A Collaboration Support Technique by Integrating a Shared Virtual Reality and a Shared Augmented Reality

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ABSTRACT

We propose seamless view-mode switching, a novel technique for supporting spatial collaboration that integrates a shared virtual environment (SVE) and a shared augmented environment (SAE) in a natural way. The technique uses two view modes: a see-through mode and a blind mode, each corresponds to an SAE and an SVE, respectively. In the initial state, the view mode is the see-through one. Whenever a user changes his/her location or a scaling factor by using a 3-D widget, the view mode is automatically switched to the blind one. In this mode, a computer graphics (CG) human body, which includes a head and two arms, is displayed in place of a real partner. When a user choose the see-through mode by using the widget, position, orientation and a scaling factor are changed to those of the partner gradually, and the view mode is switched back to the see-through one. In addition to this seamless view-mode switching, we also employ two techniques for collaboration support. First, the system optionally draws a line from the center of the partner's eyes toward his/her viewing direction to enhance face direction information. Second, the system employs two methods for precise calibration: a look-up-table based mechanism for correcting the distorted magnetic field, and a Kalman filter for compensating the computational delay. Owing to these techniques, users of our system can smoothly perform spatial collaboration.

1. INTRODUCTION

In the last decade, a networked virtual reality technique has been used for supporting spatial collaboration. In the shared virtual environment (SVE), multiple users can perform a variety of cooperative tasks [1][2]. In addition, each user may have free control over location and scale of individual coordinates. This flexibility helps to parallel activities in the shared workspace[1]. However, because of poor computer-generated representation of remote participants and communication delay, collaboration within the SVE has a drawback compared with collaboration within the real world. That is, awareness information is poorly transferred so that each participant has significant difficulty in recognizing what other participants are doing.

On the other hand, several attempts have been made to construct more informative and natural collaborative workspaces, in which co-workers are at the same location [3][4][5]. Such co-located shared workspaces permit face-to-face interaction, and still support real-time 3-D computer graphics (CG) from respective participants' viewpoints. Some systems consist of a rear projector and two pairs of liquid crystal shuttered glasses [3], others employ two optical see-through head mounted displays (STHMDs) [4][5]. In the latter type, virtual objects can be displayed at arbitrary positions, e.g., between two participants. The latter setup is referred to as a shared augmented environment (SAE). Co-located users of an SAE can observe both real and virtual worlds through optical STHMDs.

Our goal is to support spatial collaboration as smooth as possible. An SAE and an SVE are supplementary with each other, and these two types of workspaces should be chosen according to the characteristics of the task. For example, both an SVE and an SAE seem to be useful for designing 3-D spaces in different ways. When the designers want to choose different perspectives of the virtual environment, e.g., different locations and scale factors, an SVE is the only solution that permits such parallel activities. On the other hand, when designers want to make a discussion with face-to-face interaction, an SAE will be more useful than an SVE because awareness information of other participants is naturally transferred. In such a case, awareness information may improve working efficiency as well since designers will notice quickly and precisely what the partners are looking at or going to do next.

In this paper, based on these considerations, we propose a novel technique for spatial collaboration that seamlessly integrates an SVE for parallel activity and an SAE for natural communication. Also described is an empirical study which is to give a verification of the integration technique.
2. RELATED WORKS

Table 1 shows classification of computer mediated shared environments with a number of systems. There are a number of groupwares that support collaborative 3-D activities on 2-D displays. Teledesign [6], a collaborative CAD system developed at MIT is one of such applications. Through experiments using Teledesign, they showed that independent points of view between designers optimized parallel activities, and to display the viewpoints and viewing objects of different designers is effective in the workspace, when arbitrary points of views are allowed.

Shared virtual environments (SVEs) have been used for supporting collaborative 3-D activities within 3-D workspace. CALVIN [1] developed at University of Illinois at Chicago, is a good application that supports collaborative design. Making good use of the characteristics of a virtual environment, CALVIN provides collaborators with a variety of multiple perspectives that include multiple camera parameters, multiple information filters and so on. In terms of natural awareness, however, multi-perspective may break the sense of unity. For example, not being in the same coordinates, one’s here is no more the same position of the other’s here. VISTEL [2], a virtual space teleconferencing system developed at ATR, is an attempt to reproduce computer-generated remote participants as real as possible, which include gestural and facial expressions. In the system, all participants belong to a single coordinate system and they can have a virtual face-to-face meeting.

Employing a video conference technique is an easy and effective way of making remote users more realistic and providing the natural feeling of meeting together, though the image is flat. ClearBoard II [7] developed at NTT Human Interface Lab. permits co-workers in two different locations to manipulate a collaborative drawing tool while maintaining direct eye contact using a video conference technique. In this system, the drawback that the image of other participant is flat is inconspicuous since the drawing activity is limited on the surface. Networked SPIDAR [8] developed at Tokyo Institute of Technology is a networked multi-modal interface that offers a shared virtual 3-D workspace. Networked SPIDAR permits face-to-face video conference, and also transmits auditory and haptic information. In this case, the coordinates of the video image have little relation to that of the virtual workspace.

All systems mentioned above support remote collaboration. However, in many cases, collaborative partners are at the same place, e.g. the same office or the same laboratory, rather than distant places. In such cases, most convenient and effective way for acquiring both a sense of awareness as rich as possible and common coordinates in which they collaborate as exact as possible is to let the co-workers be at the same place. The Two-User Responsive Workbench [3] developed at Stanford University supports face-to-face collaboration. Two users of the system stand by a rear-projector that displays four images as two stereo pairs in each rendering cycle. However, projection-based virtual reality can display virtual objects only within a limited viewing frustum. See-through head mounted displays (STHMDs) solve this problem. As shown in Figure 1, our collaborative immersive modeling tool, VLEGO II [4], uses a pair of STHMDs. Users of VLEGO II are able to design 3-D space collaboratively with a set of two-handed direct manipulations. AR2 Hockey [5] developed at Mixed Reality Systems Lab. also uses a pair of STHMDs, permits two users to share a physical game field, mallets, and a virtual puck to play an air-hockey game. Such shared augmented environments (SAEs) support both face-to-face collaboration and displaying virtual objects at arbitrary positions, e.g., between the users.

Both an SVE and an SAE have advantages in terms of collaboration support. In an SVE, each user can see the shared workspace from an arbitrary position in any scale. This feature enhances parallel activities. On the other hand, each user can see his/her real partner in an SAE with rich awareness. This feature encourages conversation, gestural languages and even may improve collaboration efficiency.

Table 1 Classification of computer mediated shared environments.

<table>
<thead>
<tr>
<th>Level of artificiality</th>
<th>Example(s)</th>
<th>Partner</th>
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<tbody>
<tr>
<td>Fully artificial</td>
<td>Teledesign[6]</td>
<td>CG Symbol</td>
</tr>
<tr>
<td></td>
<td>VRML, CALVIN[1]</td>
<td>CG Avatar</td>
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<tr>
<td></td>
<td>VISTEL[2]</td>
<td>CG Human</td>
</tr>
<tr>
<td></td>
<td>ClearBoard II[7]</td>
<td>Video Image</td>
</tr>
<tr>
<td></td>
<td>Networked SPIDAR[8]</td>
<td></td>
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<tr>
<td></td>
<td>The Two-User Responsive Workbench[3]</td>
<td>Real Person</td>
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<tr>
<td></td>
<td>VLEGO II[4], AR2 Hockey[5]</td>
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</tr>
<tr>
<td></td>
<td>(Collaboration in the real world)</td>
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3. COLLABORATION SUPPORTING TECHNIQUES

Seamless View-mode Switching
Though there have been various kinds of computer mediated shared environments, none of them have tried to integrate an SVE and an SAE. In order to take advantages of both of them for smooth collaboration, we propose a novel technique, seamless view-mode switching. This technique integrates an SVE and an SAE in a natural way for co-located collaboration. We have implemented the technique on VLEGO II. Figure 2 shows hardware configuration of VLEGO II. The shared workspace is controlled and rendered by two graphics workstations, Indigo2 Maximum Impact (SGI), and displayed through a pair of optical STHMDs, Mediamask (Olympus). Users manipulate 3-D cursors corresponding to 3-D input devices that are composed of receivers of Fastrak and push buttons.

The technique uses two view modes: a see-through mode and a blind mode, each corresponds to an SAE and an SVE, respectively. In the initial state, the view mode is the see-through one. Whenever a user changes his/her location or a scaling factor via a navigation widget (Figure 3), the view mode is automatically switched to the blind mode. In the blind mode, a CG human body, which includes a head and two arms, is displayed in place of a real partner.

Figure 4 illustrates three cases of a user’s view of the workspace. In case A, scaling factors of two users (S_A and S_B) are identical, and the view mode is the see-through one. When a user scales down or up the workspace, the view mode changes into the blind one as shown in cases B and C. Figures 5, 6, and 7 illustrate independent views in an SVE, which is shared by two users A and B. Figure 5 shows the view of user A who is looking down a room. Figure 6 shows the view of user B who is walking around the room. Note that their scaling factors are different. Figure 7 is the scene from a God’s view showing how they are located in the SVE. When a user choose the see-through mode via the
widget, position, orientation and a scaling factor are gradually changed to those of the partner in about one second, and the view mode is switched back to the see-through one. Switching the view mode is actually realized by sending signals to external inputs of HMDs' controllers.

Other Supporting Techniques
In addition to the seamless view-mode switching, we employ a few techniques for supporting collaboration, which seem to be useful for both an SAE and an SVE.

Enhanced Awareness: We employ an awareness-enhancing technique to improve collaboration efficiency. In collaboration in the real world, we often notice what a partner is looking at by watching his/her face. If a user can see this direction more clearly, collaboration efficiency may be improved. To enhance the face direction information, a line segment (a viewing line) is optionally drawn from the center of the partner’s eyes toward his/her viewing direction. In addition to this, a viewing object is also optionally highlighted, that is a virtual object which minimizes the angle between a vector from the partner’s eyes to it and his/her face direction among all virtual objects. Figure 11, d) shows a CG partner with a viewing line and a viewing object.

Calibration: For an SAE, calibration is one of the most important issues. Though the real world objects lie in a unique world coordinate system, the virtual world does not perfectly lie in the real world coordinate system because of calibration error and computational delay. These factors cause registration error between the virtual and real worlds. For example, a virtual object unsteadily moves as the viewpoint changes. Hence, users see a virtual object at different positions in the real world. As in other efforts [9][10], we employ two techniques for precise calibration. One is a look-up-table based mechanism for correcting the distorted magnetic field, and the other is a mechanism that compensates the computational delay by using a Kalman filter. The time interval for estimation is dynamically changed based on the system cycle. Of course, these techniques are also usable in an SVE. Currently, calibration accuracy is about 1 to 2 cm within a normal working volume.

Actual Image Sequence
Figure 8 shows an actual image sequence captured through a STHMD by a small camera attached in a dummy head. First, the user sees the real partner (A). As he translates his location via the navigation box (B), his partner becomes a CG counterpart (C) and the coordinates change freely (D, E). When he clicks a button of the box (F), the coordinates automatically change to those of his partner (G) in about one second, and his partner gets real again (H).

4. EXPERIMENT
Since the superiority of an SVE over an SAE in terms of multiple perspective is obvious, the appropriateness of seamless view-mode switching is dependent on the effectiveness of an SAE compared with an SVE in terms of awareness. However, this effectiveness is not apparent, especially when computer generated human bodies (virtual humans) are displayed in place of real partners in an SVE. Therefore, we have conducted an empirical study to confirm the effectiveness of an SAE compared with an SVE [4]. Incidentally, we also investigated the effectiveness of the awareness-enhancing technique (viewing lines). To simplify the analysis, the Kalman filter is not used through the experiment.

Experimental Setup
The experimental task is a cooperative target-clicking task which requires two subjects in each trial, an instructor and an operator. They sit on opposite sides of a black wooden desk of 75cm in depth and they are asked to click the targets as quick as possible as explained below.

To investigate the relationship between the effectiveness and the configuration of the experiment, we set two configurations. One is a sparse and looking-front condition (configuration 1), in which the effectiveness would be prominent, and the other is a dense and looking-down condition (configuration 2), in which the effectiveness would be quiet. In configuration 1, there exist nine gray virtual cubes of 5cm each side and two red cubes of 3cm each side floating in the workspace as shown in Figure 9. In configuration 2, there exist twenty-five gray virtual cubes...
Experimental Results

Figure 12 shows the averages of task completion times in the configurations 1 and 2. In this figure, five dotted circles indicate there are no significant differences in each circle and five groups are statistically separated from others. This result confirms the effectiveness of an SAE compared with an SVE. Displaying head direction information, by a CG head and/or a viewing line, is effective in configuration 1, but it is not effective in configuration 2. This is probably because the objects are so jammed that such delayed information is useless to estimate the viewing direction.

Figure 13 shows the average scores of subjective evaluation in the configurations 1 and 2. This result shows using an SAE rather than an SVE improves the subjective evaluation without viewing lines. Subjects reported they could get feeling of intimacy and relief owing to direct observation of the real partner in an SAE. Displaying head direction information also improves the feeling of manipulation.

Discussion

Through the experiment, the effectiveness of an SAE compared with an SVE was confirmed for co-located collaboration. This result encourages us to use an SAE for face-to-face collaboration and an SVE for multiple perspective. Though the effects of seamless switching between an SAE and an SVE have not been investigated, seamless view-mode switching is one of reasonable solutions for natural integration of two view modes. In practice, most subjects preferred and used well seamless view-mode switching.
5. CONCLUSION

In this paper, in order to support spatial collaboration as smooth as possible, we proposed seamless view-mode switching, a novel technique that integrates a shared virtual environment for parallel activity and a shared augmented environment for natural awareness. That is, two co-located users who wear see-through head mounted displays see the real partner through the STHMDs as far as their individual coordinates are the same. Once a user changes his/her perspective via a navigation widget, a CG human is displayed in place of the real partner. When the user chooses the see-through mode via the widget, his/her coordinates are automatically changed to those of the partner in about one second, and the view mode is switched back to the see-through one. We also employ two kinds of techniques so as to support spatial collaboration: One is for displaying face direction information and the other is for precise calibration.

Since the effectiveness of an SVE compared with an SAE in terms of multiple perspective is apparent, we have conducted an empirical study to confirm the effectiveness of an SAE over an SVE in terms of awareness. Confirming the superiority of an SAE in both efficiency and feeling of collaboration, the result encourages us to use both an SAE and an SVE for flexible collaboration. We believe seamless view-mode switching is a reasonable and sophisticated approach for integration of an SAE and an SVE. One possible disadvantage of seamless view-mode switching is that users may obstruct each other physically in the SVE mode. However, in our experience, we found users prefer and used well this technique. Owing to the techniques described above, users are able to collaborate within the workspace flexibly and naturally.

Further works include additional experiments to confirm the effectiveness of seamless view-mode switching itself, development of more precise calibration methods and other awareness enhancement techniques.

REFERENCES