基礎論文

Impact of Display Shapes on Symmetric 360° Video Communication For Remote Collaboration

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Abstract –
Field-of-view limitation has been a long-standing issue in video communication systems. With the development of omnidirectional panoramic technology, the omnidirectional camera, which can provide a 360° field-of-view, has been getting more and more popular within the last few years. Previous research indicated that one-way video communication systems with a wider field-of-view improve task efficiency with fewer collisions. Therefore, we propose to utilize omnidirectional cameras in a symmetrical video communication system and study how the shape of the display affects the performance of the panoramic video communication in remote collaboration. By conducting experiments with two conditions (omnidirectional camera + spherical display vs. omnidirectional camera + horizontally placed 2D flat display), we analyzed what is the impact of display types on 360° video communication. Our results show that the spherical display is slightly better and both types of displays have their advantages and disadvantages. The findings contribute to our understanding of how to design an environment for remote collaboration with a 360° shared view of spaces.

Keywords : Remote collaboration, video communication, telepresence, spherical display, field-of-view, omnidireciontal camera

1 INTRODUCTION

A long-standing problem with video communication systems was the limitation of the field-of-view. Gaver et al. [1] [2] and Fish et al. [3] pointed out that the narrow field-of-view limits peripheral awareness of activities in a remote scene and often makes remote activities unnoticed.

Meanwhile, with the development of 360° technology, one of the recent trends in cameras is omnidirectional cameras, and several products have been commercialized in the last few years. Unlike traditional cameras, such new cameras can capture panoramic images in one shot which provides up to 360° field-of-view. Such technologies seem to open new possibilities to solve the problem of a narrow field-of-view. For example, Johnson et al. [4] compared three kinds of the field-of-view video feed from a telepresence robot, narrow (45°), wide angle (180°), and panoramic (360°), and their results showed that wider views supported better task efficiency and fewer collisions. However, the panoramic field-of-view increased the complexity of the visual image and

図 1: The 360° video communication systems. Local room and remote room are connected by two different types of 360° video communication systems, which are combining a omnidirectional camera with a spherical display(upper left)(lower left) or with a horizontally placed 2D flat display(upper right)(lower right).

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required a greater cognitive load than a narrower field-of-view. In this paper, we are interested in knowing whether these issues of increased complexity, workload, and asymmetricity of communication could be improved by using a more proper camera-display configuration. We are interested in whether this issue could be improved by using a more proper display. Current popular displays for 360° contents such as the virtual reality head-mounted display (VR HMD), the panoramic dome display, or regular 2D monitors, present some issues when used for video communication. For example, the VR HMD covers most of a user's face, hindering facial expressions which are important in communication [17]. Besides, if users on both sides wear HMDs, it won't be possible for them to view both actual environments. Also, wearing HMD for a long time and walk around may cause physical and eye fatigue. Immersive projection technologies such as a panoramic dome display [15] or a cave display [16] confine users inside their space which limit user's interactions with the real environment.

An alternative solution may be to use a spherical display [5]. Due to its three-dimensionality, we can expect that a spherical display could naturally display the 360° images and reduce observers' cognitive load. Li et al. [6] proposed OmniEyeball as a new 360° video communication device. They embedded omnidirectional cameras into a spherical display system. The OmniEyeball can capture a 360° live video stream, send the data via the wireless connection and also display the live video feed from another OmniEyeball on its spherical surface. Because the system can exchange the image of the whole environment around the devices, users are not constrained by the camera position or display orientation, i.e. users can position themselves anywhere around the device. Li et al. expected that the 360° video communication using the OmniEyeball could improve the performance of remote communication. However, they have not reported any user study with the system.

Therefore, the aim of our study is to explore the possibility of using an omnidirectional video communication system in symmetric video communication. We investigate how the shape of the displays affects remote collaboration involving a real physical environment. The findings contribute to our understanding of how to design an environment for remote collaboration and to capture and display a 360° view of a remote site.

2 RELATED WORK

2.1 Effect of Field-of-view in Video Communication

Problems caused by narrow field-of-view of a video camera has been discussed since the early studies of video communication systems [3] [1] . Fish et al. pointed out that reciprocity between participants such as "if you can see someone else, they can see you" [3] was not maintained in their VideoWindow system. To challenge this issue, Gaver et al. proposed to use multiple cameras and monitors to cover a wider range in a collaboration space. However, they found that "the necessity of switching among views increased the difficulty of establishing the relations among them and negotiating a mutual orientation towards the task [1]."

In their subsequent study, Gaver et al. [2] tested the effect of a remote-controlled camera while it revealed various problems due to unavoidable features of mechanical systems in control. Then, as a future direction, they suggested employing fisheye view image [7]. Recently, Luff et al. [10] have conducted an experiment using multiple telepresence robots. However, they also suffered from the narrow field-of-view problem and suggested employing spherical images. To investigate how the different fields of view affect remote collaboration, Johnson et al. compared three field-of-view angles for a camera on a telepresence robot [4]. Their experimental results indicated that wider field-of-view supported better task efficiency and fewer collisions. However, they pointed out that users felt more difficulty with panoramic view.

Meanwhile, some studies have already proposed video communication systems that enable the exchange of wide field-of-view images symmetrically. CamBlend [8] was a video conferencing system that integrated wide field-of-view (180°) images with high-precision in-context views. However, this system could cover only one side of the room. t-Room [9] is a room size video communication system that exchanges panoramic images of the two rooms over the distance. However, the shared area in the t-Room is constrained to the area close to the screen surfaces.

Therefore, it is still challenging to realize a symmetrical video communication system that enables to exchange spherical images over the distance.

2.2 Spherical Image System

As suggested by Gaver et al. [7] and Liccope et al. [10], we are interested in using spherical images for video communication. In this section, we briefly review the technologies related to spherical images.

Various display methods have been proposed to view such spherical images. One method is to simply use an ordinary 2D flat display. For example, the whole spherical image can be shown by distorting the image in a circular shape or, to reduce the distortion, by showing part of the image and allowing users to control the viewing orientation using cursor keys or a pointing device (QuickTime VR or Application of Ricoh Theta). Instead of using an ordinary 2D flat display, there are some alternative methods. An advanced method is to use a spherical display. GEO-COSMOS [11] is the world's first full-color spherical display. With the advance of projection technologies, however, several smaller spherical displays have been prototyped [5] [12] [13] and are even commercially available now.

To overcome the long-standing problem of a narrow camera field-of-view, we are interested in using spherical images for video communication. To the best of our knowledge, in spite of the availability of spherical cameras and displays, no studies have explored how such technologies can support symmetric video communication. Especially, it is important to explore the usability issue. Therefore, this study compares two display methods for 360° images: 2D flat displays and spherical displays.

3 PANORAMIC VIDEO COMMUNICATION SYSTEM

We created a panoramic video system by integrating the omnidirectional camera with a display, which could be a spherical display or a 2D flat display. For example, we integrated the WorldEye spherical display with the Kodak PIXPRO SP360 4K camera to create the spherical panoramic video system, shown in Figure 2. The Kodak omnidirectional camera is put on the top of the WorldEye display. The WorldEye display is a hemispherical display sold by Gakken Sta:Ful Co with an output resolution of 480*480, which is 230,400 pixels. By showing a round image in the WorldEye display, it can directly map the round image onto its hemispherical screen. The Kodak camera is equipped with a fisheye lens which covers a 235° field-of-view. It compresses the 235° space into a fisheye image by equidistant projection, and the fisheye image can be easily shown in the WorldEye display. The Kodak camera can output a live video stream which has 1440*1440 resolution with 5fps over a USB connection. Then the graphics system receives the live video

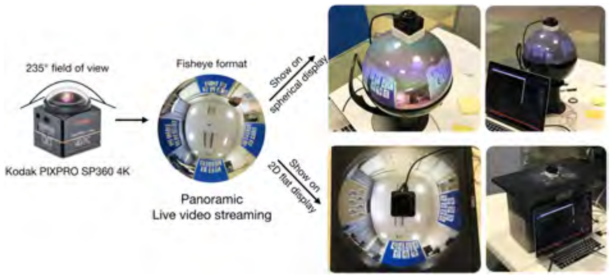

図 2: The diagram of the panoramic video system. The input of the system is from the Kodak camera. The output is either on the spherical display or the 2D flat display.

stream from the Kodak camera and converts the resolution to 480*480 to show it on the WorldEye display.

In this study, for panoramic video communication, we interconnected two identical panoramic video terminals in different rooms via LAN (local area network). To be more specific, live video stream captured by the local omnidirectional camera is transformed to 480 × 480 pixels, transferred to the remote counterpart terminal using TCP/IP protocol, and displayed on the remote hemispherical display. For audio transmission, we used Skype.

For the 2D flat display type, we employed a DELL 24 inch display. To minimize the difference between the two types of displays, the PPI (pixels per inch) were set to be the same to achieve the same display effect under both conditions. Otherwise, we employed the same technologies for audio/video transmission.

This omnidirectional communication system requires careful directional calibration to enable one-to-one communication between two environments. For instance, the orientations of cameras and spherical displays should be properly configured in a way that if a local person stands across from a remote person (in the display) at one end, the remote person should stand across from the local person at the other end.

4 EXPERIMENT

Utilizing the symmetric panoramic video communication system, we carried out an experiment to explore the possibility of using omnidirectional cameras for remote collaboration and also study the impact of display shape on 360° video communication. Specifically, we plan to answer the following questions:

1. How do users perceive the video images differently between the 2D flat display and the spherical display?

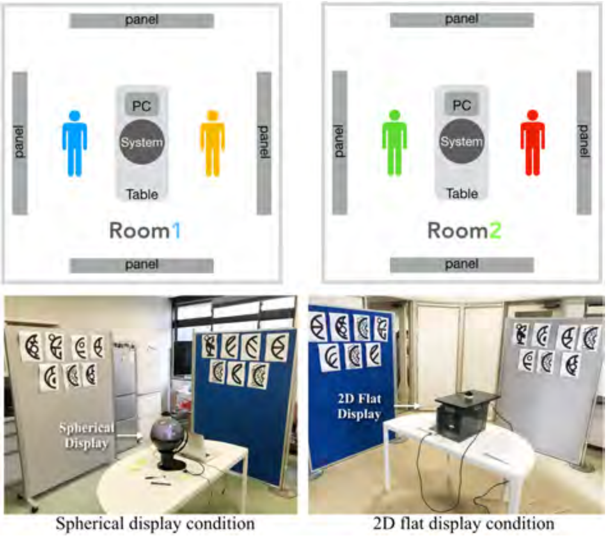

図 3: Upper: The physical layout of both two rooms. Bottom: The real environment of the room when using the spherical display or the 2D flat display.

2. How does the display type affect participants' actions during remote collaboration in a real physical environment?

4.1 Method

We based our research on four people remote collaboration because the panoramic video communication can support group-to-group remote communication. To study the features of a 360° field-of-view, we designed a pattern matching game which asked the participants to walk around the video communication system.

4.2 Conditions

We compared the 360° video communication between 360° camera + hemispherical display (spherical display condition) vs. 360° camera + horizontally placed 2D flat display (2D flat display condition), as shown in Figure 1. We chose the horizontally placed 2D display to be another display shape as the comparison of the spherical display because it can keep the advantages of panoramic video communication using the spherical display which is that the sense of space and directional relation from the remote side can be shown in the local display. Directly showing the equirectangular panoramic images on the standing 2D display is also a possible approach for panoramic video communication. However, such configuration disabled the participants who happened to be behind the display to see the image. Therefore, for equivalent visibility from all the participants standing anywhere in the room, we placed the display horizontally.

4.3 Apparatus

Two identical rooms were mutually isolated with the same arrangement, as shown in Figure 3. There were four panels (representing four walls) and one table arranged in each room. The table was set in the middle, and the distances between the table and four panels were same. The two rooms were connected by panoramic video communication using a gigabit network. The displays were located at the same height in both conditions.

4.4 Participants

Ten groups of participants (40 people in total) were recruited for this experiment. The average age is 23.5 years old. 21 of them are students in the department of computer science. 29 people use video communication in their daily life, 13 of them often do video communication with their friends or family. The participants in the same group can use the same language fluently. No participants had prior experience with panoramic video communication systems.

4.5 Task

Each task consists of four participants, with two participants located in one room. One room was provided with a set of 28 geometric pattern figures; each figure was printed on a sheet of paper. These figures were put up on four panels (seven figures on each panel) in the room. In the other room, an identical set of figures were put up at different positions on the four panels. We asked the participants to match all the figures collaboratively across the rooms. Time was measured during the task, and all participants were asked to finish the task as quickly and correctly as possible. If needed, they could take off the figures from the panels freely to show them to the remote partners or to just rearrange the figures. Scotch tapes were used on the back of the figures whereby the figures could easily be placed back on the panels.

The design of our collaborative task is affected by [8] [4] and [10], in that it requires participants to move around in a shared space and show objects to remote participants, identify remote objects, refer to remote objects, and ask the remote participants to manipulate remote objects. Although it may not be naturalistic, we designed our task to incorporate as many of these actions as possible.

The experiment was based on a within-participants design, that is, participants conducted the task in two rounds, once in the spherical display condition and once in the 2D flat display condition. Therefore, two different sets of figures (round set and rectangular set) were prepared whereby the same figures would not be used for two rounds of tasks. In addition, the two different sets of figures were used for the two conditions in alternation; thus the difference of difficulty between the two sets did not affect the results of the experiment.

Each group had to complete two rounds of tasks. To minimize the learning effect, half of the groups used the spherical display in the first round and used the 2D flat display in the second round, whereas the other half did it in the opposite order.

4.6 Procedure

1. Preparation: Participants were given a brief introduction to the experiment and panoramic video communication system, introduced to each other, split into two groups and did a practice round with six patterns. After the practice, the correctness of their answers was checked, and they were given two minutes to discuss how to complete the task more efficiently in the main experiment.

2. Main experiment: Five of the ten groups started the round with the panoramic video communication using the spherical display and the other five groups started using the 2D flat display. They were asked to pair all the 28 different patterns with the corresponding patterns in the other room. Stickers and pens were prepared on the table so they could number the patterns by writing the number on the sticker and stick it on the pattern. When they finished all patterns for the first round, participants were asked to complete a short questionnaire concerning their thought about the condition in the first round. Then the display was replaced by the other one and the patterns were also changed to the other set. Next, participants were asked to do the second round of task with the same rules. When they finished the task, participants completed another short questionnaire about the current condition.

3. Debriefing: After finishing the two rounds of the task, participants filled in a final questionnaire about their opinions and comments on the two conditions and the panoramic video communication.

4.7 Measures

We employed objective and subjective measures to examine task efficiency and users' perception of video images during the remote task. Each session was videotaped for post-analysis. We evaluated the collaborative efficiency based on completion time (the time it took the participants to complete the task) and completion accuracy (the number of correct pairs/total pairs).

Category	Question
Visual Cognition	Q1. It was easy to identify the objects/figures shown in the display.
Presence	Q2. I felt as if the remote participants were in the same room.
	Q3. I had a feeling of closeness to the remote participants.
Perceived Workload	Q4. I felt tired to work with the remote participants.
Communication Difficulty	Q5. I had difficulty in talking to only one of the two remote participants.
Compatibility	Q6. For displaying 360 panoramic image, which type of display do you think is better?
	Q7. Which display is easier and faster for searching?

図 4: Seven questions in the questionnaire.

For the subjective measures, we conducted a post-task questionnaire consisting of five questions (Q1-Q5) per condition (10 in total), designed on a 5-point scale (1 = Strongly Disagree to 5 = Strongly Agree) to measure the feelings of participants after using the panoramic video communication systems with two different displays. A measure of the participants' feeling concerning which display is more suitable for the 360° video communication system, was evaluated by Q6 and Q7. The detailed questions are listed in Figure 4.

The features including the pros and cons of both displays were investigated by an additional free-response question. Question contributing to this measure was: *Please write down the advantages and disadvantages of each display which are found in this experiment*.

5 RESULTS

The results of the experiment will be presented from two different perspectives: Firstly, we analyzed the data based on objective measures. Next, we evaluated the questionnaire results to see how the shape of the display affects the video communication in the remote collaboration.

The average task completion time was 485.6s ($SD = 71.65$) with the spherical display and 513.6s ($SD = 124.29$) with the 2D flat display. The Wilcoxon signed-rank test showed no significant difference between the two conditions ($Z = -.7139$, $p = .4752$). As for the completion accuracy, the average task completion accuracies were .9892 ($SD = .0339$) and .9928 ($SD = .0226$), respectively. The Wilcoxon signed-rank test showed no significant difference between the two conditions ($Z = -.0743$, $p = .9407$).

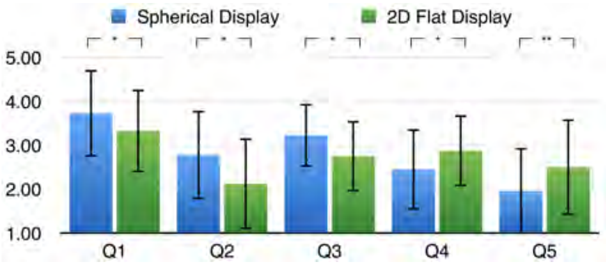

図 5: Mean scores of questions from Q1 to Q5. "*" and "**" denote significant difference at p < 0.05 level and < 0.01 level. The error bars depict the standard deviation.

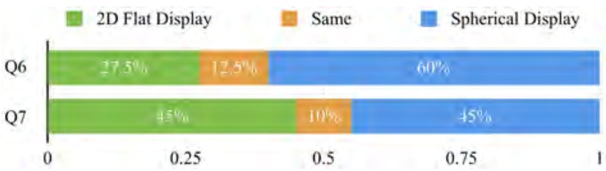

図 6: The statistical results of Q6 and Q7.

5.1 Questionnaire Results

As for the results of the questionnaires, because the Kolmogorov-Smirnov test showed the significant difference between the distributions of the two sample sets, we ran a Wilcoxon matched pairs test. As shown in Figure 5, the results of the questionnaires were analyzed using the Wilcoxon signed-rank test with the display condition as the factor.

1. Visual Cognition – The average scores of Q1 were 3.73 for the spherical display and 3.33 for the 2D flat display; also, we found a significant difference ($Z = 2.0296,\ p = .0424$) between the two conditions. According to the results, the participants seemed to feel that images in the spherical display were easier to recognize than the images shown in the 2D flat display.

2. Presence – The average scores of Q2 were 2.78 for the spherical display and 2.13 for the 2D flat display and there was a significant difference ($Z = 2.5098$, $p = .0121$). The average scores of Q3 were 3.23 for the spherical display, 2.75 for the 2D flat display and there was a significant difference ($Z = 2.1059$, $p = .0352$). Overall, it seems that the spherical display provided a stronger feeling of telepresence than the 2D flat display.

3. Perceived Workload – The average scores of Q4 were 2.45 for the spherical display and 2.88 for the 2D flat display, and we found a significant difference ($Z = -2.2141,\ p = .0268$) between the two conditions. The results indicate that the participants felt more fatigued when using the 2D flat display.

4. Communication Difficulty – The average scores of Q5 were 1.95 for the spherical display and 2.50 for the 2D flat display. We found a significant difference between the two conditions ($Z = -3.0918$, $p = .0019$). The results indicate that the participants found it more difficult to have one-to-one conversations when using the 2D flat display compared with when the spherical display was used.

5. Compatibility – According to the results of Q6, 60% of the participants thought that the spherical display is better for displaying the 360° image. The results of Q7 indicate that the 2D flat display is equally fast and easy to use as the spherical display is to search within the display, as shown in Figure 6.

Advantages of the spherical display	Number of people
Strong three-dimensional sense	20
The spherical display is easier to be seen because of less distortion	20
The spherical display is more natural to be seen. Users just need to lower their head a little bit to see the display	10
Since the spherical display only shows half of the 360-degree images, it brings a better feeling of private conversation with remote partner and they would not be disturbed by the information from the opposite side	8
The spherical display provides better sense of position and directional relation	6
The sense of telepresence is better, which leads to a good feeling of conversation	6
The image on the spherical display is visible from anywhere in the room	5
Users can better be aware of the space range where the remote partner can see, which helps to understand what they are saying	3
Disadvantages of the spherical display	**Number of people**
Users often have to walk around to check the other sides of images, which is not convenient	30
Sometimes, users get lost with their remote partners or just hear the voice of remote partners without seeing them	5

図 7: The pros and cons of using the spherical display in the panoramic video communication.

Advantages of the 2D flat display	Number of people
Users can directly see the whole 360-degree image	32
They could put lots of objects above the omnidirectional camera to show them and they knew that these objects could be seen by the remote partners	3
Disadvantages of the 2D flat display	**Number of people**
The distortion is too serious to make it easy to be seen	23
It is hard to see the display clearly from a slight distance	9
Always have to lower head which is tiring	8
The sense of distance and space is bad	5
Sometime, it is hard to tell which remote partner is talking to you	4
Figures shown on the other side are inverted. If users want to see it clearly, walking is still needed	2

図 8: The pros and cons of using the 2D flat display in the panoramic video communication.

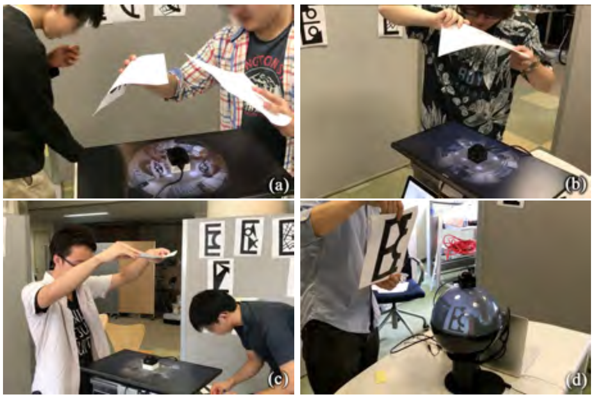

図 9: The camera occlusion issue was observed in the 2D flat display condition(a)(b)(c). While in the spherical display condition, we did not find this situation and participants could naturally show patterns(d).

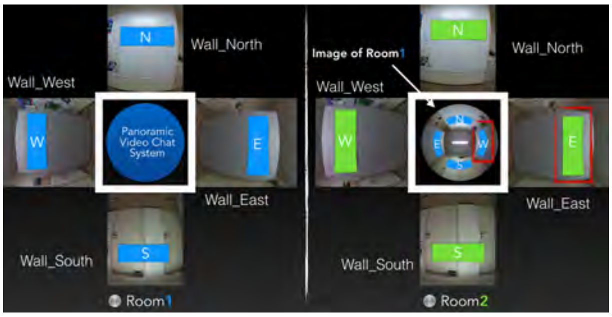

図 10: The exchanged directions. Two rooms with the same arrangements are connected by the 360° video communication system. However, the east wall in room2 does not face toward the image of east wall from room1. Instead, it faces the image of west wall from room1.

5.2 Participants' Comments

Comments were obtained from the free-response question in the questionnaire. After summing up these results, the high ranking answers of the advantages and disadvantages of the spherical display as well as the 2D flat display are shown in Figure 7 and 8 with the corresponding number of people.

5.3 Findings from Observational Analysis

We found distinctive scenes in the video recordings of the experiment. For example, distinctive behaviors were observed in the 2D flat display condition. The participants encountered the camera occlusion issue when showing the figures to their remote partners. As shown in Figure 9 (a)(b)(c), participants tried to place the figures exactly on top of the 2D flat display to show it. However, the image was blocked by the camera on the remote side because the object located on the top of the Kodak camera will be captured and shown at the center of the image. Four out of 10 groups were observed to suffer from this issue when only using the 2D flat display. Normally showing the image at the side of the 2D flat display could solve the occlusion issue. However, in the free-response question, two participants indicated that "*They had to look down to the 2D flat display, while showing the objects at the side of the display instead of above the display made them feel inconsistent*." In the spherical display condition, we did not find this issue and participants could naturally show figures, as shown in Figure 9(d). The occlusion issue of the 2D flat display was caused by the unusual configuration of the 2D flat display's video system. If the omnidirectional camera becomes much smaller or users get more used to this system, it might not be a serious issue. However, as mentioned by a participant,"*it is not intuitive to look down on the 2D flat display while showing the objects at the side of the display*."

5.4 The Exchanged Directions

Also, we found an interesting phenomenon in the 360° video communication system, which was named the exchanged directions. As shown in Figure 10, assume that there were two rooms with the same arrangement, and the four walls were marked as wall north, east, south, and west, which correspond to the actual directions. These two rooms were connected by panoramic video communication systems located in the center of the rooms. Therefore, the 360° image of room 1 was shown in the display in room 2 (which is the circular image in the center of room 2). We found out that when the wall north and wall south of room 2 face toward the images of walls north and south of room 1 in the display, the image position of walls east and west are exchanged. Therefore, the east wall in room 2 faces toward the image of the west wall in room 1, shown by the red rectangles in Figure 10. This means that if there were two people standing face-to-face in the current situation, and the person in room 2 stood on the east side, his remote interlocutor in room 1 would be standing on the west side instead of the east side. The exchanged directions seems to be a common phenomenon in the panoramic video communication. We tried to solve it by horizontally flipping the panoramic images of room 1. In that case, the four walls in the image of room 1 can respectively and correctly match to the four walls in room 2. However, all the objects including texts and pictures are also horizontally flipped in the panoramic images, which is unacceptable in the panoramic video communication. In addition, the expressions related to left and right in the remote communication would be more complicated to understand after flipping.

6 DISCUSSION

The results of the objective measures, including completion time and accuracy, showed there was no significant difference in collaboration efficiency between the two conditions. Meanwhile, on the basis of the questionnaire results, the results of six out of seven questions showed that the spherical display was significantly better than the 2D flat display, indicating that the spherical display was slightly preferred over the 2D flat display as a whole. Below, we discuss the potential reasons for this result by focusing on other factors, for example, visual perception, awareness, perceived workload, and affordance.

6.1 Visual Perception, Awareness, and Perceived Workload

We found that the 2D flat display enabled the participants to see everything in one view but increased their cognitive load because of image distortion and the necessity for mental rotation. The spherical display could only show half of the environment at once but provided a better visual cognition, sense of space, and consistency and coherency of the two distant spaces.

Such findings are supported by the questionnaire results and comments from the participants. The results of Q1 showed that the spherical display provided users a better visual cognition, which is supported by the participants' comments such as "*The spherical display has less distortion and stronger three-dimensional sense*" or "*The 2D flat display has severe distortion*". Besides the easiness to recognize the images displayed on the screen, participants also mentioned that "*The spherical display provides a better sense of space, distance, and directional relation*" and "*The sense of distance and space is bad in 2D flat display condition*", which might explain the results of the questions related to presence (Q2 and Q3). Overall, these results indicate that the images displayed on the spherical display enabled the recognition of spatial relationships more intuitively and brought a better feeling of telepresence. We suspect that such good sense of space, direction, and telepresence helped generate the consistency and coherency of the two distant spaces.

On the other hand, the advantage of the 2D flat display was mainly reflected by the fact that users could see the whole 360° images at a glance, which presents several merits. For instance, some participants mentioned that "*They could quickly locate remote partners or obvious objects by seeing the whole 360° image*."

However, seeing 360° images in one view might also give rise to discomfort when using the 2D flat display. The results of Q4 indicated that the use of the 2D flat display resulted in the users feeling more fatigued. One explanation might lie in what nine participants indicated that "*They always have to lower head which is tiring when using the 2D flat display*". Another reason might be due to the overloaded visual information. Johnson et al. [4] indicated that 360° images were found to be more difficult to use than a 180° interface, which they believed supported the theory that a wider field-of-view requires greater amounts of cognitive processing to synthesize the larger quantity of visual information provided. In our case, the reason why the participants thought that using the 2D flat display made them feel more fatigued may be because the 360° images include more visual information that adds to the cognitive processing burden. On the other hand, in the spherical display condition, participants did think likewise because the opposite side of the spherical display was invisible and they could only see half of the 360° image. But some participants expressed that "*it provided them a more private conversation environment because they would not be distracted by the opposite half of the 360° image*". Thus, they could concentrate on communication without distraction. In addition, 10 participants commented that "*The spherical display is natural to be seen, they just have to lower head a little bit to see the screen*." These factors might help the participants to lower the perceived workload when using the spherical display.

Moreover, we think that restricting the visual space (i.e., showing only half of the space) gives the spherical display more advantages concerning awareness of remote communication. Luff et al. [14] proposed an issue about the ecology of video communication, and they noted that the local person might not be able to make out where the remote person is looking during the video communication, particularly when the field-of-view is wide. We found that the same issue occurred in the symmetrical 360° video communication as the participants could see the whole remote space in the 2D flat display condition. However, we infer that the issue may be resolved by using the spherical display. Indeed, three participants commented that "*When using the spherical display, they can better be aware of the space range where the remote partner can see, which helps to understand what they are saying*."

6.2 Affordances of Displays

The scenes arising from the camera occlusion might indicate that the upward orientation of the 2D flat display affords participants to hold objects right above the display. The spherical display affords participants to naturally hold objects in front of their chest. The 2D flat display requires participants to look down to see the display which is quite unnatural for the participants when they are showing objects. A similar issue was also reported by Licoppe et al. [10]. The spherical display does not have such issues.

In addition, we observed that participants in the 2D condition communicated a little more as a group (with four people) than parallel one-to-one communication, compared with the communication pattern in the spherical display condition. We suspect that such findings might indicate that the spherical display better affords one-to-one conversation, whereas the 2D flat display better affords many-to-many conversation. This point is also supported by eight participants' comments, "*The spherical display brings a better feeling of private one-to-one conversation*". Moreover, the results of Q5 showed that it was easier to talk to a specific remote partner when using the spherical display.

6.3 Proper Application Scenarios

Comments about the 360° video communication were obtained from participants and they thought that "*The 360° video communication is not able to protect their privacy during video communication with families or friends in daily life since the whole room is shown to the remote side*". But they did agree that "*The 360° field-of-view shows much more information than regular video communication and they felt a better sense of the space, directional relation and telepresence of the remote side*."

As realistic scenarios, previous studies [8] [18] demonstrated a new remote meeting environment that merges distributed rooms and allows participants to move around. Also, recent discussion rooms tend to use a whole wall or multiple walls in a room as whiteboards, and a company like Smart Wall Paint is proposing to transform any smooth surface in a room into a write-on wipe-off surface. With the advancement of video technologies, researchers have been envisioning the use of most of the surfaces in a room as video displays. In such a room, participants inevitably walk around in the room to use all the available surfaces, and refer to, manipulate, and discuss the objects and drawings in the room. These trends strengthen the necessity for video communication systems to support collaboration between such rooms by solving the narrow field-of-view problem. Therefore, we are expecting our proposed system would contribute to a new style remote meeting.

7 LIMITATIONS AND FUTURE WORK

One of the limitations of our system was that we only supported hemispherical live video streams. We occasionally observed instances where a local participant exited the field-of-view of the camera when he/she bent down to put the image on the lower part of the wall. In such cases, a remote partner had to hold his/her talk and wait for the local participant to come back into the field-of-view. It is interesting to see that even hemispherical field-of-view was not wide enough to cover all the possibilities of the participants' bodies' spatial positions during the interaction. To solve this problem, we are currently developing a full-spherical version of the panoramic video communication system.

Finally, as we already mentioned, our task is rather artificial. Therefore, we are planning to conduct a qualitative study with a quasi-naturalistic task. We are expecting that such studies will give us a deeper understanding of how the 360° panoramic video communication system affects remote multi-party collaboration.

8 CONCLUSION

This paper challenged one of the long-standing issues of video communication systems, narrow camera field-of-view. We proposed two symmetric 360° hemispherical video communication systems and explored their possibilities in assisting remote collaboration. One of our interests was the impact of the display shape, the 2D flat display or the spherical display, on the remote collaboration. Our experimental results showed that both systems enabled two pairs of people to communicate over the distance simultaneously from anywhere around the devices. However, subjective results indicated that participants preferred the spherical display over the 2D flat display possibly due to better image quality (less distortion) and a better sense of three-dimensional space, directional relation and telepresence. Our future work includes extending our hemispherical system to full spherical system and better user interface for 360° video communication systems.

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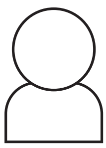

19XX 年〇〇大学大学院〇〇研究科修了。19XX 年バーチャル大学〇〇学科助手、20XX 年 同学科講師、現在に至る。人工現実感および感覚情報提示に関する研究に従事。博士 (〇〇)。