the most basic among the three ways. When the remote person approaches the remote camera, you can see the person's body motion on the display. However, it is known that such a visual motion is much less noticeable than a physical motion that occurs in the same room [6]. Therefore, we aimed to diminish this gap in order to improve the reality of videoconferencing.

The second way, i.e., the camera's zooming in, is a common visual effect that is used in films and TV programs. When the remote person approaches the remote camera, the picture of the person is enlarged according to the camera's field of view (FOV). This enlargement is amplified if the camera's zooming in narrows its FOV exactly when the person moves forward. This paper shows that this amplification can make the remote person's movement more noticeable and enhance social telepresence.



Figure 1. Three ways of representing a remote person's movement

The third way, i.e., the display's forward movement, is rapidly becoming popular thanks to the recent release of various commercial telepresence robot products. While their appearance varies, their structure is almost the same: a camera, a display, a microphone, and a speaker that are mounted on a remote controlled robot. A telepresence robot moves around a remote site instead of its operator. It is expected that an on-site person, who stands in front of the robot, feels as if the operator comes up to the person when the robot moves toward the person. We examined this expectation empirically. This paper shows that even a tiny movement of the display can represent a remote person's movement and enhance social telepresence.

RELATED WORK

This study is located at the intersection of the two telepresence research areas, which are videoconferencing and telerobotics.

Videoconferencing research has revealed several effects of live video on telepresence [2]. Basically, live video can transmit the social presence of a remote person [3,7]. It is well known that social presence is strengthened if the setup of cameras and displays allows eye contact to be established [1]. A past study found that stereoscopic video and a life-size picture of a remote person had the effect of strengthening social presence [20]. A recent study reported that a moving point of view, which can be implemented as a remote camera that moves according to the position of the user's eyes [5], strengthened social presence [17]. In this paper, we add new ways to make live video strengthen social presence: zoom cameras and movable displays.

Telerobotics research has developed various kinds of telepresence robots. Some of them exhibit their own robotic face instead of the operator's face [11,14,23]. And others are equipped with a display that shows the operator's face, but its size is usually small [8,9,16,19,24]. Because of the small display, those robots can show either a small-size picture of the operator or a life-size picture of the operator's head. The small-size picture is harmful to social telepresence, and the picture of a head is also harmful to social telepresence [18]. In this study we used a larger display – a 30-inch wide-screen display that was placed vertically in order to show a nearly life-size picture of the entire upper body of a remote person [12]. This large

display allowed us to investigate the relationship among the three ways that are described in the previous section.

EXPERIMENT

Goal

We conducted an experiment to clarify the effects of the two ways to augment a remote person's movement: zoom cameras and movable displays.

We anticipated that normal zooming would have little influence on social telepresence, since it is a familiar visual effect. However, we predicted that zooming in and out could enhance social telepresence if it were synchronized with the remote person's approaching and moving away from the remote camera. In this synchronization, zooming in and out amplifies the enlargement and shrinkage of the remote person's picture, which is originally caused by the changes of the distance between the person and the camera. We thought that this amplification could function as an exaggeration of the person's movement. Thus, the first hypothesis is the following.

H1: The remote camera's zooming strengthens the social presence of the remote person if the camera's zooming in and out is synchronized with the person's approaching and moving away from the camera.

The movement of telepresence robots is supposed to be interpreted as the remote operator's movement. This supposition means that the distance between the robot and an on-site person who stands in front of the robot represents the distance between the remote person and the on-site person. The supposition also means that the remote person's actual movement does not need to occur. Thus, we established the second hypothesis as follows.

H2: The display's forward-backward movement strengthens the social presence of the remote person, whether the movement is synchronized with the person's movement or not.

Setup

To examine hypotheses H1 and H2, we contrived a situation in which a remote person had to move forward and backward several times. We selected the presentation of books as the task of a remote person. One of the experimenters played the role of a presenter. A whiteboard



Figure 2. Setup of the experiment (length unit: centimeters)

was placed behind the presenter as shown in Figure 2(a), and three books were arranged on the metal stand of the whiteboard. The presenter, who was seated in a chair, slid his chair backward to pick up one of the books, then slid his chair forward to return to the former position, and described the book to the subject. The presenter repeated this behavior three times.

The display, which is depicted in Figure 2(b), showed the presenter's live video that was sent from a network camera, which is depicted in Figure 2(a). We modified the functions of the display and camera as follows. (The camera in the subject's room and the display in the presenter's room are omitted in Figure 2.)

To examine hypothesis H1, we made the camera zoom in and out in synchronization with the presenter sliding his chair forward and backward. As shown in Figure 2(a), the camera expanded the vertical FOV from 22.7 degrees to 27.2 degrees when the presenter slid his chair backward, and then reduced it from 27.2 degrees to 22.7 degrees when the presenter slid his chair forward. These slides were detected by a laser rangefinder that was placed in front of the whiteboard.

To examine hypothesis H2, we made the display movable by attaching a linear positioner to it. As shown in Figure 2(b), the linear positioner moved the display six centimeters forward or backward when the presenter slid his chair fifty centimeters forward or backward. Thus, the display's movement was much shorter than the presenter's movement. We used a vertically placed 30-inch wide-screen display in order to show a nearly life-size picture of the remote person's upper body. The subject was seated 1.2 meters away from the display.

We determined the amounts of the zooming (from 27.2 degrees to 22.7 degrees) and the presenter's movement (fifty centimeters) so that both produced the same degree of enlargement (1.25 times as large as the original size) in the picture of the presenter. Figure 3 shows that the simple zoom camera and human movement conditions produced the same degree of enlargement. In the preliminary experiment we tested various degrees and observed that 1.25 times seemed a minimum enlargement which could be perceived by subjects. In the preliminary experiment we also tested display movement that was longer or shorter than six centimeters and rejected them as described in the Discussion section.

Conditions

To examine hypothesis H1, we observed the effects of the two factors: whether the camera zoomed or not (zoom-camera factor) and whether the presenter moved or not (human-movement factor). Thus, we compared the following four conditions:

| | Presenter moves forward while picking up a book. | Presenter moves forward after picking up a book. |
|-----------------------------|--|--|
| | | |
| | (a) Control | (b) Human movement |
| No effect | | |
| | (c) Simple zoom camera | (d) Synchronized zoom camera |
| Camera zooms in | Image: Second se | The second secon |
| | (e) Simple movable display | (f) Synchronized movable display |
| Display moves forward | | |
| | Moves forward | Moves forward |

Figure 3. Conditions of the experiment

Control condition: This is a basic condition (Figure 3(a)). The camera did not zoom and the display did not move.

Human movement condition: Also in this condition, the camera did not zoom and the display did not move. However, the presenter's behavior was different from the control condition, in that the presenter slid his chair backward and forward while turning his body to pick up a book. In this condition, the presenter kept facing forward while sliding his chair, and did not slide it while turning his body to pick up a book, so that the subject could clearly recognize that the presenter moved (Figure 3(b)). You can

see this difference in Figure 4, which shows how the presenter's behavior of picking up a book and moving forward was seen by the subject.

Simple zoom camera condition: The presenter's behavior was the same as the control condition, but the camera zoomed in and out in this condition. The camera's FOV expanded just before the presenter picked up a book, and reduced just afterward. The presenter did not move at all while the camera was changing its FOV. Each change took about three seconds. Figure 3(c) shows how the camera's zooming in enlarged the presenter's picture.



Figure 4. Presenter's behavior

Synchronized zoom camera condition: The presenter's behavior was the same as the human movement condition, and the camera zoomed in synchronization with the presenter's sliding. The camera's FOV expanded when the presenter slid his chair backward, and reduced when the presenter slid his chair forward. The time to change the FOV was the same as in the simple zoom camera condition. Figure 3(d) shows how the combination of the zooming in and the forward slide enlarged the presenter's picture.

To examine hypothesis H2, we observed the effects of two factors: whether the display moved or not (movable-display factor) and whether the presenter moved or not (human-movement factor). Thus, we compared the following four conditions:

Control condition: This condition is as described above.

Human movement condition: This condition is as described above.

Simple movable display condition: This condition is almost the same as the simple zoom camera condition, but the subject experienced the display's movement instead of the camera's zooming. The display moved backward just before the presenter picked up a book, and moved forward just afterward. The presenter did not move at all while the display was moving. Each move took about three seconds. Figure 3(e) shows that the display moved across the wall.

Synchronized movable display condition: This condition is almost the same as the synchronized zoom camera condition, but the subject experienced the display's movement instead of the camera's zooming. The display moved backward when the presenter slid his chair backward, and moved forward when the presenter slid his chair forward. The time to move the display was the same as in the simple movable display condition. Figure 3(f) shows that both the display and the presenter moved forward simultaneously. Figure 5 clarifies that this condition did not use camera zoom, and the picture of the presenter was enlarged only by the presenter's movement. In the figure you can see that the size of the paper attached to the whiteboard remained unchanged in this condition, while it was enlarged and also the size of the whiteboard was enlarged in the synchronized zoom camera condition.

Because the above two comparisons shared two conditions, there were six conditions as shown in Figure 3. In all of these conditions, the display was positioned nearest to the subject, and the FOV of the camera was set for the minimum during the book descriptions. The camera or the display acted differently in each condition only when the presenter picked up a book.

Subjects

The experiment was between-subjects and ten subjects participated in each condition, so sixty subjects participated in total. All the subjects were undergraduate students who lived near our university campus.

Conversation

As shown in Figure 6, the duration of the entire conversation was two or three minutes, and the description of each book was about thirty seconds. In the descriptions, the presenter asked the subject the same questions as given in the figure. The presenter constantly conducted almost the same conversation in all trials. To establish a vocal channel



Figure 5. The two synchronized conditions

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- 0.00

| 0.00 | | | |
|---|--|--|--|
| Greet 🥆 | Presenter: Hello. | | |
| - 0:13 Pick up the first - 0:23 | Presenter: I'm going to introduce three books about humanoid robots. Are you ready? Subject: Yes, I'm ready. | | |
| Describe | Presenter: OK, I'll start introducing the books (move backward and pick up the first book). Now I'll describe the first book (move forward). | | |
| the first | Presenter: Are you interested in state-of-the-art humanoid robotics? Subject: Yes, I am. | | |
| — 0:55 Pick up | Presenter: I am, too. This book reports recent technological advancements in a casual style (description omitted) | | |
| the second | Presenter: I'm finished describing this book. Let's go on to the next book (move backward, put the first book down, and pick up the second book). Now I'll describe the second book (move forward). | | |
| the second | Presenter: Do you think it's difficult to construct a humanoid robot? | | |
| - 1:30 Pick up the third | Presenter: I think so, too. This book is written for novices at robotics (description omitted) | | |
| - 1:45 | Presenter: I'm finished describing this book. Let's go on to the next book (move backward, put the second book down, and pick up the third book). Now I'll describe the third book (move forward). | | |
| Describe | Presenter: This book proposes a scientific approach to the development of realistic humanoid robots (description omitted) Would you like to have a humanoid robot that is a realistic copy of yourself? | | |
| | Subject: Yes, I would. | | |
| | questions or comments about the books? | | |
| | Subject: No, I don't. Presenter: OK, thank you. | | |
| | | | |

2:40

Figure 6. Conversation

between the subject and the presenter, we used an Internet telephony tool.

Questionnaire

The questionnaire asked the extent to which the statements matched the impression the subject had. The questionnaire included the following statements to check the quality of the presentation.

- The video was sufficiently clear.
- The audio was sufficiently clear.
- The presentation was intelligible.

The questionnaire included the following statements to estimate the degree of social telepresence.

- I felt as if I were viewing the presenter in the same room.
- I felt as if I were viewing the books in the same room.

- I felt as if I were facing the presenter in the same room.
- I felt as if I were talking with the presenter in the same room.

All the statements were rated on a 9-point Likert scale where 1 = strongly disagree, 3 = disagree, 5 = neutral, 7 = agree, and 9 = strongly agree.

The "viewing" and "talking" statements could effectively measure social presence of a remote person in our previous study [16,17], thus we reused them. The "viewing" statement could measure the visual aspect of social presence, and the "talking" statement could measure the conversational aspect. To measure another aspect, we used the "facing" statement additionally. According to the interviews, this statement was approximately equal to the "viewing" statement, but could measure subjective interpersonal distance rather than just the visual aspect.

RESULTS

Effects of the zoom camera

To examine hypothesis H1, we compared the control, human movement, simple zoom camera, and synchronized zoom camera conditions by 2x2 two-way between-subjects ANOVA. We also analyzed the simple main effects of the zoom-camera factor with the Bonferroni correction. Figure 7 shows the results, in which each box represents the mean value of the responses to each statement, and each bar represents the standard error of the mean value.

We found strong interaction between the zoom-camera factor and the human-movement factor. We found significant interaction in the perceived quality of the video (F(1,36)=4.739, p<0.05) and the audio (F(1,36)=6.096, p<0.05), and in the feelings of viewing the presenter (F(1,36)=7.003, p<0.05), facing the presenter (F(1,36)=8.341, p<0.01), and talking with the presenter (F(1,36)=14.642, p<0.001). We also found a tendency for significant interaction in the feeling of viewing the books (F(1,36)=3.842, p=0.058). We found no interaction and no main effect in the intelligibility of the presentation.

We found simple main effects of the zoom-camera factor in all the statements that had significant interaction in the above analysis. When the presenter moved (human movement condition vs. synchronized zoom camera condition), the zoom camera caused significantly greater feelings of viewing the presenter (F(1,36)=4.722, p<0.05), facing the presenter (F(1,36)=14.722, p<0.001), and talking with the presenter (F(1,36)=23.007, p<0.001). When the presenter did not move (control condition vs. simple zoom camera condition), the zoom camera caused significant reduction in the perceived quality of the video (F(1,36)=5.474, p<0.05) and the audio (F(1,36)=4.863, p<0.05), and the feeling of viewing the books (F(1,36)=8.614, p<0.01). There was no other significant effect of the zoom-camera factor.



Figure 7. Results of the questionnaire (zoom-camera and human-movement factors)

The above results support hypothesis H1, which states that the synchronized zoom camera condition enhances social telepresence. We observed that the social presence of the remote presenter increased only when the remote camera's zooming was accompanied by the presenter's movement. We could additionally observe that the pure zooming lowered the evaluation of the audio-visual quality and the presence of the books.

Effects of the movable display

To examine hypothesis H2, we compared the control, human movement, simple movable display, and synchronized movable display conditions by 2x2 two-way between-subjects ANOVA. Figure 8 shows the results.

We found strong main effects of the movable-display factor. The movable display caused significantly greater feelings of viewing the presenter (F(1,36)=9.456, p<0.01), viewing the books (F(1,36)=6.399, p<0.05), facing the presenter (F(1,36)=7.089, p<0.05), and talking with the presenter (F(1,36)=16.438, p<0.001). We also found a main effect of the human-movement factor (omitted in Figure 8 due to the figure's complexity), which was a reduction of the feeling of talking with the presenter (F(1,36)=5.918, p<0.05). There was no other significant main effect and no significant interaction.

The above results support hypothesis H2, which states that the synchronized movable display condition and also the simple movable display condition enhance social telepresence. We observed that the display's movement increased the social presence of the remote presenter even when he did not move. We could additionally observe that the presenter's movement lowered the reality of the conversations.

DISCUSSION

In the introduction section we explained the three possible ways of representing a remote person's movement. In the experiment we observed that the first way – human movement – was harmful to the reality of the conversations. According to the interviews, this might be because the subjects felt that the presenter was distant when the person moved backward and away from the remote camera.

We observed that the second way – camera zooming – contributed to social telepresence. It was interesting that a combination of the first and second ways could enhance social telepresence, even though each way was harmful to it. The drawback of the first way is described above. The drawback of the second way is as follows. In the simple zoom camera condition, the remote camera's zooming out shrank the picture of the remote person and the book carried by him. According to the interviews, this seemed to be the



Figure 8. Results of the questionnaire (movable-display and human-movement factors)

reason why the evaluation of visual quality including the books was low. The evaluation of audio quality seemed to be affected by the low evaluation of visual quality. The positive effects that were generated by the combination of the first and second ways overcame these negative effects, even though the remote person's picture was shrunk by both the zooming out and the person's backward movement in the synchronized zoom camera condition.

In the simple zoom camera condition, the zooming was unimpressive probably because it occurred solely. In the interviews we found that only two of the ten subjects remembered the zooming. In the synchronized zoom camera condition, the zooming and the presenter's movement occurred simultaneously. As a result, six of the ten subjects remembered the zooming, and three of the six subjects answered that they were made to pay attention just when the presenter came up. This answer suggested that the zooming caused the feeling of shrinkage of a useful field of view (UFOV), since the degree of attention and the size of UFOV are inversely proportional to each other [13]. When a remote person moves toward the remote camera, the distance of that approach can be recognized based on how much the foreground picture of the person occludes the background. If the zooming enlarges the picture in synchronization with the approach, the size of the picture becomes larger than the size that is expected based the

occlusion. This extra enlargement can cause the feeling of shrinkage of UFOV, since the enlargement reduces the area of the remote person's body that is seen within the UFOV.

We observed that the third way – a movable display – also contributed to social telepresence. The difference between the second and third ways was that the third way could enhance social telepresence even when the remote person did not move. It seemed that the display's movement could provide the subjects the feeling as if the remote person were moving. It was evidential that in the interviews several subjects of the simple movable display condition said that they felt as if the remote person were coming forward. It was surprising that this feeling could be generated by such a subtle stimulus as a 6-centimeter movement of the 30-inch display that was 1.2 meters away from the viewer. This implied that people are sensitive to the movement of a physical apparatus, and so the mobility of telepresence robots is an excessive capability just for giving a feeling of approaching and leaving.

In the preliminary experiment, we tested display movement that was longer than six centimeters. As a result, the movement tended to provide the subject with the artificial feeling of watching a display device, and this feeling deteriorated social telepresence (Figure 9(a)). Therefore, we hid the display device behind the wall and made only the inside of the display frame viewable (Figure 9(b)). This



(c) Final version

Figure 9. Three steps of designing a movable display

construction removed the artificial feeling but also prohibited the subjects from perceiving the display's movement even when the movement was much longer than six centimeters. Because of this prohibition, the display's movement could not influence social telepresence. We also confirmed that less than a 6-centimeter movement could hardly be perceived and had little influence on social telepresence. Thus, in the main experiment, we showed the subject that the display moved six centimeters forward and backward across the wall that surrounded the display (Figure 9(c)).

In this study we did not test the combination of the second and third ways. This combination would be somewhat worse than just the third way, since the second way is harmful unless it is accompanied by the first way. However, the combination of all three ways may be the best, since the second way accompanied by the first way is effective. This combination can be a simple collocation of a zoom camera and a movable display: the remote camera zooms in and out and the display moves forward and backward in synchronization with a remote person's approaching and moving away from the camera. Furthermore, it is possible to combine this with a movable camera, which is a remote camera that moves according to the position of the user's eyes [17]. Testing these combinations is a subject for future work.

Another subject for future work is an investigation of the real-world usage of zoom cameras and movable displays. Movable displays may be used more widely than zoom cameras, since movable displays do not require a remote person's actual movement so that the display's movement can be added to various scenes. For example, if the display moves forward when the remote person begins talking, the beginning of the speech can be emphasized. This mechanism would give the user a feeling as if the remote person came up to the user when he or she began talking. On the other hand, movable displays may be used less widely than zoom cameras, since movable displays need an additional mechanism to move and their purchase and maintenance costs must be higher than normal displays. However, we do not worry about this issue very much, since various commercial telepresence robot products have already been available and the mechanical structure of movable displays can be much simpler than them. Zoom cameras are much less costlier than movable displays, since almost all webcams are already equipped with a zooming function and only a sensor to detect a remote person's movement has to be installed. In the experiment the system sensed the slides of the remote person's chair. This method is accurate but can work only when the person slides the chair to do something, e.g., picking up an object that is a little distant from the person. A more generic method is face tracking, which can detect the distance between the camera and the person's face.

CONCLUSION

There are three possible ways of representing a remote movement toward the user in person's visual communication: a) the remote person's movement toward the remote camera, b) the remote camera's zooming in to enlarge the remote person's picture, and c) a forward movement of the display that is displaying the remote person. It is known that visual motion such as the remote person's movement toward the remote camera is much less noticeable than a physical motion that occurs in the same room. We aimed to diminish this gap by means of a remote camera's zooming and a display's movement. We conducted an experiment to see the effects of zoom cameras and movable displays on social telepresence, i.e., the degree of resembling face-to-face interaction. The results of the experiment are the following:

Zoom cameras: In the experiment, the remote person's movement lowered the reality of the conversations, and the remote camera's zooming lowered the visual quality. However, social telepresence was enhanced when both the person's movement and the camera's zooming occurred simultaneously.

Movable display: In the experiment, the length of the display's movement was only six centimeters. However, it enhanced social telepresence, whether the remote person moved or not.

The main and peripheral contribution of this study is 1) to propose and evaluate two user interfaces that improve the reality of videoconferencing; 2) to reveal that human positional movement is useful for improving the reality of videoconferencing; 3) to hint that common visual effects would have little influence on the reality of videoconferencing; and 4) to indicate that people are sensitive to the movement of a physical apparatus.

ACKNOWLEDGMENTS

We thank Gaku Senoo and Tatsuya Asano for helping to conduct the experiment. This study was supported by JSPS Grants-in-Aid for Scientific Research No. 21680013 "Telerobotic media for supporting social telepresence" and No. 20220002 "Representation of human presence by using tele-operated androids."

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