Exploring Configuration of Mixed Reality Spaces for Communication

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ABSTRACT
Mixed Reality (MR) enables users to explore a wonderland which is not realizable in the physical world. This provides users with the chance to communicate in many different ways. We present our MR multi-user workstation system to investigate how different configurations of participants and content affect communication between people in the same immersive environment. We implemented mirrored face-to-face communication, side-by-side communication and eyes-free communication by using the presentation tool Chalktalk as the content creation server and designing a multi-user MR environment. We have conducted a preliminary user study for our mirrored face-to-face configuration, evaluating with respect to one-to-one interaction, focus shift and eye-contact. We provide experimental results and interview responses.

KEYWORDS
mixed reality; communication

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Virtual Reality and Mixed Reality (VR, MR) are being explored increasingly, spurred by the availability of high quality consumer headsets in recent years. VR and MR enable rich design spaces in HCI by providing 3D input and immersive experiences. Decades ago, the "Office of the future" was proposed to allow remotely located people to feel as though they were together in a shared office space [9], via a hybrid of modalities including telepresence, large panoramic displays and shared manipulation of 3D objects. The core idea was that VR/MR had the potential to enhance communication among groups of people. Since then, significant progress has been made in exploring techniques for communication [4, 7]. However, less studied is the configuration (see our full definition in table 1) of people and shared manipulable objects in the environment, which may lead to a different communication experience.

In daily life while speaking to others, we commonly use gestures or visual aids to help ourselves present ideas. We might use gestures subconsciously or purposely. Visual aids can be drawn on paper, a whiteboard, or a shared screen (via video chat). A key task for participants in a conversation is the shifting of focus between other participants’ spoken words, gestures and visual aids such as notes and drawings. Smooth transitions in conversations have been found to be important for collaboration [1]. Prior works addressed this with alternative configurations of spaces for communication. [10] built a face-to-face presentation system for remote audiences. ClearBoard [4] created a shared workspace, in which two users can collaborate remotely without losing some advantages of in-person face-to-face interactions. For example, one such advantage relates to learning. When a teacher looks away from the audience, Lanir et al. [6] observed that audiences in a classroom would not focus on the presenter, which might "create a learning environment in which there is no interpersonal engagement between the presenter and the audience, thus reducing learning outcomes." We find that personal engagement, such as one-to-one interaction and eye-contact [3], in addition to focus shift [1], is therefore relevant to evaluating communication experiences.

Still, it is unclear how the configuration of users and content in an MR space affects the communication experience for co-located and distant people. We have implemented a multi-user MR workstation to explore how configuration impacts communication by providing three different configurations: (1) mirrored face-to-face, (2) side-by-side and (3) eyes-free. We conducted a preliminary user-study of our mirrored-face-to-face configuration in which participants experienced a presentation in our system. Afterwards, we proceeded to user interviews in which participants spoke about the face-to-face experience, one-to-one interaction, focus shift and eye-contact.

### RELATED WORK

Quite a few works have contributed to collaborative applications in VR/MR. T(ether) is a spatially-aware display system for co-located collaborative manipulation and animation of objects [5].
attaching trackable markers to pads and the digital gloves, people can use gestures to manipulate objects in space. Virtual Replicas for Remote Assistance is a remote collaboration system, allowing a remote expert to guide local users to assemble machine parts by using virtual replicas. SpaceTime is a scene editing tool designed for multi-user collaboration in VR, allowing either co-located or remote participants. To support conflict resolution in the case where two users wish to work on the same object simultaneously, it created per-user branches of the object, which could later be merged [11]. As opposed to enhancing experiences related to specific tasks, our system aims to enhance the experience of general communication, which can benefit various kinds of more specific collaborative work.

Some previous work contributed to communication in VR/MR too. ClearBoard allows a pair of users to shift easily between interpersonal space and a shared workspace [4]. The key metaphor of the ClearBoard design is “talking through and drawing on a big transparent glass board.” No gaze or eye-contact information is lost while working on the content. ShareVR enables communication between an HMD user and a non-HMD user [2]. By using floor projection and mobile displays to visualize the virtual world, the non-HMD user is able to interact with the HMD user and become part of the VR experience. The work discusses how people with different devices communicate with each other. MMSpace allows face-to-face social interactions and telepresence in the context of small group remote conferences [7]. To achieve this, the system uses custom-built mechanical displays on which images of remote participants are projected, and which move in response to users’ movements. Pairs of participants can maintain eye-contact with each other and remain aware of each other’s focus. In addition to designing specific configurations for the communication in VR/MR, our system provides three different configurations to evaluate how it affects the collaborative communication.

**DETAILED DESIGN AND IMPLEMENTATION**

**Three Configuration Designs.** We implemented three configurations for communication in our system: 1) side-by-side, 2) mirrored face-to-face and 3) eyes-free (see figure 1). We implemented 1) by placing users facing a content board (see full definition in table 1) from the same side.

For 2), the users are face-to-face in the virtual environment with the content board placed between them, so that each sees the other on the opposite side of the content board, left-right flipped as if reflected in a mirror. For a regular face-to-face configuration, the problem is that the content will be left-right reversed on one side of the board. For example, text will be illegible and asymmetric objects will appear differently on one side. The challenge is ensuring all the content is consistent and legible for everyone on either side of the board. ClearBoard [4] implemented “mirror reversal” via video capture and projection techniques to solve a similar problem for 2D displays. **Inspired by that, we implemented a 3D immersive mirror reversal for our MR configuration.** We place the users physically (in the real world) on the same side of the content board and mirror all other users to the
other side. This way, we maintain the correct format of the content and face-to-face information including gaze direction and hand position (see figure 3).

For 3), instead of writing or drawing in mid-air, users can create content in MR by writing while resting their arms atop a horizontal surface in the real world (e.g. table). Being able to rest one’s arms on a surface counteracts the potential fatigue of drawing in mid-air without support for long periods of time. For this configuration, we now have two boards in the MR world: a horizontal drafting board used for writing and drawing, and a vertical board that displays all information in mid-air for all people in a group to see. All content is duplicated onto the vertical board, and we display a cursor on the board corresponding to the position of the user’s hand on the horizontal board. This way, the person using the horizontal board need not look downwards and is free to look at the vertical content board and other people in the group. Freeing users from focusing on the drawing surface allows users to pay more attention to the environment and each other in a shared experience. This configuration can extend 1) and 2) since we can choose where to place the vertical duplicate board.

The MR System. Our system comprises 1) a content creation server, 2) an internal network framework, and 3) VR/MR clients (see figure 2 for a detailed data flow description). 1) To enable interactive content during communication, we chose Chalktalk as our content creation server. Chalktalk is a web browser-based 3D presentation and communication tool, written in JavaScript, in which the user draws interactive “sketches” to express ideas. We designed a generic data (de)serialization protocol to connect and decouple the content creation server and the VR/MR clients, so alternative content could easily be plugged into the system. 2) To ensure communication between different devices, we used Holojam [8], a shared space network framework designed at our lab, written in Node.js and C#. It synchronizes data across devices and supports custom data formats, so we can use our protocol. 3) We implemented the VR/MR clients with Unity to support multiple VR/MR devices.

PRELIMINARY EXPERIMENT

We plan to conduct experiments for each configuration design and to compare the configurations. So far, we have conducted a preliminary user study on our mirrored face-to-face configuration. The user study was conducted with 8 participants (F=4) between the ages of 22 and 26 (M=23.71, SD=1.50), recruited via email and word-of-mouth. The participants were required to have taken a linear algebra class and to have had prior experience with VR/MR. First, we introduced Chalktalk to to participants who were unfamiliar with it to reduce the novelty effect. Afterwards, we gave a presentation on matrix transformations (a concept in the computer graphics curriculum) using our system in the mirrored face-to-face configuration. To create a realistic presentation, we invited a computer graphics professor to present a lesson on matrices, and he permitted us to use his presentation as the basis for our experiment (see the rationale for our choice in topic and the steps in the presentation in sidebar 1). We ran the experience with Oculus Rift headsets. Upon the completion of all sessions, participants
We chose the topic of matrix transformations so participants could see and interact with 3D moving content. For content within the 3D immersive environment, we chose visualization of the way a matrix translates and rotates geometry. During the matrix lecture, the presenter demonstrated matrix transformations, including translation and rotation, by using 3D interactive visualizations from the content server. Then she showed that matrix operations are non-commutative. Here lists the steps of the presentation.

1. The presenter creates a 4x4 matrix object and links it to geometry.
2. Modifying the matrix values rotates the geometry in 3D space, and students are invited to walk around the MR environment to observe from any angle.
3. The presenter creates a second 4x4 matrix for translation, which she composes with the rotation matrix.
4. To demonstrate that matrices are non-commutative, she shows that by changing the order in which the translation and rotation matrices are applied, the geometry's position and rotation change visibly with the same matrix values.

Sidebar 1: Matrix Lecture

completed a questionnaire to gauge their opinion on one-to-one interaction [6], eye-contact [3] and focus shift [1] during the experience. Participants then joined a semi-structured exit interview. All factors were evaluated using the 7-pt Likert scale. The study was recorded with users’ permission.

RESULTS AND FINDINGS

The three main discussion topics during the post-test interviews were "the feeling of one-to-one," "ability to shift focus smoothly" and "eye-contact" (see questions in Table 2 and results in Figure 4).

One-to-one Experience. Most participants felt that it created a feeling of one-to-one interaction with the presenter (6/8 agree or strongly agree). P1(F): "It felt like it was a one-on-one lesson even though there was more than one person there. It felt like the person [the presenter] was right in front of me." P1(F) contrasted the experience with college lecture format in which the lecturer stands to the side, which she considered "more distant". Similarly, P4(F) thought "really felt like a private lesson. It felt like it was one-to-one–like we were together in this."

Focus Shift. Participants responded differently to the question concerning how often they shifted focus between content and the presenter (2/8 very rarely, 2/8 more or less rarely, 3/8 more or less frequently and 1/8 frequently). Those who shifted focus least often (P2, M and P4, F) thought the presenter was always in the field of view and felt that they did not need to shift focus while looking at the content. Most reported that they could follow both content (3/8 agree and 5/8 strongly agree) and the presenter (6/8 agree or strongly agree) well. This suggested that the focus shift between content and the presenter was smooth to some extent in the mirrored face-to-face configuration.

Eye Contact. Some participants did not always want eye contact. P5(M): "you don’t want the presenter to be always looking at you." Others like P4(F) felt it was necessary: "I look at the professor the whole time. That’s the only way I can pay attention." Those who preferred less eye contact (6/8 reported eye contact less than rarely) admitted they felt the presenter was looking at them frequently, but chose to look at the content instead of the presenter. Participants who preferred to have eye contact reported having it more often (2/8 more than half the time). This suggests that our mirrored face-to-face configuration supports eye contact well and that the users chose whether to make eye contact or not.

Findings. Participants also thought that the face-to-face format helped them to concentrate during the presentation. Referring to the front-and-center presence of the presenter’s avatar, P3 said "I don’t think I’d be able to concentrate if I was just listening to somebody. I’d need someone to actually be there." P6(F) also found it easier to concentrate: "It felt one-to-one, so you won’t be distracted by other people." P3(M), P4(F) and P5(M) noted the format also made the experience feel interactive, unlike a video.

CONCLUSIONS AND FUTURE WORK

We have presented our ongoing work, a multi-user MR system for communication. We designed three configurations for MR communication. In this paper, we evaluated mirrored face-to-face configuration
with respect to one-to-one interaction, smooth focus shifts and eye contact. Our user study suggests that the face-to-face format has the potential to facilitate a feeling of one-to-one collaboration. Participants responded positively to being given attention and feeling as though they were working directly with the lecturer in VR. Positioning the presenter in-front helped some participants concentrate.

In the near future, we plan to conduct multiple user studies in which we will compare side-by-side, mirrored face-to-face and eyes-free configurations. We will investigate which configurations are best suited to communication experiences involving presentations, group discussions and collaborative tasks. Additional questions remain to be explored. For example, how does the feeling of one-to-one interaction change with the configuration of the users and content?

Table 2: Questions in Questionnaire

| Q1 | To what degree do you feel it is a one-on-one lecture? |
| Q2 | It is easy to follow the presenter. |
| Q3 | It is easy to follow the content. |
| Q4 | How often did you switch your focus between the presenter and the content? |
| Q5 | How often did you have eye-contact with the presenter? |

![Figure 4: Results for Questionnaire. Each dot (·) represents one participant on a 7-point Likert scale.](image)

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