遠隔共同作業における異なる視野角を持つカメラの効果比較のための被験者内実験

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Abstract: 無線を含む高速通信や高解像度カメラが広く普及し，遠隔共同作業が日常のさまざまな場面で用いられるようになった．遠隔共同作業では，カメラによる映像は音声と同じく重要な役割を果たす．一方，広角カメラが急速に普及しつつあり，広角カメラを用いることで，より広範囲の情報を共同作業者へ伝えられる．遠隔共同作業ではカメラは作業空間の共有や記録などのために用いられるが，カメラの視野角が与える影響は実際の共同作業者を用いて検証されていない．そこで本研究では，広角カメラを用いて遠隔共同作業の被験者内実験を行い，一般的な Web カメラを用いる場合と比較評価した．実験ではタスクはブロック玩具の組み立てとパズルの 2 種類を行い，作業にかかる時間と被験者による主観的なアンケートの結果を比較した．

Keywords: Collaborative and social computing, Remote Collaboration, Video Call, Panoramic Camera, View

1. Introduction

Collaborative physical behavior varies among many fields, like a team of workers repairing a complex machine, a group of students doing an experiment, family members are cooking together. While with the widespread use of mobile devices and communication tools, distributed working behavior become common to our life. With no need of traveling together, workers can get technical information and experience from experts remotely, like delivering health care service, technical support for facility maintenance. In recent years, digital cameras are getting less expensive and mass produced, quality high definition cameras are more affordable as a result. In the same time, small size panoramic cameras are getting popular, for which could be supported by web services like YouTube and Google Street View. With the popularization of web cameras, except for video chat, it could also be used to support remote collaboration. Especially panoramic cameras are promising in supporting remote collaboration for it could share workspace more effectively.

In some studies, despite remote collaborators who get shared task space has benefit in collaboration performance, their tasks mainly focused on working on the desktop, or confined to a small field of operating area [1], [2]. For example, Fussell compared three kinds of ways of visual information sharing, and they found that dyads completed the task more quickly under view shared environment [1]. Others discussed the importance of gestures sharing, or development of system enabling helper to give gestural guidance of physical tasks which also designed to be taken in desktop [3], [4], [5], [6], [7], [8]. Although some research took notice of collaboration in the non-traditional-desktop environment, which is mining, and they developed a system mainly focused on support richness of hand gestures of the helper [9]. In a word, whether er different range of workspace sharing would cause different collaborative performance is seldom discussed. And the effectiveness of the full range of view sharing is still unknown.

In this paper, in order to explicate the issues talked above, we designed a study, on one hand, we want to find whether the panoramic camera could support remote collaboration in two kinds of tasks, traditional desktop environment with one task and non-desktop environment with multiple tasks. On the other hand, whether more space sharing would cause behavioral effectiveness on remote collaboration is also considered to discuss. For each task, we chose two kinds of technical method, which are web camera and panoramic camera. The concept we compare the way of supporting workspace information sharing by using different kind of cameras derived from some previous work, including grounding in communication, shared visual information, and synchronous problems in multilayer representation of space, gesture, and speech.

From the result of our study, in both tasks panoramic view share showed better performance in supporting remote collaboration, especially in completing more steps in the task and decrease the communication of camera location. And behavioral difference under different technical method has also been confirmed. Our findings showed the importance of completed view share of workspace in remote collaboration, and give implications for future device designing and research.

2. Related Work

The previous works found that remote collaboration has specific features. Fussell et al. gave a definition of a collaborative physical task as “Two or more individuals work together to per-

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form actions on concrete objects in the three-dimensional world." [10]. As for collaborative behaviors, it is necessary for communicating in speech, gesture and view space. Tang and Hutchins indicated that all these three aspects of communication are combined to construct the complex multilayered representations in which no single layer is completed or coherent by itself [4], [11]. However, executing a collaborative task remotely requires information to be exchanged through video calls, which is different from co-present communication. Since partners are not working side-by-side, the difficulty in synchronizing speech, gestures, and space leads to the problem of mutual understanding in remote collaborative tasks. In previous researchers, there has been extensive discussion on how these three aspects worked in collaboration and interacted with each other.

The previous work concluded that speech is a critical way of communication to exchange information and cannot be replaced compared to other two aspects. The verbalization place the actions in a temporal framework. By using words with different tense or other description of time, the relationship between actions could be indicated, especially the order of motion. And then ensure that partners would understand each other synchronously. Hutchins et al. had investigated the cockpit of a commercial airliner, recorded and analyzed crew's conversation and behavior, they concluded that speech is strongly relevant to actions [4]. Also, speech or conversation is contributing to common ground, which the partners try to reach a mutual belief about understanding what their partners mean through communication. For collaborative physical tasks, conversational grounding can be constructed in three phases. First, collaborators come to construct the agreement on the referential expression of objects. Then, helpers provide instruction about how to operate those objects. Finally, they check the status with each other to ensure the operation are executed correctly [10].

The gesture also plays the important role in constructing of common grounding. The close relationship between speech and gestures has been demonstrated by prior works. [3]. For physical collaboration, enabling remote gestures would enhance the task performance, as the meaningful actions provide a simple reference of objects that result in a reduction of words spoken [4], [6], [12]. Except for simply related to objects, a more complicated form of gestures can also enhance task performance by influencing the structure of discourse and grounding process [5], [8]. Even gesture plays a significant role in communication, what kind of gesture could outperformed in remote physical collaborative task need to be explicit. The prior study demonstrated the unmediated representation of hands leads faster completion with high accuracy in the physical task, meanwhile, the gesture-based instruction also improved the efficiency of learning [7], [8]. Systems of supporting different kinds of the gesture was also an essential topic in previous work like DOVE allow helpers to overlay gestural sketches on the live video captured by workers, and presented back to workers monitor [5]. Others like HandOnVideo which combined the near-eye display and optical filter to capture hands to support richness of gestures in the non-traditional-desktop environment, like mining [9]. The GestureMan systems equipped a robot with a laser pointer in the workspace to represent helper's gesture in referring objects [13].

View space in previous work also found that collaborators have better performance in co-presence, which means working at the same place for which they can share views of the workspace. Fussell et al. conducted a robot construction experiment in five media conditions, where the results indicated that participants working side-by-side has better performance for which has the richest visual space shared [10]. The shared visual space can help them to understand the current state of the task and promote communication effectively. Kraut et al. did a experiment of puzzle completing in three visual space conditions, which is immediate, delayed, none visual space, and two color conditions, static and drift, could seen by helpers, the results showed that having immediate shared view of working area is associated with less solving time, also with less conversational time and number of words [2]. Early research identified sharing visual information by video could improve conversational negotiations. Facial expressions and head nods that can be seen between pairs make needs of checking mutual understanding less often [14]. Other collaboration used video chat like telehealth, the partner could see each other and make reasoned choices of devices between each other when drawing and pointing [15].

Even previous work found that space is also an important part of the remote collaboration, and task performance would get better with space sharing in collaboration, how to share the view of the workspace is seldom discussed. Especially, whether view sharing with the different angle would make performance changing is still unknown. Additionally, previous work has mainly considered the tasks as desktop works, which needless view information of rest space of the room. But in many cases, workers need to move around to manipulate, repair or maintain in factories. Therefore, whether and how this information of the rest space impact on task performance also remains undiscovered.

3. Study Objective

Nowadays, it is common to see remote collaboration in many fields, like remote technical support for machine repair or plant maintenance in the factory. During the collaboration, it is necessary for helper or supporter to observe the workspace while giving instruction. At the same time, with the increasing use of the panoramic camera in both usual life and work, the wide angle of view share could also be considered useful in supporting remote collaboration. Therefore, we formed a hypothesis on there will be beneficial for using the panoramic camera in remote collaboration, and we expected to explicit whether it proves better performance in different kinds of collaboration. Furthermore, how these benefits work in collaborative behavior is also intend to analyze. We predict the panoramic view share will get better performance in remote collaboration, no matter on traditional desktop condition with one task or non-desktop condition with multiple tasks. If the prediction is proved valid, we hope the results of our study could be used in supporting future design and research.

3.1 Measurement of Study

From our hypothesis, in order to understand whether and how different angles of view share of working space affect the effi-

ciency of remote collaboration, we designed a 2×2 within-subject study, which contains two tasks. One is toy assembly, the other one is puzzle solving. Participants will be divided into pairs. For each of the two tasks(toy assembly and puzzle), ten minutes is assigned, and the performance of remote collaboration is compared using two camera devices(web camera, panoramic camera). We decided to observe how these devices affect collaborative behavior, process, and performance.

To measure the behavior in collaboration, the performance of tasks and perceptual after tasks, we will analyze the subjective and objective results of the collaboration. To capture the behavior, the video shown on helper's screen will be recorded. Then we analyze the utterance, especially proportion of requiring adjust the direction of the camera by the helper; confirmation on the camera's location by the worker. To measure the performance, we considered complement level and the error rate. The time is set to 10 minutes. The completed level would be considered as steps taken relative to the whole steps. The error will be count if the wrong objects were taken, assembled, or the color was talked.

For objective measurements, we designed two questionnaires used for both tasks, one for workers and the other one for helpers. The questionnaire is designed on the basis of previous work, each contains 16 questions about participant's impressions of the tasks, 16 basic questions of individual information like age, gender. All question items were scaled in five-point from 1(Strongly disagree) to 5(Strongly agree). The contents of the questions were set to similar to other questionnaire used in prior works. Such as, "How hard or easy was the task to achieve?" for both roles, and "It was useful to see your partner's workspace." or "It was important for my partner to see what the workspace look like." were role separated items.

3.2 Study Design

The study is designed on the basis of our objective of the study. Each task is conducted by a pair of participants, which is grouped by a worker and a helper. The worker is the one who operates the task objects under instruction, and the helper is the one gives instructions during the task. Because our experiment is designed to get results of the different range of view share in different kinds of tasks, so the results of the experiment would be affected by the type of devices and tasks. Therefore, our study has two independent variables.

The first independent variable is task types. The difference between these two tasks is whether the task is carried on under one desktop environment or three operating spots. For the task of toy assembly, where the parts of a block placed on three tables surrounded the worker, who assembled them to build a toy. The goal of this task is shown in Fig.1. The helper will be given a detailed manual with pictures showing explanation about assembly steps at the beginning of the task. The helper will be not allowed to tell the colors of blocks to the workers in collaboration. This is necessary to make sure that the difficulty of the task is set appropriately and could be completed in ten minutes. The aim of this task is to simulate the physical collaboration activities with working tools and material placed around workers, like machine repairing or surgical.

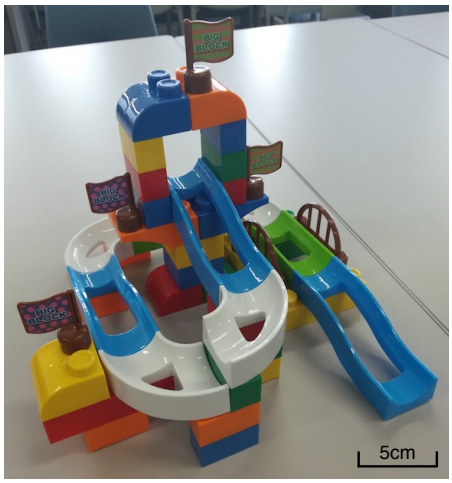

Fig. 1 Object of assemble task

The other task is puzzle solving in which 12 pieces(4×3) are collected from 25 pieces scattered over the room. In this task, the remote helper will be not told about the operating spots before the experiment. The helper needs to find the spots by observing the environment firstly via camera hold by the worker, then give instructions. Since the task is set to solved by helper's independent mind, the detailed step by step manual was not provided. The pattern of the pieces of the puzzle is designed by a complex unreadable character that no participants would know. The restriction set to ensure that the task would not treat as collaborated only by voice. The pieces are placed in anywhere in the workspace, the final goal is to make three sheets shaped in 2×2, each sheet is formed by four different character pieces collected from the workspace. There are three operating spots in the room, and each spot defined by placing the upper left character of each sheet. The goal of this task is shown in Fig.2.

Fig. 2 Object of puzzle task

The second independent variable is the technical method used

for view share. We used two kinds of methods, the first one is a representable web camera, which is Logitech HD PRO WEBCAM C920. It has the ability to capture video and audio in 1080p in normal viewing angles at 78 degrees. The second method is a panoramic camera, which is Ricoh Theta S. This camera can shoot a high definition smooth 360-degree video at 1920×1080 pixels. As all tasks in our study need mobility we decided to set the way of carrying the cameras as a handhold. Also, the other advantage of hold camera by hand is that easy to share view or objects.

3.3 Setup

Working space is shown in Fig.3 and Fig.4. During the two different tasks, the worker will work in the same room as the helper. But the two tasks will be taken in two different rooms, one room is designed for assembly task, the other one for puzzle task. The space of two participants is separated by whiteboards, they can communicate with each other directly via voice, so we will not use video chat software for speech communication. The reason is that we mainly focus on investigating the influence of changing viewing angles in collaborative performance rather than communication quality related to network delay. In Fig.3, the situation of the worker working space in Lego assembling task is shown.

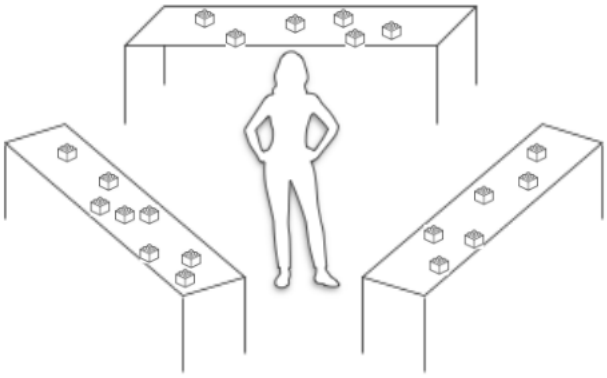

Fig. 3 Work space of assemble task

For the situation of the worker working space in puzzles task. The details are shown in Fig.4.Pieces will be placed all around the room to ensure making full use of the space. To guarantee the fairness, the places of each operating spot is fixed in the same places for each pair of the participant. The camera is held by hand mainly because it is convenient to adjust the distance by a hand-holding device for detail display. While the situation of the helper working space in both tasks, the computer as the main device, which was a 13-inch 1440×900 pixel silvery MacBook Air produced in 2015. It was connected with the camera worker hold by a USB cable. And the video captured by the camera is shown on the computer screen on helper's side by a video software named VLC Media Player. The helper will sit front the computer and provided guidance based on manual and video sent from the worker. More details are shown in Fig.5.

4. Preliminary Experiment

Before the main experiment, we did a preliminary experiment

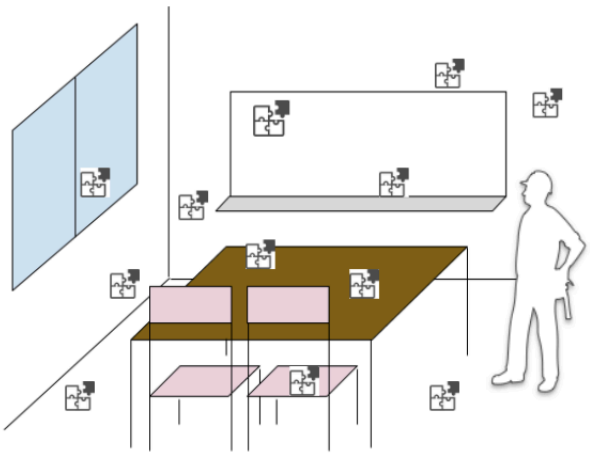

Fig. 4 Work space of puzzle task

in order to investigate whether there is any problem in many aspects of procedure of the study and collect data to adjust and perfected the full study design. Depending on the results of the preliminary experiment, the main experiment would be carried out by using the adjusted full trial procedures with more participants.

4.1 Participants

We have gathered four individuals for task one (lego assembly), and two people for task two (puzzles). For each task experiment, we asked one pair to take part in. All participants were students came from Nara Institute of Science and Technology, Graduate School of Information Science, and they also are native speakers of Japanese, so that language problem has no need to be considered in our study. The age of participants is from 24 to 26. In addition, they all have experience in using video player or video chat applications and can operate the experiment device freely resulting from our investigation before the experiment.

4.2 Procedure

The participants were divided into two groups of two different camera devices. For each device group, Initially, the participants were combined to pairs according to their participant numbers. More specifically, the participant who got No.1 was associated with No.2 to make pair one, and pair two were made by No.2 and No.3, and the last pair is grouped by last one and the No.1. As we have 4 participants for assembling task, so we got 4 pairs in total. And for puzzle task, we got one pair. Each pair were told to take two tasks(assembly and puzzle) in total. For example, if the helper of pair one took assemble task in web camera condition, then he would play the role of a worker when taking panoramic camera condition next time.

Furthermore, Each participant was told to take each technology method in one of the tasks only one time. In each task, the experimenter would stay in the same room with the pair to count time and collect the results of the completed level. Additionally, before task began, the experimenter would brief the materials to participants and connect the camera devices with the laptop to check if there was any problem. While the connection was confirmed successfully and the pair signaled ready to the task, the study would begin with the timer set to go. When times out, the

experimenter told the pair to stop and took notes of the results. The screen was recorded during the study by using Quicktime Player installed on the laptop.

After each task done, the pair exited the room and were handed out questionnaires. At the same time, the experimenter returned the devices and materials to the original condition. Then the experimenter collected the questionnaire and led the next pair to the room. The experimenter of the second task in other room would conduct the process of the task the same as the first task. Because we had two room, we did two tasks at the same time with different devices groups. Once the participants completed their whole tasks, the compensation was provided for their involvement.

4.3 Results

Guided by our study objective, we gathered the data of task performance and perceptual measurements from the preliminary experiment. As our initial desire has been explicated whether panoramic view share makes better performance in different kinds of remote collaboration, the results can be seen in Table 1 and Table 2. From the results, it could be seen that under panoramic view share condition, the achievement level is high in both assemble and puzzle tasks. And the Positive instructions of camera location in panoramic view share condition is significantly reduced compared to web-camera condition.

Table 1 Results of assemble task in web-camera condition

	Positive instructions of camera location	Assemble errors	Color told by mistake	Achievement Level
pair-1	23	3	1	24(45)
pair-2	19	1	1	28(45)
pair-3	18	1	0	17(45)

Table 2 Results of assemble task in panoramic camera condition

	Positive instructions of camera location	Assemble errors	Color told by mistake	Achievement Level
pair-1	3	1	1	30(45)
pair-2	5	1	3	25(45)
pair-3	8	1	1	22(45)

Across assemble errors in the results, there is no obvious difference between these two conditions. The reason is considered as assemble task is conducted mainly on the desktop, which needs less environment information share about the rest of the workspace. Thus, panoramic view share hasn't had great effects on task performance. However, from these results, we could see that panoramic camera also worked well as web-camera in the same traditional desktop condition. As illustrated in Table 1 and Table 2 below, our results of color told by mistake showed that under panoramic view share condition, there was more mistake taken. From our observation during the experiment, the reason is considered that blocks were easy to find as all workspace could be seen, and less word spoken about changing camera direction, so the process of the experiment became fast, thus it was easy to talk about color by careless.

Our results of puzzle task can be seen in Table 3. It showed that panoramic view share had better performance with higher achievement level, and used less time in total. From the results, under the panoramic condition, all parts were formed less than

Table 3 Results of puzzle task in two condition

	Achievement time	Achievement level
panorama camera	564	12(12)
web-camera	600	7(12)

Achievement time : seconds.
Achievement level : formed parts.

10 minutes, but in web-camera condition, only 7 pieces were found and formed in 10 minutes. From our observation and analysis of recorded video, the reason may be considered that with panoramic view share of the workspace, helper could find next piece when his partner was forming, instead asking his partner to change camera direction and search pieces one by one, so that spoken words were cut down and finally lead to achieved time reduced. Also if one of the pieces was collected, it was formed to its spot immediately as the spot could be seen even if it is behind the worker in the panoramic screen. Related to search spot by pieces or search pieces by spot in web-camera condition, the process of search, confirm and form communication between pairs was faster in panoramic view share condition.

Other objective results from participant's feedbacks showed that it is a better experience with panoramic view share condition. For assemble task, even though the task target is operated on a fixed desktop, the wide angle view helped to understand the task environment and find items quickly. In addition, even items that were difficult to describe in words, it is easy to get them according to its location with the panoramic view shared. Also, it is efficient that the helper could find the items while giving instruction and confirming the worker's operation. However, their mainly view on web camera's condition is that it is easy to get details of items because the items look larger on the screen in the same distance. But it is difficult to describe the direction and location.

5. Discussion

Even we got the results illustrated that panoramic view sharing would benefit the remote collaboration in process and perception. We also found some problems that need to be improved in our future plans. The first point is about the experience of watching the panoramic view. For example, some helpers had opinions about what it cost time to adapt to the fisheye images. In addition, others said that when blocks or pieces showed on edge of the screen, it was not smooth to recognize because the image is out of shape. Although all participants had adaption process of the panoramic camera because had no experience before, it is necessary to confirm the participant's experience of the device before the experiment in our main study to ensure the fairness of experiment. The second point is the conflict of the results. For example, the pair-2 had the different result with other two pairs. By our observation from the recorded video, the helper in panoramic view share condition spoke slower in communication. So it is necessary to get more participants in the main study to collect convincing results.

For study design, the arrangement, conduction, and procedure of the assemble task are designed to refer to experimental task used in prior work. The puzzle task designed for the task operated with multiple spots in collaboration. As the results, which is panoramic view share also benefit the remote collaboration be-

havior and performance, could be seen in the preliminary experiment, we also considered that conduct only puzzle task in our main study. Because it is common that worker operates the object while with the need for mobility in the workspace, like technical support in the factory, in remote collaboration. And our hypothesis is mainly derived from this kind of situation.

For experimental pair design, we set one helper and one worker to form a pair to carry out the task in the preliminary experiment. It is the same design as prior work, the task is set to be operated on one desktop. But in our puzzle task design, the operating spot is set to three, which means the task could be conducted by multiple workers. So in our future plan, we suspect that maybe panoramic view share could benefit the condition that one helper with multiple workers in remote collaboration.

6. Conlusion

In our study, we examined the effects of using panoramic camera and web camera in two different collaborative tasks performance, collaborative behaviors, and participant's perceptions. In order to get the results of these differences, we conducted two kinds of tasks: task in one working table and in multiple working spots, which differ from each other in whether the worker is operating in a fixed working spot. From our results, we found that with panoramic view share, the performance of achievement level was better in both tasks, especially in the task with multiple working spots. Furthermore, the process of constructing the common ground during the task is faster in panoramic view share condition, because fewer words used to describe the objects or direction of the camera. Our findings implicate that in remote collaboration, it is important to give the whole view of the working environment to helpers. Even it is likely that the worker would spend the time to adjust to panoramic view for the first time, the whole view share still benefits the remote collaborative performance, behavior and perceptual. Our findings also have suggestions for designers future researchers of collaborative devices and systems, need to consider the importance of widely view share in which the workers need working in multiple spots when developing collaborative technologies.

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