HoloPort – A Device for Simultaneous Video and Data Conferencing Featuring Gaze Awareness

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ABSTRACT

Complex business processes and globally distributed teams require new means to support net-based teamwork. Here, virtual reality technologies offer new ways to a more intuitive collaboration. In this paper, a system setup dubbed HoloPort is presented, which enables intuitive point-to-point video conferencing between two small groups. The device features gaze awareness between local and remote conferees during video and data conferences, and pen-based on-screen interaction.

After an introduction to tele-collaboration systems, the working principle of the proposed HoloPort is illustrated, and the device's individual components are described in detail. Then, different application scenarios using the HoloPort are discussed. Finally, the paper concludes with an outlook on future improvements.

Categories and Subject Descriptors: H.5.3 [Information Interfaces and Presentation]: Group and Organization Interfaces – Computer-Supported Cooperative Work

Keywords: Video and data conferencing, gaze awareness, computer supported cooperative work, networked collaboration, teleimmersion

1 INTRODUCTION

Following Short, Williams, et al. [1], the principal function of the visual channel in communication is to provide feedback of interpersonal attitudes, characterized as a direct expression of one's attitudes and unconscious feelings. Video conferencing technology opened the visual channel also for distant communication.

The importance of eye contact in the context of video conferencing has often been discussed. According to Kobayashi and Ishii [2], people feel it difficult to communicate when they cannot tell if the partner is looking at them. Eye contact plays an important role in face-to-face conversations because "eyes are as eloquent as the tongue".

Acker and Levitt [3] showed in an experiment that eye contact increases satisfaction within video conferencing as a medium for negotiation. Eye contact allows people to evaluate more confidently their counterparts, and to participate more comfortably in exchanging information.

However, most of today's video conferencing system setups do not allow eye contact between the interconnected partners. Video conferencing participants intuitively talk and gaze into the direction of the image from the remote participant, while the cameras used to capture images of the participants are positioned offset to their gazes. Mostly, this leads to a lack of eye contact between the video conferencing participants.

Chen [4] proposed an appropriate positioning of a standard desktop camera on top of a monitor to allow people to perceive eye contact during video conferences. He is taking advantage of the human tolerance for eye contact, which is up to about 5 degrees of parallax in the vertical down direction.

Ishii, Kobayashi, et al. [5] suggested that even more important than eye contact may be the more general capability called gaze awareness: The ability to monitor the direction of a partner's gaze and thus his or her focus of attention. Eye contact can be seen as a special case of gaze awareness. In experiments, Ishii, Kobayashi, et al. [5] observed complex uses of gaze awareness, e.g. a person continues pointing to a position on the display while monitoring the gaze of the remote partner. This enables a verification that the partner is looking at the correct spot.

Gaze awareness plays an important role if video conferencing is combined with data conferencing, in which the participants are not only talking to each other, but also use an interactive vertical workspace, e.g. for sketching during the discussion. Again, today's video conferencing systems with cameras placed on the side of the display or screen do not allow gaze awareness. Instead of intuitively pointing with their hands to specific data, participants must use e.g. a mouse pointer to show the remote partner what they are talking about. This affects the natural and intuitive working with these tele-collaboration systems.

This paper describes a setup that allows simultaneous image acquisition of a user's front-view, who is standing close to a projection screen displaying a remote partner, and therefore enabling gaze awareness between the two partners connected via a network. The efficiency of the system is shown by a collaborative video and data conferencing application, as well as by a networked group discussion application. The presented work is part of the project *blue-c II*, aiming to develop a modular hardware environment for local and remote collaboration.

2 RELATED WORK

In the field of time-multiplexed image acquisition through and display on a projection screen, previous work was done by Shiwa, Ishibashi, et al. [6] [7] in 1991. They used a phase dispersed liquid crystal (PDLC) screen that is switched with 60 Hz between its transparent and its opaque state. A camera is placed behind the screen and acquires images with periodic shuttering while the screen is in its transparent state. In the opaque state of the screen, a video projector displays the camera's image on the screen, establishing a digital mirror. A recent work using PDLC screens has been presented by Gross, Wuermlin, et al. [8]. They realized a CAVE-like 3D video portal for telepresence with alternating image acquisition through and image projection onto switched PDLC screens.

PDLC screens suffer from a slow transition time from the transparent to the opaque state. One complete cycle of image acquisition and image projection must not take longer than about 16.7 ms (60 Hz) to avoid a flickering projection. Thus, the slow transition consumes important time, while neither an image can be acquired nor displayed. Maintaining a projector duty cycle of 50 % (8.3 ms), the image acquisition time is limited to about 25 % (4.2 ms) of the time of one complete cycle. The remaining time is used for the PDLC to change its state. For image acquisition, this results in rather dark or noisy images even with additional illumination. The quality of the displayed image is also reduced, since the PDLC screen does not become fully opaque anymore when driven with 60 Hz. Furthermore, projecting through an external ferro-electric shutter lowers the contrast of the projected image. Finally, the PDLC requires sophisticated electronics to be switched between its two states.

Time-multiplexing is only one principle for quasi-simultaneous or simultaneous image acquisition and image display at optically the same place. Other principles include optical combination and image synthesis.

In 1993, Kobayashi, Ishii, et al. [2] [5] proposed a system based on the optical combination principle called ClearBoard. For optical combination, a semi-transparent mirror is used. An incident ray on such a mirror is partly reflected by it and partly goes through it. Therefore, the camera and the display can be made to appear virtually at the same position by placing a semi-transparent mirror at an angle of 45 degrees in front of the viewer. This semi-transparent mirror combines the image of the display behind it and simultaneously reflects the user's image into the camera.

Systems based on optical combination require large amounts of space in front of the display, thus leading to bulky setups. Furthermore, the setup imposes restrictions on the viewing angle. A third disadvantage of the optical combination principle is that the camera captures objects close to (but not on) the semi-transparent mirror twice, because then the object itself as well as its reflection on the mirror is seen by the camera.

In another approach, multiple cameras are placed at different positions around the display area for image synthesis. From the images of the different cameras, an image of a virtual camera positioned in the centre of the display area is interpolated. Such a system was presented by Chen and Williams [9] in 1993, but could deal with completely static scenes only. A recent example of image synthesis is the work of Criminisi, Shotton, et al. [10], in which an interpolation between two images of an upper body is made.

Image synthesis is limited to setups, in which the cameras are able to take images overlapping by a certain amount. Experiments we made showed that images do not overlap enough if people are directly in front of large interactive screens like e.g. touch-sensitive whiteboards.

3 Contribution

The basic idea is to use a rear projection screen that's transparency is a function of the angle, at which light rays reach the screen. Several manufacturers provide such angle-dependent transmission screens, which they often refer to as holo screens.

A holo screen is a hologram in the form of a thin film, laminated onto a transparent acrylic or glass plate. The hologram is very selective about the direction from which it receives the light - it only responds to light being rear projected under a particular angle. The holographic film is designed in such a way

that the screen remains transparent at locations with no projected image.

Setups that use holo screens have been published only within the last few years. A first setup using a holo screen was introduced in 2001 by Ogi, Yamada, et al. [11]. However, no image acquisition through the holo screen was provided. In 2004, Wilson [12] presented TouchLight, a touch screen technology based on a holo screen. He acquired images in the IR-spectrum through the screen in order to enable gesture-based interaction. Also in 2004, Matsushita, Iida, et al. [13] presented Lumisight Table, an interactive tabletop using two orthogonally oriented holographic films laminated onto a glass plate as a projection screen. This sophisticated rear-projection screen allows displaying different projected information to each of four users sitting around the tabletop. Finally, the MultiView system presented by Nguyen and Canny [14] in 2005 uses a self-made angle-dependent reflective projection screen. MultiView is a spatially faithful group video conferencing system: Every user at each side can correctly interpret the direction of the gaze of any user in any group. Unfortunately, the MultiView system does not provide any interaction possibility between the conferees.

Considering simultaneous image acquisition through and display on a projection screen, the use of holo screens has two major advantages compared to PDLC screens: (1) Since a holo screen is transparent and opaque at the same time, there is no transition time between these two states of the screen. Therefore higher repetition frequencies or even simultaneous image acquisition and displaying a projected image are possible. This results in a higher quality of the acquired image as well as the displayed image. (2) Holo screens are passive, i.e. they do not have to be synchronized with the image acquisition and image display. This would lead to a reduced system complexity.

However, there are also some drawbacks, which have to be overcome when using such a holo screen. Spurious light captured by the camera reduces the contrast in the acquired image, and therefore must be avoided. On the other hand, the user in front of the holo screen must be well illuminated in order to achieve a high quality of the acquired image. Consequently, proper installation of the light sources is mandatory. Furthermore, the camera must be prevented from the light intentionally emitted by the projector and being partly reflected by the holo screen. Blanking the projection during the image acquisition is done e.g. by an external shutter. Since this reduces the visible frame rate of the projector, one has to ensure that the resulting projection still has a frame rate of at least 60 Hz to avoid flickering. The projector must also feature a sync option allowing the camera and the projector to be synchronized.

Figure 1 illustrates the working principle of the proposed device: The computer graphics card sends a standard video signal to the projector, which throws the respective image via the mirror onto the holo screen. The synchronization unit forces the projector to run at a duty cycle of only 50 %, meaning that it projects a black image for half the time.

During the periods in which there is no projection, the camera behind the holo screen is also triggered by the synchronization unit to acquire images of the user standing in front of the screen. The captured images are sent to the computer, and then transmitted to the remote station via a network. On the remote side, the camera images acquired by and received from the other station are displayed on the holo screen by the projector. This configuration is similar to standard video conferencing, whereat the monitor is replaced by a projector, and the camera is not on top of the monitor, but behind the projection screen.
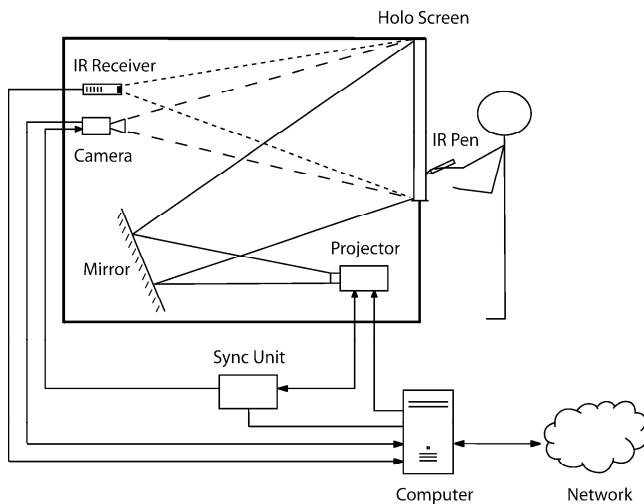
Figure 1: Working principle of the proposed HoloPort setup. A projector is rear-projecting an image via a mirror onto a holographic screen. Beside the image, the projector periodically projects a short black interval. During this time, a camera acquires images through the holo screen. Synchronization of the projector and the camera is done by a sync unit. On-screen interaction is enabled via an IR pen and a respective receiver. An audio system (not shown in the figure) adds audio conferencing capability.

Figure 2 shows one of our HoloPort prototypes, in which we implemented the working principle described above.

4 HARDWARE SETUP

The proposed hardware setup consists of a holo screen, projector, mirror, camera, synchronization unit, infrared (IR) receiver and pen, an audio system, and a computer with network access. Except for the screen, the rack is completely covered with a light absorbing drapery. In the following sections, the individual components of the system are described more in detail.

4.1 Screen

For the holo screen, we used a 67" holographic-optical projection screen (HOPS) from *sax3d.com*. The screen displays incoming light with around 38 degrees of incidence. All other light goes through the screen with attenuation depending on the angle of incidence. Our HOPS provides a horizontal half gain angle of 26 degrees. It further preserves the polarization of horizontally and vertically linear polarized light, which allows passive stereoscopic projections, or alternative projection shuttering methods, as presented by Kuechler and Kunz [15] earlier. However, we do not use any polarized light for the HoloPort setup.

4.2 Projector and mirror

For the projection, a DLP projector must be used. As proposed by Divelbiss and Swift [16], its Digital Micro-mirror Device (DMD) can be used as a light valve by switching all micro-mirrors to the off position. Alternately doing so, the projection is periodically shuttered for the chosen time. However, the projector's hardware and software must be adapted to enable such a DMD-based shuttering, making this feature available to only few projectors at the moment. A projector with 2000 ANSI lumens or more is required, since the periodic shuttering reduces the duty cycle of the projector and therefore lowers the amount of emitted light.

Figure 2: HoloPort prototype. For a better inside view, the light absorbing drapery is removed on one side.

For our setup, we used an F1+ SX+ single-chip DLP projector from *Projectiondesign*. The device provides an image projection at a resolution of 1400 x 1050 pixels, and a brightness of 2500 ANSI lumens in standard operation mode. Color generation is performed using a three-segmented color wheel. The necessary changes in the projector's hardware and software for DMD-based shuttering have been done by *digital IMAGE*.

Figure 3 shows the timings for DMD-based projector shuttering. Signal R2 (bottom) represents the vertical sync signal of the computer graphics card. Since we use a vertical refresh rate of 60 Hz, the synchronizing rising edge of the signal occurs every 16.7 ms. Signal 1 (top) represents the relative luminance of the projected light over time when projecting white (RGB 255/255/255). By sequentially projecting the three primary colors red (RGB 255/0/0), green (RGB 0/255/0), and blue (RGB 0/0/255), the peaks were assigned to the corresponding primary colors. The different levels for each color are a result of the changing sensitivity of the photo transistor used for measuring the luminance. The speed of the projector's color wheel is twice the vertical refresh rate. We set the projector to shutter the projection for every second turn of the color wheel (50 % duty cycle). This gives a periodic black period (K) of 8.3 ms at a rate of 60 Hz.

To keep the overall setup compact, the projection is redirected via a glass mirror with a reflectivity of at least 96%.

4.3 Synchronization unit

Both the projector shutter electronics and the camera shutter need control signals which must be synchronized. The signals are calculated with respect to a sync signal coming from the projector, and generated by a synchronization unit. For programming purposes, the synchronization unit is connected to the computer via RS232. In our setup, the synchronization electronics is assembled on a standard PCIe card and mounted into an empty extension slot of the computer motherboard.

In figure 3, signal 2 (middle) is the camera triggering signal. The rising edge in the signal releases the camera shutter. Since we acquire images at 30 Hz, the camera shutter is released only at the beginning of every second black period.
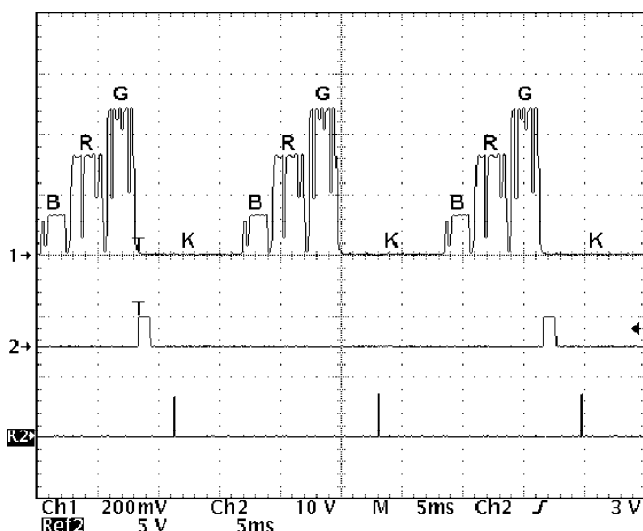
Figure 3: Timings for DMD-based periodic shuttering of a single-chip DLP projector. R2: Vertical sync signal of the computer graphics card. 1: Relative luminance of the projected light. The three primary colors blue (B), red (R), and green (G) are projected sequentially, followed by a black period (K). 2: Camera triggering signal.

4.4 Camera

For our setup, we used an IDS uEye 2210-C CCD USB2.0 color camera from *Imaging Development Systems*.

Color images were taken at 30 Hz with a resolution of 640 x 480 pixels. The camera shutter was externally triggered by the camera triggering signal, and the CCD integration time was set to 8.3 ms via the camera driver software.

4.5 IR Pen and IR Receiver

For data conferencing, it is of use to have the holographic screen interactive. We therefore designed and implemented an interaction device in the form of a pen (see figure 4).

The device is a modified Digitizer Pointer LV-DP11 from *Canon*. The pen gives full control over the mouse position on the holo screen, and includes left and right mouse-click functionality. It emits modulated infrared light from the pen's tip, which penetrates the holo screen, is captured by the IR receiver's CCD line sensors, and is read by a photo diode. The signals are then sent via RS232 to the computer, which updates the mouse position.

The modulated IR light is not affected by the holo screen. The sensitivity of the receiver is high enough to detect the pen even if it is 1 m away from the screen. This also allows using the pen as a pointing device in free space.

4.6 Audio system

For the audio system, we used an AccuMic II video conferencing microphone pad from *ClearOne*. The microphone features echo cancellation and noise suppression. Audio output is made via a common active-loudspeaker stereo system.

4.7 Computer

The whole system is operated by a computer with an *Intel* Pentium IV 3.8 GHz processor running *Microsoft* Windows XP SP2. The computer's motherboard features an onboard high definition audio codec for the audio processing. Graphic output is made by a dual head graphics card. One of the two outputs is

Figure 4: Infrared pen for on-screen interaction. The pen includes left and right mouse-click functionality. The devices' electronics was taken from a commercially available digitizer pointer.

connected to a signal splitter, which simultaneously routs the graphic signal to the projector and a control monitor.

5 APPLICATION SCENARIOS

The HoloPort was designed to support gaze awareness for video and data conferencing between two users at different locations. Furthermore, on-screen interaction and free space interaction are possible with the IR pen. This makes the HoloPort setup suitable for many applications. In the following, two investigated application scenarios are presented to demonstrate how the HoloPort enables a new feeling of remote collaboration.

For our tests, two functionally similar setups were built and connected via TCP/IP. Video and audio conferencing were done using the commercially available *Polycom* PVX 8.0.1 software at 1920 kbps call speed.

5.1 Collaborative video and data conferencing

Figure 5 shows the collaborative video and data conferencing application scenario. The 67" holo screens offer enough space to partially superimpose data atop the remote video stream. This gives the possibility to simultaneously display the remote partner as well as data shared between the two connected stations. This application scenario is similar to the ClearBoard metaphor 'talking through and drawing on a big transparent glass window' introduced by Ishii, Kobayashi, et al. [2] [5].

We investigated two different types of collaborative video and data conferencing. All tests were done with two participants at a time, each standing in front of a HoloPort.

In the first test series, we used the Teamcenter Visualization Mockup 2005 software from *Unigraphics Solutions* to share a JT-model of a mechanical part between the two participants. The Visualization Mockup application window was placed below the center of the display area. Doing so, we made both participants stand centrally in front of the HoloPorts, thus having the sensation of spatially faithful video conferencing with gaze awareness.

By using the IR pen, the conferees could easily perform a remote collaborative redlining task. Three of the twelve test users suggested that pressing the pen tip onto the screen should also trigger a right mouse button event.

Figure 5: Collaborative video and data conferencing by using commercially available collaboration software to share data between the two conferees.

Figure 6: Our CollabStudio software used with an interactive whiteboard during a creativity session without partners joining over a network.

As for every tele-collaboration system, interpersonal distance between the conferees also has to be taken into account for the HoloPort. Our setup creates the impression of participants standing about 1 m apart, which is comparable to the results from the ClearBoard proposed by Ishii, Kobayashi, et al. [5]. Following the studies of Hall [17], they considered this 'personal distance' as appropriate when people use the device with close friends or colleagues. In fact, none of our test users felt uncomfortably close to its respective remote partner, but our user group neither contained persons of much different ranks.

However, there are three drawbacks for this type of collaborative video and data conferencing. (1) Since the user is standing close to the holo screen, he sees the projector lens, which is uncomfortable where a light color or white is projected. (2) Spatially faithful video conferencing is only available in the case where there is exactly one participant at each station, and both standing centrally in front of their HoloPort. As soon as one participant stands at the sides of the screen, the HoloPort setup suffers from the Mona Lisa effect: the displayed representation of the remote participant lies no longer in a line with the local participant's eyes and the camera, resulting in an offset between the remote participant's displayed eyes and the camera. Surprisingly, no test user objected that she or he was distracted in the communication with the remote participant, although they placed themselves not centrally in front of the screen for all the time. They also stated that they're gaze was mostly directed to shared data content displayed on the screen. In fact, such direction can be correctly interpreted by any participant at both sides of the interconnected HoloPorts. We therefore assume that faithful eye-contact is less important for applications based on the ClearBoard metaphor. (3) The application window that displays the shared data occludes the hands of the remote partner during his redlining. For the same reason, pointing with the hand at a specific detail is not visible to the remote partner. Only pointing with the IR pen-controlled mouse pointer can be perceived by the remote partner, but reduces the intuitive handling of the shared data.

Since the third drawback applies only for classic nontransparent application windows, we designed and implemented CollabStudio, a software to support teams during local and remote collaboration creativity sessions. CollabStudio is preferably used together with a system that features a large interactive display, but can also be used e.g. with a TabletPC. CollabStudio allows pinning digital cards of any size and writing onto these cards. The cards are also available in different shapes, as it is known e.g. from the Metaplan method used in creativity team sessions (see figure 6). To support Mind Mapping sessions as well, the cards can be linked together. All digital cards can be shared between software clients subscribed at a server. Therefore, also remote people can participate in a creativity session. In a point-to-point session, the digital pin board (where the digital cards are pinned up) can be set to transparent. Doing so, and by overlaying the CollabStudio software atop the video received from the remote site, one sees the digital cards with a video from the remote site in the background.

Figure 7 shows a user in a tele-collaborative video and data conference using the CollabStudio software during our second test series. Both partners can control the digital cards. Since this application is typically used in creativity sessions, it is important that the system provides continuous gaze awareness to stimulate the ongoing discussion between the collaboration partners.

Since the digital pinboard covers almost the whole display area, the users did not stand centrally in front of the screen all the time. Therefore only gaze awareness, but no faithful eye-contact was provided between the test users. However, in the interviews after the test, again no user objected that she or he was distracted.

However, the video quality provided by the HoloPort did not completely satisfy all test users. Here, more efforts concerning appropriate lighting conditions have to be done to better illuminate the conferees standing in front of the HoloPort.

The presented HoloPort setup could be an alternative for the hardware setup proposed by Everitt, Klemmer, et al. [18] for their Distributed Designers' Outpost, a system to support distributed design collaboration processes. Our software is similar to theirs, which also features an awareness mechanism. However, their projection screen's transparency is very low, and no true image of the collaboration partners can be acquired through the screen and transmitted to the respective remote station. The HoloPort hardware setup is more flexible here, and allows exchanging a real video of the remote partners, which sometimes may be useful. Where a real video would distract the collaboration participants, a simple digital representation of the remote partners (as provided
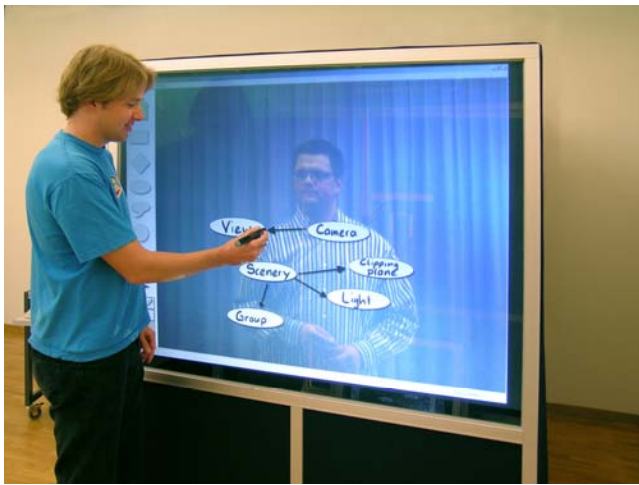
Figure 7: Collaborative video and data conferencing by using the CollabStudio software to share data between the two conferees. The digital pin board was set to transparent, and the application window was overlaid atop the video received from the remote site.

Figure 8: Networked group discussion using two HoloPorts, one for each group. The tables are both placed adjacent to the HoloPorts' screens to give the conferees the sensation of sitting virtually at the same conference table.

by the Distributed Designers' Outpost) could be generated by appropriate processing of the acquired video.

5.2 Networked group discussion

A day-to-day application scenario using the proposed HoloPort is a standard video conferencing situation, where members of two spatially separated groups have a discussion.

Figure 8 shows such a networked group discussion. Each group is sitting at a table in front of a HoloPort. The image acquisition from the camera behind the screen enables gaze awareness between the local and remote participants. Furthermore, if the tables are adjacent to the HoloPorts' screens (as in figure 8), the participants have the sensation of sitting virtually at the same conference table. Together with full screen display of the video stream received from the remote station, this further increases the immersion during the conference.

As shown in figure 8, the participants sit in a certain distance to the screen. The placing creates the impression of local and remote participants sitting about 4 m apart, which is at the limit of the so called 'social distance' of 1.22 - 3.66 m (4 - 12 feet) introduced by Hall [17]. The slightly long distance also reduces the ability to correctly detect, react and interpret the direction of the remote participant's gaze. However, the distant placing provides major advantages too: (1) The Mona Lisa effect is reduced and therefore less disturbing. This is important since the users clearly do look at the displayed remote participants in this application scenario. (2) The conferees do not see the bright and therefore disturbing projector lens behind the holo screen. (3) All participants can sit within the field of the screen's half gain angle, and see the projected video of the remote partners with an acceptable brightness.

Tests concerning networked group discussions were all done with six participants divided into two groups at a time, each sitting on a table in front of a HoloPort. During the tests, gaze awareness between local and remote participants could be verified. All conferees were able to address a specific remote partner during a discussion by simply looking at him or her, although no faithful eye-contact but only gaze awareness was provided to the participants seated off-center. The test users favored the sensation

of sitting virtually at one conference table. None of the 18 test users was disturbed by the fact that the video representation of the remote conferees was horizontally flipped to maintain their correct location. They also accepted the slight lag of the system, which is caused by the conferencing software. The video quality provided by the HoloPort was stated to be alright.

6 Conclusion and future work

A novel hardware setup for simultaneous video and data conferencing was presented. The HoloPort uses a projector and a camera in combination with a holo screen, which allows projection onto an otherwise transparent surface. By using the holo screen instead of a switched PDLC screen, the time available for the camera to acquire an image could be doubled, resulting in an enhanced image quality. The novel shuttering concept using the projector's DMD instead of an external ferroelectric shutter further enhances the contrast of the displayed content.

The HoloPort setup allows video and data conferencing with gaze awareness between the interconnected partners. Two different application scenarios have been presented. In collaborative video and data conferencing, the HoloPort provides faithful eye-contact between two connected users. In networked group discussions, the HoloPort brings two spatially separated groups virtually together at one table, and features gaze awareness between local and remote participants. For both application scenarios, on-screen interaction and free space interaction is possible by using an IR pen. The feedback from first test users performing is promising.

Future research includes the following topics: (1) We want to achieve more favorable lightning conditions to better illuminated users standing close to the screen, and therefore further improve the quality of the images acquired through the holo screen. (2) For an in-depth evaluation of the system, we plan to integrate our HoloPorts into student exercises. (3) We will combine the HoloPort setup with other CSCW hardware, e.g. by replacing the table with an InterActable from *Wilkhahn* to create an L-shape display. The HoloPort was developed as part of a modular hardware environment for local and remote collaboration. We will integrate one of the two devices into our virtual conference room.

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