Spatial Switching between Shared and Private Modes in Remote Cooperative Work with Mixed Reality

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Abstract

This paper proposes spatial switching between shared and private modes in remote cooperative work with Mixed Reality (MR) .

Recently, many reserchers have studied MR collaboration systems which achieved the sharing of real objects between remote sites without any mechanical devices. And there are also collaboration systems in which private mode is implemented. Because the sharing of data is not executed when the systems are this mode, a user can use information in cooperative work which he don't want to share. However, these private modes support only two dimensional data and manipulations, and cannot support three dimensional information such as manipulation of a real object. To achieve cooperative work efficiently when a user must use information which he does not want to share, it should be possible to switch between shared and private modes smoothly without other input devices. In addition, the mode of an object is expected to be easily understandable, especially in the case that there are many objects.

We construct three dimensional shared and private space in workspace with MR and achieve the switching of an object between shared and private modes by the position of it. This system enables a user to switch between modes smoothly and to understand the mode of an object viscerally. We expect that remote cooperative work can efficiently be achieved with the spatial switching.

This paper presents the evaluation of this switching method by comparing it to a method which switches by buttons.

Keywords: Remote Collaboration, Computer-Supported Cooperative Work, Mixed Reality, Privacy Control

Index Terms: H.5.4 [Information Applications]: Communications Applications—Computer conferencing, teleconferencing, and videoconferencing; H.5.5 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; K.4.3 [Computers and Society]: Organizational Impacts—Computer-supported collaborative work

1 Introduction

In remote cooperative work with real objects, it is very important how to synchronize the condition of real objects between remote sites [1] [3] [11]. Recently, many studies about collaboration system for such work have focused on Mixed Reality (MR), which can bring virtual information in the real world [13]. In previous study, we ever proposed MR collaboration system which synchronized objects between remote sites [7] [8] [14]. Unlike other previous studies which needed a mechanical device or enabled only one user to have real objects, this system enables both users to have real objects and shared them between remote sites without any mechanical devices.

Most of these systems always share all data because sharing is the most important component in remote cooperative work. Therefore, they share even information that a user doesn't want to share, such as an action not related to work and secret know-how. In order to avoid sharing such information, they have limitation to available actions and information. As a solution for this problem, many researchers have studied switching method between shared and private modes. If an object is in shared mode, the information about it was shared. And if an object is in private mode, the information about it isn't shared [2] [6] [9] [10] [12] [5] [4]. Some of these studies achieve this proposal by means of constructing private space. However, their two modes support only two dimensional data and manipulations, and don't support three dimensional information such as manipulation of a real object. Thus, shared and private modes which support three dimensional information and the method of switching between the two modes are needed. It is expected that a user can switch between the two modes smoothly without other input devices and understand easily which mode each object is in.

In this paper, we present spacial switching between shared and private modes in remote cooperative work, by constructing a three dimensional shared space and private space in workspace with MR. When an object is in the private space, information about it isn't shared with remote site. If a user wants to share information about an object, he moves it into the shared space. If a user doesn't want to share information about an object, he moves it into the private space. By choosing an appropriate space, a user can do the cooperative work which needs information he doesn't want to share. As the result, the category of information which is used in remote cooperative works is augmented.

Our proposed switching method allows a user to switch between shared and private modes smoothly. Because a user can switch the mode by just moving an object into proper space and there isn't barrier between the two spaces, such as the difference of device, this system achieves seamless switching. Furthermore, the mode of an object is easily understandable because a user can judge it by the position of the object. This understandability reduces the error of judging the mode. We expect that this switching system improves the efficiency of remote cooperative work. The spatial switching seems to be suitable for work in which the switching frequently occurs and which many objects are needed.

This paper reports the implementation of the spatial switching, which is our proposed system, and the evaluation of its effectiveness, by an experiment for comparing our method to a method

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which switches the mode by buttons. We asked participants to do a task in which a pair cooperatively painted objects, and recorded the completion time of this task. In addition, we asked each participant to return our questionnaires. From the result of these researches, we found the spatial switching efficient, usable and easy for judging the mode.

2 Related Work

2.1 Remote Collaboration Using Real Objects

Unlike face-to-face collaboration, it is impossible that multiple users use a same object in remote collaboration with real objects. Thus, it is an important proposition how to share the condition of an object between remote sites.

As a solution for this proposition, the sharing of objects by mechanical devices was proposed. Brave et al. proposed PSyBench which offers a physical shared workspace with a remote user [1]. This is a system which synchronizes the move of real objects on a table between remote sites by electrical magnets. When an object on one site moves, one on the other site moves similarly. They implemented an application of remote chess with real objects by this system. Sekiguchi et al. proposed RobotPHONE which achieves remote haptic communication by synchronizing robot's move between remote sites [11]. Wesugi et al. proposed lazy susan which is video projection communication system composed of a shared disk system and a video projection system. [13] In this system, the workspace is shared by synchronizing the rotation of disk between remote sites. However, these systems have the limitation of moving objects because all users cannot freely move them by forced synchronization.

As an alternative, the sharing of objects by video of the working user on a remote site was proposed. Kuzuoka created Shared View that supports spatial workspace collaboration [3]. While this system enables users to share information in the workspace, there is a problem that only one user could use objects.

For solving these problems, we proposed the sharing of objects with MR in previous studies [7] [8] [14]. In the system which achieves this proposal, a virtual object is similarly moved overlapped on the real world on the other's site when a user moves a real object. A user can intuitively see the manipulation of a remote user in this system. In addition, getting a sense of touch, both users can manipulate real objects because each user can have them. There is no limitation to the manipulation of objects. This system allows a user to do a work with a remote user which needs the manipulation of real objects, and to learn a work spatially by moving an object following a virtual object that a remote expert moves.

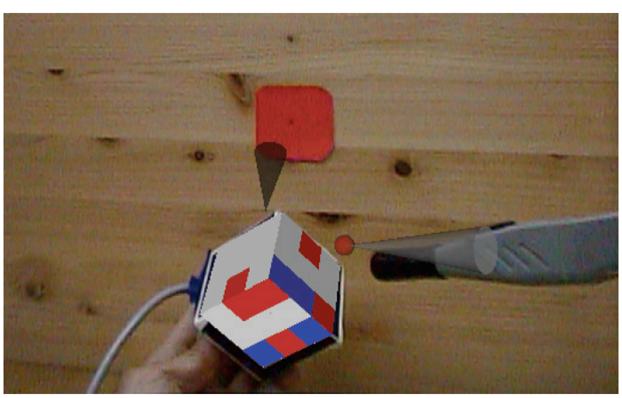

Figure 1: Our previous work [14].

2.2 Switching Shared and Private Mode in Collaboration Systems

To achieve a cooperative work in which a user must use information that he doesn't want to share, many collaboration systems which offer shared and private modes have been created. Morris et al. proposed a system that allows four users to each receive sound from a private audio channel while they use a shared tabletop display, and find differences in work strategies when groups are presented with individual versus public audio by a user study [6]. This is the realization of an auditory shared and private modes. Schnädelbach et al. proposed mixed reality architecture which enables a user to work collaboratively by linking multiple physical spaces across a shared three dimensional virtual world [10]. In this system, a user can choose whether a physical space is linked across the virtual world. This system cannot achieve the sharing of real objects between remote sites.

Some of studies about shared and private modes are achieved as shared and private spaces. Pinelle et al. proposed a table-top personal space in which a user is free from the other user's interference [9]. This system enables a user to protect objects on a table by the private space, which is a defined area in front of each user, in table-top collaboration. But this private space is available for only operation of objects and doesn't visually hide objects. Sugimoto et al. proposed Caretta which supports face-to-face collaboration by Personal Digital Assistant (PDA) and a multiple input sensing board [12]. A user can operate the board through the PDA. This system can hide user's action of preparation by the PDA. In this system, the PDA is defined as the private space, and there is the difference of devices between the shared and private spaces.

Some private spaces are achieved in VR system. Lombardi proposed user interface for self and others in virtual collaborative social space [5]. Users can publish elements by pushing them from private overlay space to the collaborative space. Langer proposed Greenhouse that is a virtual working environment [4]. In the greenhouse, users can create virtual contents and publish and hide their progress in a community. Honda et al. proposed the virtual office environment which integrates the natural communication and the secure private space [2]. They defines "Awareness Space" where user can sense other's awareness such as sound and movement information. A user can concentrate on own works by narrowing this space.

These private spaces are two dimensional or virtual such as the space on a display. Because three dimensional private space in real world haven't been studied, a collaboration system in which a user can hide three dimensional manipulations with real objects hasn't been achieved.

3 Spatial Switching between Shared and Private Modes

3.1 The Importance of Private Mode in Remote Cooperative Works

In remote cooperative work, a private mode in which information isn't shared may seem unnecessary because the sharing of information between remote users is very important. But there is also information that a user doesn't want to share in this work. It is classified in two information: information that a user doesn't want to see or show.

The information that a user doesn't want to see is an action whose result has no relation to the purpose of work, such as preparation and trial for work. While this is an essential action for work, this doesn't have to be shared between remote sites at all time. Actions for preparation may disturb a remote user. In addition, when a user manipulates an object by mistake in a trial for work, the mistaken information transmits to a user. The information a user doesn't want to see is also an unintended action such as an action in break time. This action also doesn't have no relation to the purpose

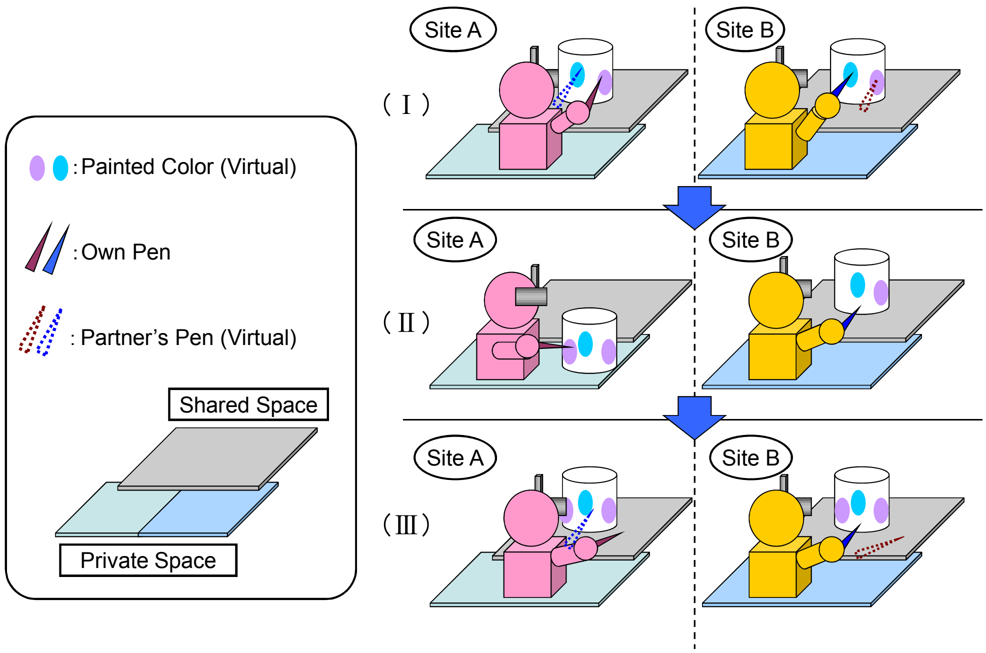

Figure 2: Two users work with using two space. (time advances in the following order: (I) (II) (III)

of work. Thus, a remote user doesn't need the information of this action.

The information a user doesn't want to show is an action which a user wants to conceal the process and component of, such as an action which includes secret information and know-how. This action must not be shared, but its result should be shared.

To complete a remote cooperative work which needs these actions, it should be possible for each user to choose freely whether to share information, or to switch between shared and private modes. In past studies, although there were private spaces in a display, hand-held device or virtual world, these systems couldn't support three dimensional data in the real world. Therefore, it needs a switching method between the two modes supporting three dimensional information in the real world.

To achieve the switching in remote cooperative work with real objects, a user must be able to switch the mode of each object. Then, if it needs an other input device, he cannot smoothly switch it because of stopping a current work to operate the input device. In addition, it is important that a user can easily and viscerally understand which mode an object is in. When there are many objects, this is especially significant because a user must know the mode of each object.

3.2 Remote Collaboration System Switching Two Modes Spatially with Mixed Reality

We propose spatial switching between shared and private modes in remote cooperative work with MR. In workspace of our previous system, all information is always shared between remote sites. Then, we divide the workspace into shared space in which the information of an object is shared and private space in which the information of an object isn't shared, and achieve our proposal. In this system, each user can use real objects and interact with a remote user. Because these spaces are three dimensional, this system enables users to choose whether they share three dimensional information. By using the two spaces as the situation demands, a user can concentrate attention on own task. In addition, the category of information that is used in remote cooperative works is augmented because a user can hide information which he doesn't want to share.

There is no barrier between the two spaces, and any input devices aren't needed for switching the mode. A user can switch the mode of an object by just moving it. This means that seamless and intuitive switching is achieved. Furthermore, it is easy to understand which mode each object is in because a user can visually understand it from the location of the object. This understandability reduces the error of judging the mode. It is a serious mistake that a user performs an action which he doesn't want to show for an object which is in shared mode. The decrease of such error is important for work in which secret information is needed. By these advantages, it is expected that this system improves the efficiency of remote cooperative work including information a user doesn't want to share, especially in the case that the switching frequently occurs and that many objects are needed.

As an application of our proposed system, we expect remote cooperative work in which a user uses know-how only he knows: for example, cooperative design among some companies. In this case, each designer may need to use secret know-how toward the other designer. Then switching between shared and private modes is needed. Our proposed system is good for this case because a user can smoothly switch the mode in it.

3.3 Using Two Spaces: Shared and Private Spaces

A user can easily switch between shared and private modes as the situation demands, by constructing a shared and a private space in one workspace. This section describes the example that two user work cooperatively by these spaces.

Figure 2 shows a painting work with MR. There is distance between site A and site B. Each user has an object, which is same shape and size as one on a remote site, and a pen device which can paint it in a virtual color. A user who is on site A can paint it in purple, and a user who is on site B can paint it in light blue. The gray space is a shared space, and the green or blue space is a private space. A remote user's brush is shown as a virtual object.

Figure 2(I) shows the case that both users's object lies in each shared space. An object which lies in the shared space is in shared mode, and the information of it is shared between the two sites. Color of the object on one site is displayed on the other site, and a virtual brush intending the brush on a remote site is displayed. A user can understand information of the other user's work, such as where he has painted and where he is going to paint. In the shared space, while a user can share information he wants to transmit to a remote user, information he doesn't want to share is automatically shared.

Figure 2(II) shows the case that the user's object on site A lies in the private space, then he newly paints the object. An object which lies in the private space is in private mode, and the information of it isn't shared between the two sites. The new color painted on site A isn't displayed on site B, and there isn't a virtual pen device on site B which intends the pen device on site A. In a similar way, data on site B isn't sent to site A. The user on site A, therefore, can hide own information from the user on site B, and make information he doesn't want to see invisible.

Figure 2(III) shows the case that the user on site A move own object into the shared space after the case of figure 2(II). When the object on site A comes back to the shared space, the information of it is sent to site B. The color painted in the case of figure 2(II) appears on same area of the object on site B. By this switching of spaces, users can integrate each work. Integrated data is saved. This data is shared between remote sites for all time even if the object is moved into the private space.

In this example, a user integrates own work by the shared space after he works in the private space. Users proceed remote cooperative work, reiterating this process with the two spaces. Of course, a user may work only in the shared space if he wants to share information with a remote user.

4 Implementation

4.1 Remote MR Collaboration System

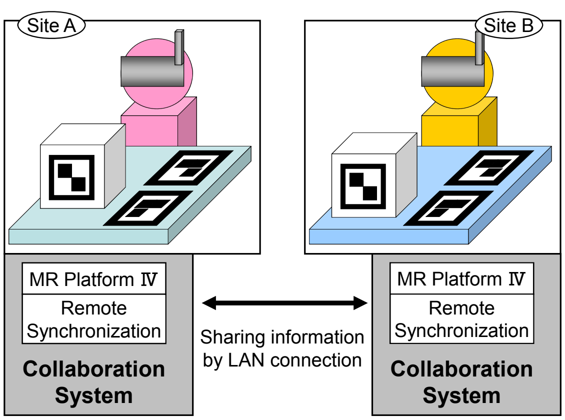

Figure 3: The overview of the remote MR collaboration system.

In the following, we describe the remote MR collaboration system. We created this system by embedding remote synchronization part in MR Platform IV (made by CANON Inc.) which constructs MR environment by position tracking of two dimensional markers(figure 3). In this system, a user wears a stereo video see-through Head Mounted Display (HMD), which offers a MR environment via stereoscopic vision. (figure 4 Top) A real object is covered with

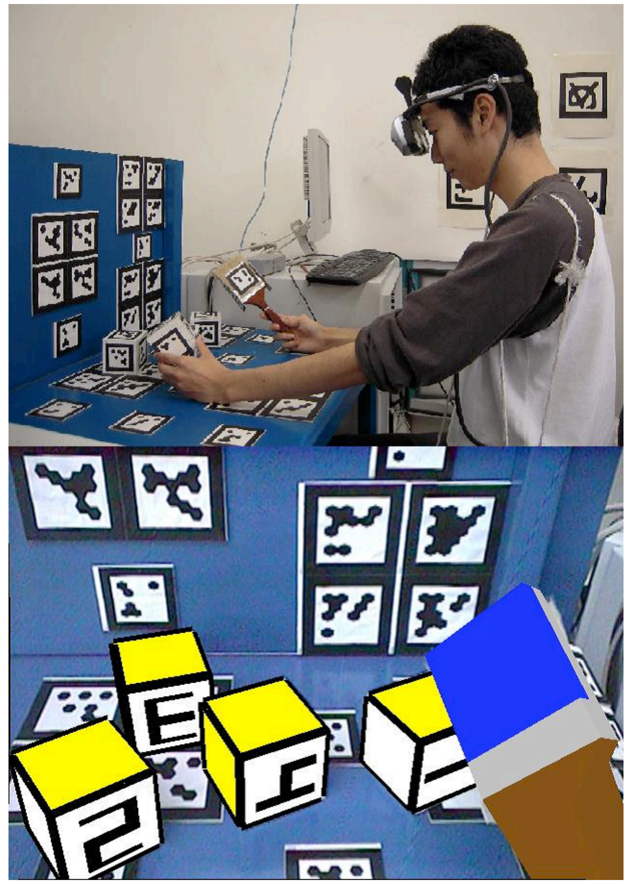

Figure 4: Top: a user in this system who wears HMD. Bottom: a user's view from HMD

a virtual one in the view of a user. (figure 4 Bottom) This system runs at a rate of 30.07 frames per second with treating the tracking and remote synchronization.

This system enables a user to share information, such as the condition of an object, with a remote user. Then, any changes on one site must similarly be caused on the other site in realtime. That means that remote synchronization of objects between two sites is needed. The following describes the way of it.

First of all, objects used for work must be registered in advance, by defining all objects as ID numbers. Any objects can be referred by this number. The ID number accords between two sites. When the condition of an object is changed, this system can know which object is changed, by the ID number. The information of the object, including the ID number, is sent to a remote user's site. On the remote site, the object corresponding to the received ID number is updated by the received data.

In the study of this paper, we defined color of an object which is used for an experiment for evaluation as shared information.

4.2 Structure of Shared and Private Spaces

This section describes how to construct the shared and private spaces in workspace. We constructed two spaces in one workspace by defining a boundary line. A user can use real objects because two spaces are constructed in the real world with MR.

We explain the design of two spaces by figure 5. The boundary line that divides the workspace into the shared and private spaces is on top of a table. The shared space is defined as a part of the table (the blue part in figure 5) and the private space is defined as the rest.

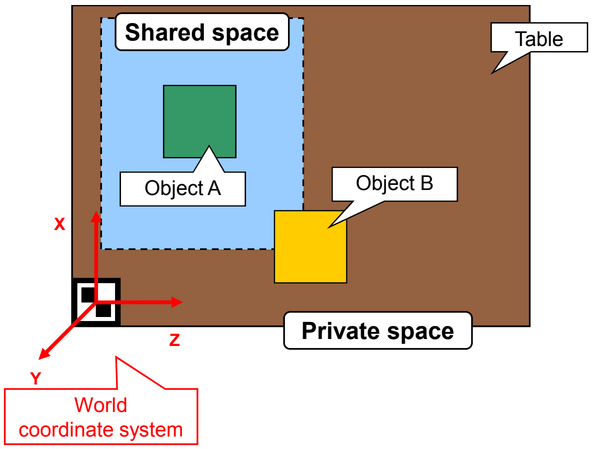

Figure 5: The Overhead view of the workspace including two spaces.

Figure 6: The workspace seen by a user.

To allow a user to distinguish two spaces visually, the boundary line is drawn by CG (figure 6). The shared space is a space surrounded by white curtains. Which mode (the shared and private mode) an object is in is decided by a space which it lies in, and which space an object lies in is decided by the position of it in world coordinate system, which is a system of coordinates with their origin at a point of the table here. If all part of an object is in the shared space, it becomes the shared mode.(object A in figure 5) If a part of an object is in the private space, it becomes the private mode.(object B in figure 5) However, the height of an object doesn't effect the judging of these modes. Even if an object stays aloft, the mode of it is decided by the two dimensional position on a plain of the table.

These design allows a user to choose whether to share an object or not by just moving it. We expect a user can promote remote cooperative work in an efficient fashion because of the smooth switching of the two modes.

5 Evaluation

We performed an evaluation experiment in order to examine the effectiveness of our proposed switching system. We asked participants to do a task in which a user needed to switch the mode, in two cases of switching between the shared and private modes. One was the spacial switching we proposed in this paper, and the other was button switching which was a method of switching the mode of an object by pushing a certain button.

We evaluated the working efficiency, usability and ease of judging the mode of the spatial switching by comparing two switching cases. We expected that the spacial switching receives a higher evaluation than the button.

5.1 Procedure

Twenty students participated in this experiment. We asked them to be divided into pairs and to do a task in which the pair cooperatively painted objects. In this task, they frequently needed to switch the mode of objects between the shared and private modes. We recorded the completion time of this task. If they could switch the mode smoothly, it was expected that the completion time becomes short. In addition, we asked each participant to return our questionnaires after the task. This questionnaires were about the ease of switching the mode, of judging which mode an object was in and of collaboration with a remote user.

5.1.1 Task

Each participant had four cubes which were 7 centimeters on a side and a brush. Virtual objects were overlaid on these objects. Each of four cubes was marked with a number, from "1" to "4". Participants did virtual painting of four cubes by the brush together.

Participants could paint a plane of a cube by touching it with the brush. However, there was an order of painting. Color in which a participant could paint a plane was decided by current color of the plane, and is different between two participants. For instance, if we named one participant "participant A" and the other one "participant B", participant A could change a plane from yellow to red and from blue to green, and participant B could change a plane from red to blue and from green to pink. When the brush touched a plane of a cube, a participant could paint it if this rule was fulfilled. If it wasn't fulfilled, the color of the plane didn't change.

Each cube had a shared and a private mode. When a cube was in the private mode, the change of color on one site wasn't reflected on the other site. In contrast, when a cube was in the shared mode, the data of color of it was shared between two sites. Thus, both cubes on two sites became same color. Color in which a participant last painted it was reflected. The goal of this task was to change planes which were yellow at first into pink planes on both sites. As a result, participants had to use the shared mode to share the color of cubes. In addition, we established the rule which forbade a participant from painting a cube which was in the shared mode. By this rule, participants had to switch the mode many times. Therefore, this task was well suited to the evaluation of switching method.

The following describes the concrete process of this task. The default mode of all cubes is the shared mode. At first, participant A switches a cube into the private mode, and paints yellow planes in red. After changing all yellow planes to red, participant A switches the cube to the shared mode and shares the color of it with participant B. Then, participant B paints red planes in blue in the same way. By the repetition of this action, yellow planes of the cube becomes pink. When four cubes become pink, this task finishes. While the partner worked about one cube, a participant could work about the other one. Participants could also communicate each other by voice.

5.1.2 Two Cases of Switching

We asked participants to do this task by the two switching methods: spatial switching and button switching. Half of ten pairs first did it by the spatial switching and later did it by the button. The rest first did it by the button switching and later did it by the spatial.

The spatial switching was our proposed method. Participants could switch the mode of a cube between the shared and private

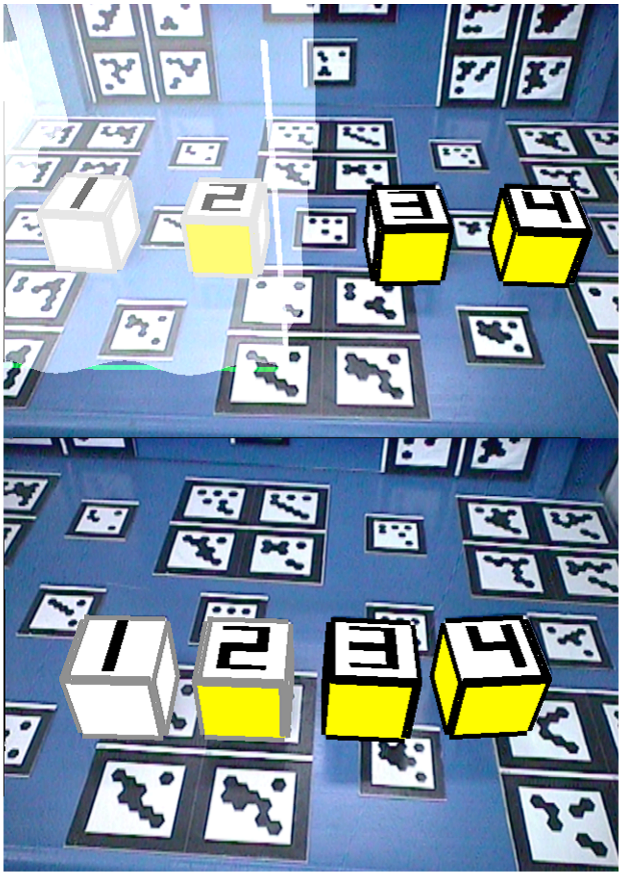

Figure 7: Used cubes. In this figure, "1" and "2" are in the shared mode, and "3" and "4" are in the private mode. Top: spatial switching. Bottom: button switching.

modes by just moving it. A cube became the shared mode if they moved it into the shared space, and a cube became the private mode if they moved it into the private space.(figure 7 top)

The button switching was a method which switched the mode of a cube by pushing a button. In the case using this switching, there was a keyboard beside the workspace. By pushing the key of "1", participants could switch the mode of the cube which was marked with "1". In the same way, they could switch the mode of the rest by pushing the key of "2", "3" and "4". The mode of a cube were represented by the border color of it. When a cube was in the shared mode, the border color was gray. When a cube was in the private mode, the border color was black.(figure 7 bottom)

5.2 Result and Discussion

We recorded the completion time of this task. Figure 8 shows the average of ten pairs. The average in the case of the spatial switching is 131.31s, and that in the case of the button switching is 182.19s.

The completion time in the case of the spatial switching was shorter than that in the case of the button switching, and there was significant difference between the two cases.($p < .01$) This meant that the spatial switching had better working efficiency for cooperative work than the button switching. In the case of the button switching, participants had to look towards the keyboard, and push an appropriate key from some keys. As a result, there was a waste of time. In the case of the spatial switching, there was few seconds for switching because they could switch the mode of a cube by just moving it in the workspace. There was also a waste of time in the case of the button switching because of attempting to paint a cube which was in the shared mode by mistake.

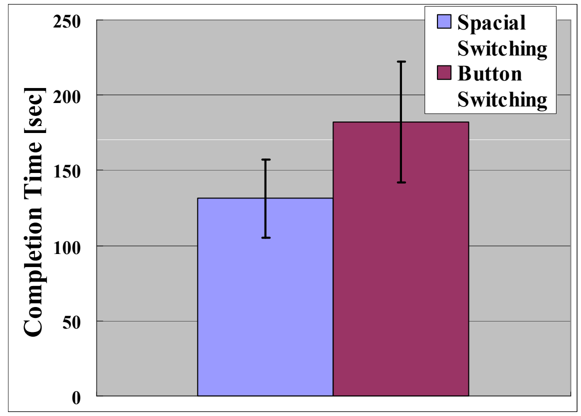

Figure 8: The completion time.

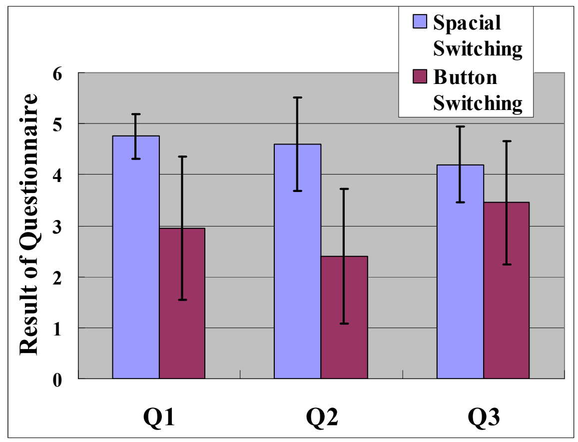

Figure 9: The result of questionnaires.

In addition, we asked each of twenty participants to return the following questionnaires.

Q1 It was easy to understand which mode a cube was in.

Q2 It was easy to switch the mode of a cube.

Q3 We could collaborate efficiently.

These questionnaires were a scale of one to five. If a participant felt "Yes" for a questionnaire, the value was higher. Figure 9 shows the average of the results. In the case of the spatial switching, the value of Q1 is 4.75, that of Q2 is 4.6 and that of Q3 is 4.2. In the case of the button switching, the value of Q1 is 2.95, that of Q2 is 2.4 and that of Q3 is 3.45.

Each value of all questionnaires in the case of the spatial switching was higher than ones in the case of the button switching, and there was significant difference between the two cases.(Q1 Q2: $p < .01$ Q3: $p < .05$) In addition to the results in Q1 and Q2, some participants said "In the case of the spatial switching, I could switch the mode of a cube without regard to the number with which it was marked.". From these results, we could verify the usability and understandability of the spatial switching. Furthermore, the result of Q3 declares the efficiency of it for remote cooperative work.

From the completion time of the task, we found that the spatial switching advanced the working efficiency for remote cooperative work. From the questionnaires, we found that the spacial switching had the good usability and allowed a user to easily judge which mode an object was in. Therefore, this switching method is more adapted for remote cooperative works.

6 Conclusion

Many studies about a system which supported remote cooperative work have focused on the sharing of information between remote sites. Some of them allowed users to do cooperative work including information they didn't want to share by switching information between shared and private modes. However, there wasn't a system which could hide three dimensional information, such as real objects and manipulation of them. It needed to design a switching method which could switch the mode of real objects.

We proposed the spatial switching between the shared and private modes in remote cooperative work with MR. It was expected that this switching method enabled users to switch an object between the shared and private modes smoothly, and to easily judge the mode of it. We considered the spatial switching a effective method for remote cooperative work.

We have implemented and evaluated this system. To achieve our proposal, we constructed a shared and a private three dimensional space in workspace. The mode of an object was decided by a space which it lies in. Because of this system, a user could switch the mode of an object by just moving it. The evaluation experiment was a comparative experiment between two switching methods: spatial switching and button switching. From the result of this experiment, we have verified the smoothness and usability of switching and the ease of judging the mode of an object in the case of the spatial switching. In addition, we found that the spatial switching advanced the working efficiency of remote cooperative work. We expect that the spatial switching is more effective especially when users must frequently switch the mode.

For future work, we plan to design a system that avoids collisions of data between two sites. If two users edit same part of an object, the collisions of data may occur when a user moves it into the shared space from the private space. In the experiment of this paper, the collisions didn't occur because there was an order of colors in which users could paint cubes. But the collisions may occur in an application of our proposed system. Therefore, a system which decides how to deal with the data of the collisions will be needed for future. In addition, our proposed system has a limitation. The system cannot support the work in which it is impossible for users to move objects freely. For example, if users cannot carry objects in their hand or there is fixed position for the work, the spatial switching isn't achieved. we also plan to study intuitive switching system for such works.

Acknowledgements

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References

[1] S. Brave, H. Ishii, and A. Dahley. Tangible interfaces for remote collaboration and communication. In *CSCW '98: Proceedings of the 1998 ACM conference on Computer supported cooperative work*, pages 169–178, New York, NY, USA, 1998. ACM.

[2] S. Honda, H. Tomioka, T. Kimura, T. Oosawa, K. Okada, and Y. Matsushita. Valentine: an environment for home office worker providing informal communication and personal space. In *GROUP '97: Proceedings of the international ACM SIGGROUP conference on Supporting group work*, pages 368–375, New York, NY, USA, 1997. ACM.

[3] H. Kuzuoka. Spatial workspace collaboration: a sharedview video support system for remote collaboration capability. In *CHI '92: Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 533–540, New York, NY, USA, 1992. ACM.

[4] C. Langer, A. Raab, C. Strothotte, and C. Zwick. Wouldn't you like to have your own studio in croquet? In *Creating, Connecting and Collaborating through Computing, 2006. C5 '06. The Fourth International Conference on*, pages 150 –159, jan. 2006.

[5] J. Lombardi and M. McCahill. User interfaces for self and others in croquet learning spaces. In *Creating, Connecting and Collaborating through Computing, 2005. C5 2005. Third International Conference on*, pages 3 – 10, jan. 2005.

[6] M. R. Morris, D. Morris, and T. Winograd. Individual audio channels with single display groupware: effects on communication and task strategy. In *CSCW '04: Proceedings of the 2004 ACM conference on Computer supported cooperative work*, pages 242–251, New York, NY, USA, 2004. ACM.

[7] Y. Okajima, S. Yamamoto, Y. Bannai, and K. Okada. Expression of the remote user in the mixed reality remote collaboration. In *Proc. of The Fourht International Conference on Collaboration Technologies*, pages 116 –121, august 2008.

[8] Y. Okajima, S. Yamamoto, Y. Bannai, and K. Okada. An instruction method for displaying trajectory of an object in remote collaborative mr on the basis of changes in relative coordinates. In *SAINT '09: Proceedings of the 2009 Ninth Annual International Symposium on Applications and the Internet*, pages 43–49, Washington, DC, USA, 2009. IEEE Computer Society.

[9] D. Pinelle, M. Barjawi, M. Nacenta, and R. Mandryk. An evaluation of coordination techniques for protecting objects and territories in tabletop groupware. In *CHI '09: Proceedings of the 27th international conference on Human factors in computing systems*, pages 2129–2138, New York, NY, USA, 2009. ACM.

[10] H. Schnädelbach, A. Penn, P. Steadman, S. Benford, B. Koleva, and T. Rodden. Moving office: inhabiting a dynamic building. In *CSCW '06: Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work*, pages 313–322, New York, NY, USA, 2006. ACM.

[11] D. Sekiguchi, M. Inami, N. Kawakami, and S. Tachi. The design of internet-based robotphone. *International Conference on Artificial Reality and Telexistence*, pages 223–228, 2004.

[12] M. Sugimoto, K. Hosoi, and H. Hashizume. Caretta: a system for supporting face-to-face collaboration by integrating personal and shared spaces. In *CHI '04: Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 41–48, New York, NY, USA, 2004. ACM.

[13] S. Wesugi and Y. Miwa. Facilitating interconnectedness between body and space for full-bodied presence - utilization of “lazy susan” video projection communication system -. In *7th Annual International Workshop on Presence (PRESENCE 2004)*, pages 208–215, 2004.

[14] S. Yamamoto, H. Tamaki, Y. Okajima, Y. Bannai, and K. Okada. Symmetric model of remote collaborative mr using tangible replicas. In *Virtual Reality Conference, 2008. VR '08. IEEE*, pages 71 –74, march 2008.