# Implementing Eye-to-Eye Contact in Life-Sized Videoconferencing

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## ABSTRACT

Videoconferencing systems available for end users do not allow for eye-to-eye contact between participants, also known as a lack of mutual gaze. The different locations of video camera and video display used for video conferencing makes it impossible to directly look into each other's eyes. This, combined with a lack of a life-sized video image of the communication partner makes a videoconferencing session an artificial experience leading to a decreased communication quality, empathy and trust.

First, we present a survey on possible solutions to implement life-sized eye-to-eye contact and discuss briefly their pros and cons. The discussion of the characteristics and limitations of each concept can be used as a guideline for designing videoconferencing systems. Second, we present our own 1:1 scale videoconferencing solution, which builds upon advantages of other approaches while minimizing their disadvantages. Third and final, we report on the experiences made with our system in empirical evaluations.

### Author Keywords

Eye gaze, mutual gaze, eye contact, trust, empathy communication quality

### ACM Classification Keywords

H.4.3 Information Interfaces and Presentation (e.g., HCI) - Communications Applications: *Computer conferencing, teleconferencing, and videoconferencing;* - H.5.3 Group and Organization Interfaces: *Computer-supported cooperative work*

## INTRODUCTION

In an increasingly globalized world real-time communication such text-based chats but especially audio chats and videoconferencing becomes more and more important. It reduces travel times as well as travel costs and leads to more and faster decision-making amongst the communication partners. The ongoing upgrade and extension of the network infrastructure allows to virtually connect any two partners in the world. Together with the increased performance of video encoding and decoding algorithms needed to compress the high resolution signals of the integrated cameras and microphones, video conferencing is nowadays possible at high quality standards. This technology is also extensively used, in particular for private communication such as in Skype[1] or Google Hangout[2]. However, in certain other situations, for instance business meetings with a strong negotiation character, people are often reluctant to use videoconferencing. Despite the availability of business videoconferencing solutions, communication partners often prefer face-to-face meetings though. Possible reasons for the slow uptake are the lack of the integration of collaboration aspects (sharing of artefacts), a lack of support for non-verbal cues (e.g. body language availability) and the limited size of the video of the communication partner combined with the inability of the systems to provide eye-to-eye contact. In particular the latter aspects form the basis for forming empathy and trust-building in a lot of situations – would you agree to a risky million dollar deal without looking into the business partner's eyes?

Bekkering & Shim (2006) found that the absence of eye-to-eye contact in videoconferencing systems is the main factor for the lack of trust: "People associate poor eye contact with deception" (p.103). Furthermore they argue that this is a main reason for the missing large-scale adoption of the technology.

Fox (2005) stresses the importance of eye gaze to indicate another's person intentions, interest in conversation etc. In business meetings (and other "non-chat" situations) this is of high importance. Relationships involving complex tasks can be maintained by increasing the frequency and flow of communication (McKinney &Whiteside, 2006) – this requires the indication of gaze and mutual eye contact. It was shown that systems using communication with eye contact induced behaviour similar to face-to-face communication (Mukawa et al., 2005). In interview situations for instance, perceived eye contact and mental workload were identified issues when using videoconferencing (Ferrán-Urdaneta and Storck, 1997)

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[1] www.skype.com

[2] www.google.com/tools/dlpage/res/talkvideo/hangouts/

In experiments with half-silvered mirrors Quante & Muehlbach (1999) show that users have significantly more often the feeling of being addressed, i.e. of being looked at and recognise that they are addressed. We look at the partners' faces to continuously make sure that they are still with us in the meeting and that we can trust them. Predictive valid faces (targeting the partner) are appearing more trustworthy (Bayliss & Tipper, 2006). Even if we cannot see a real or video-mediated representation of our partners, for instance in Second-Life-like conferencing, gaze awareness with avatars is important (Garau et al., 2000).

However, if people are using videoconferencing frequently, they might learn to interpret gaze direction to a very high degree of accuracy if the equipment is configured optimally (Grayson & Monk, 2003). This is helpful when addressing objects in the environment, but does not provide the perception of eye-to-eye contact. Gamer & Hecht (2007) emphasize the importance of observer distance, head orientation, visibility of the eyes, and the presence of a 2nd head on the perceived direction and width of the gaze cone in videoconferencing. Also, we are less sensitive to eye contact when people look below our eyes than when they look to the left, right, or above our eyes. Additional experiments support a theory that people are prone to perceive eye contact. That is, we will think that someone is making eye contact with us, unless we are certain that the person is not looking into our eyes (Chen, 2002). Those aspects help to mitigate the effects of the lack of (well configured) videoconferencing.

Related to the issue of lacking eye-to-eye contact is the perceived scale of the communication partner. Am I talking to a miniature representation of my partner? Is the partner presented poster-sized? How convincing is the scaled presentation of the communication partner and can we actually maintain eye-to-eye contact within the scaled representation of my communication partner (e.g. with much too small or much too big video faces)? On one hand Okada et al. (1994) found that the size of the communication partner on screen is an important factor for achieving a sense of reality. If the partner is presented smaller than life-size he/she might be perceived as far away. Also, it is difficult to read facial expressions or gestures. On the other hand, a larger than life-sized communication partner in videoconferencing implies dominance. Buxton (1992) suggests that social relationships, such as power, may be more balanced and natural in life-size video conferencing. Detenber and Reeves (1996) found that the display size has an effect on people's arousal, and Lombard (cited in Detenber and Reeves, 1996) found that people evaluated others more positively when presented on large screens (in the right size). There are commercial systems supporting life-sized videoconferencing, e.g. business solution such as LifeSize[3] or the Cisco Telepresence[4] series.

[3] www.lifesize.com

[4] www.cisco.com/en/US/products/ps7060/index.html

In summary, videoconference systems offer a high quality in terms of audio and video performance, but still lack to transport non-verbal communication queues such as eye-to-eye contact and have perception issues such as the 1:1 scale representations of the communication partners. All these factors add to the artificial experience that can arise from existing videoconference solutions.

The underlying, principal problem for the lack of eye-to-eye contact is the positional offset between the capturing camera and the display of the partner's video image. Ideally the camera should sit between the displayed eyes of the videoconferencing partner (see Figure 1).

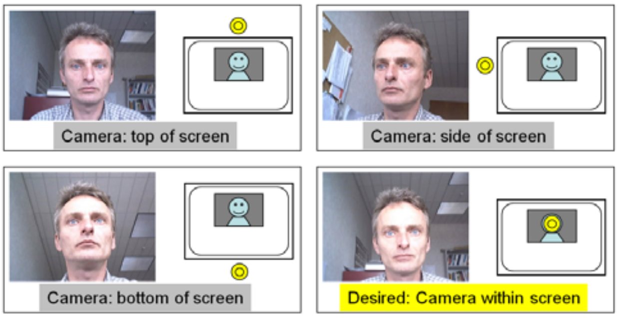


**Figure 1. Eye-to-eye contact: separation of camera and screen.**

Unfortunately, placing a camera at this position would normally block one's view of the partner, which makes the solution unsuitable. As a best practice approach most non-consumer videoconferencing systems try to place the camera as close as possible to the displayed partner video, as for instance illustrated in figure 1 in the top left image. This can be implemented in desktop videoconferencing and in room-like systems. The size of the screen and video image, the distance from the user to the camera and screen and the position of the video image on the screen are the parameters to be considered her. Because of the practical spatial limitations in most environments, true eye-to-eye contact cannot be achieved with this approach. Other technical solutions have to be applied to achieve a real sense of mutual eye contact.

How should a videoconferencing system to be set up to allow maximising empathy- and trust-building needed in many business communication situations? The size of the displayed face of the partner and the provision of mutual eye gaze are important factors to build trust and deliver the basis for high communication quality that is combined with non-verbal communication queues.

In the remainder of the paper we present three contributions: (1) We are surveying different approaches for the implementation of life-sized eye-to-eye contact systems and discuss their pros and cons. (2) We present our own system, which delivers the required characteristics of size and eye contact and finally, (3) we report on experiences made with our system in empirical investigations.

## IMPLEMENTATION APPROACHES

In the following, we present five approaches how to implement eye-to-eye videoconference solutions. To our knowledge, those approaches virtually account for all systems reported on in research and market today. For each approach we describe the technology in brief, give representative references where appropriate and discuss advantages and disadvantages including some guidelines for their application.

We discuss the systems with respect to the achievable size and visual quality of the displayed partner, the environmental constraints, the affordability and the need for specialized components.

### Hole in Screen

The naïve obvious solution is to drill a hole in the screen exactly at the desired position, place a camera there and with this allow for eye-to-eye contact. Apparently this is not a suitable technique for CRT or LCD monitors, but can be implemented with a screen canvas and a projector (Figure 2). The opening and the camera should be as small in diameter as technically possible – the hole will be visible in the very center of the focus of attention between the eyes of the videoconferencing (V/C) partner. Even with very small (i.e. in the order of 5 mm in diameters) cameras the user has to be positioned decently far from the screen to mitigate the disturbing effect of the hole between the eyes effect.

Also, the position of the displayed video stream has to be aligned properly to the fixed position of the hole/camera and the rim of the camera should be painted in the canvas screen color to minimize the visibility of the camera.

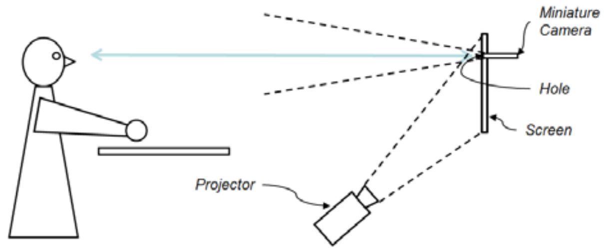


**Figure 2. Schematic of hole in screen approach**

Back projection is generally not possible because of the size and shape of the camera: this would cast shadows on the back projection screen.

Despite the need for a frontal projection the hole-in-the-screen approach allows for an unrestricted interaction space in front of the screen (see Figure 2). It can easily be implemented: all it needs is a projector, an inexpensive canvas (should be inexpensive because one has to drill a hole in it) and a small camera. The main disadvantages are (a) the visible artifact of seeing a (black) spot between the eyes and (b) to minimize the spot effect the user has to be rather far away from the screen which requires much more space and also determines the achievable size of the video face display.

### Long Distance

If the room size permits, eye-to-eye contact can also be implemented by viewing the screen from a far distance and by placing the camera as close as possible (i.e. at the edge of the screen) to the displayed video stream. If the angle between the viewing axis and the eye axis (ß in Figure 3) is small enough then the offset between eyes and camera isn't noticeable.

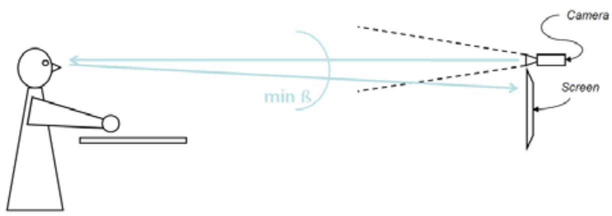


**Figure 3. Schematic of long distance approach**

Experimentation in our laboratory showed that ß should be not much greater than 3 degrees and with this a rather long distance is needed to achieve the desired effect. Hence, if one wants to present a life-sized head (and only the head) and the camera is placed as closest as possible to the rim of the display a distance of at least 3 meters is required (atan (160mm/3000mm) = 3.05°), assuming an average adult head size.

Even if one can free that much space the face of the videoconferencing partner appears rather small. Increasing the screen size to display a bigger face or a bigger portion of the partners' body would increase the angle ß and consequently requires even a longer distance.

A special form of that setup is described by Nguyen and Canny (2007) where they used (in development iterations, starting with half-silvered mirrors (see below)) directional retro-reflective screens in combination with projectors with mirrors to minimize the distance between viewer(s) and screen (18' to 8', ca. 5.40m to 2.40m).

In summary, the long-distance technique is the most affordable one and does not require specialized equipment and calibration. Similar to the Hole in screen approach there is enough room for interactions in front of the display and there are no visual artifacts. However, this technique requires a lot of space. The distance needed between the user and the display does not allow for close communication between the partners, this can only be achieved by much bigger than life-size displays, which is undesirable in most cases.

### Half-silvered Mirror

Using a half silvered-mirror is probably the most common solution in research and on the market to achieve eye-to-eye contact. The user can see through a mirror while being observed by a well-positioned camera at the same time (Figure 4).

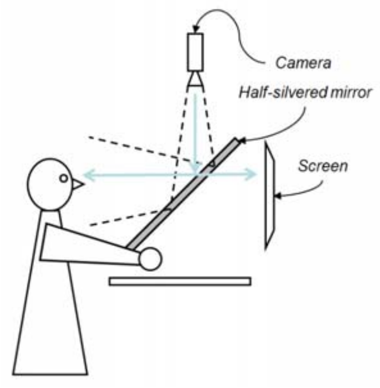


**Figure 4. Schematic of half-silvered mirror approach**

This can be implemented by either placing the camera above or below the mirror and the screen behind the mirror or the other way round by placing the screen above or below and the camera behind the mirror. Figure 4 shows one possible but most common configuration.

The space in front of the user, where usually the desk is, provides only limited access because of the half-silvered mirror placement. However careful positioning, akin to ReachIn[5] setups can produce an interesting interaction space, where virtual objects can be blended with manual interaction (augmented reality interaction space).

Half-silvered mirror solutions in videoconferencing setups have successfully been used by Mukawa et al. (2005), Quante & Muehlbach (1999) and others. There are also commercial solutions available, normally with smaller screen sizes (e.g. iris2iris[6])

The main advantage of half-silvered mirror systems lies in the simplicity of the setup: only the mirror and standard monitor and camera are needed. It needs careful calibration though and usually produces optical artifacts due to the fact that the camera captures only half (or a certain percentage) of the true image of the user. Besides unwanted reflections, the maximum of achievable brightness and contrast levels might be problematic. The main disadvantages are the high price and limited availability of large enough half-silvered mirrors needed for life-size displays and the space occupied in front of the display. While this was of lesser concern with the previously introduced approaches, here and with the following systems, the user should be placed in a way that the camera directly captures the eyes without too much deviation from the ideal spot.

### Video Interpolation

In some prototype systems a computer-vision approach is used to synthesize the views of multiple cameras around the screen to compute an image from a virtual camera place in front of the user's eyes, which is then transmitted to the conferencing partner. Here, two or more cameras are positioned on the sides or corners of the screen (Figure 5). The closer the cameras can be positioned to the targeted screen position the better usually the results.

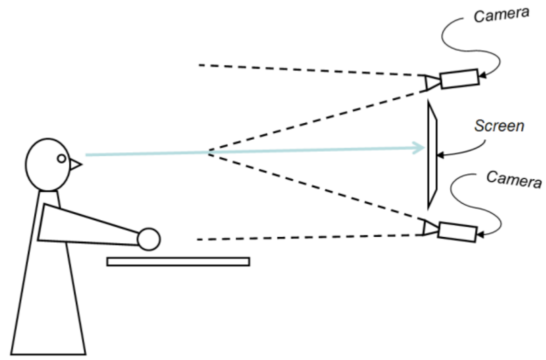


**Figure 5. Schematic of video interpolation approach**

Almost perfect implementations require high quality cameras, careful calibration and a real-time and error-free computation. (Schreer & Kauff, 2002).

Synthesizing videoconferencing images is a vivid area of research (Ott, Lewis, & Cox, 1993) ranging from one or multiple camera systems which artificially replace the eye gaze in the video stream (Jerald & Daily, 2002; Gemmel et al., 2000) to systems which combine a half-silvered mirror with multiple cameras for multi-party videoconferencing (Vertegaal et al., 2003) or videoconferencing systems delivering a 3D-like impression of telepresence (Xu et al., 1999; Maimone & Fuchs, 2011);

Test implementations and studies in our laboratory have shown that one should not expect perfect interpolation results. Humans are very sensitive when it comes to realize subtle artificial elements in other faces. Even the slightest artifacts will be noticed and eventually destroy the eye-to-eye illusion.

Video-interpolation systems allow for life-sized display and close proximity eye-to-eye contact, do not occupy the space in front of the screen and also usually do not require much environmental space and the visual display parameters like brightness, contrast etc. can be very well controlled. As the position of the virtual camera is not fixed the (spatially tracked) user can move to some extent while it is still possible to compute an image, which looks directly into his eyes tracking users' head.

However, solutions using video interpolation require specialized and often expensive hardware and software. Due to the complexity of the vision-based computation of the virtual camera these approaches also introduce perceivable artifacts while realizing eye-to-eye contact.

### Shuttered Screen

As first shown by the blue-C (Gross et al., 2003) and later by the HoloPort (Kuechler & Kunz, 2006) systems a camera can be placed behind a back projection screen to virtually see-through the screen if the screen itself and/or the projection and cameras are shuttered (Figure 6).

[5] en.souvr.com

[6] www.iris2iris.com

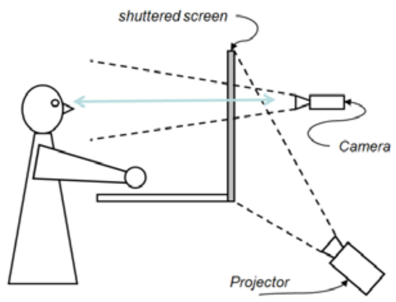


**Figure 6. Schematic of shutter screen approach**

Between update cycles of the system a black projection image is rendered and a camera image is captured. During that period of time the screen is transparent, either because a so-called Holographic Optical Element (HOE) is used as projection surface or a shutter glass is used, triggered to transparent mode synchronously.

A similar, but not shuttered approach uses a "light transmissible screen". A special film/material on the screen is used that allows only passing a certain percentage of light (e.g. MAJIC system by Okada et al. 1994).

This type of installation allows for 1:1 scale videoconferencing but requires (expensive) instrumentation (i.e. shuttered glass). The shuttering (flicker) and the limited achievable transparency of the used screens introduce some artifacts in the displayed videoconferencing video though. Furthermore, the shuttered screen needs some time to fully switch its state and depending on the used screen quality the direction and progress of switching the surface can cause visible artifacts.

In summary, all the approaches presented above are able of producing eye-to-eye contact in videoconferencing and a life-sized display of the communication partner to some degree. There is no optimal solution though: the system might not be affordable (enough), too much environmental space and distance is needed, the interaction space in front of the display is occupied, specialized hardware and software is needed or the visual quality (e.g. flicker, visible artifacts, brightness) is not acceptable for the purpose.

In the following we present the principal setup and report on the evaluation of a system we have developed addressing those issues. The requirements derived from previous studies targeting eye-to-eye contact, body language availability and trust in videoconferencing in non-chat situations (business-type scenarios) (Teoh et al. 2010, Teoh et al., 2011).

### "I2I" SYSTEM

Our own approach is based on the idea of the shuttered screen, but minimizes the artifacts introduced by shuttering the screen and the limited opacity of the screen. When using a standard HOE-based screen in combination with a back projection there are still considerable, not intended reflections and diffusions visible on the back of the screen, which will be captured by the camera.

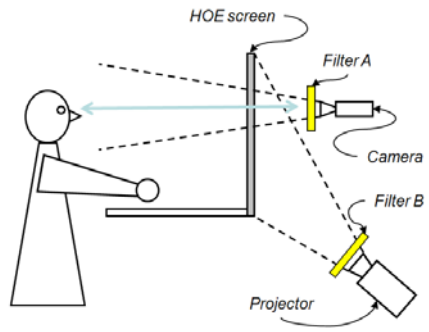


**Figure 7. Schematic of "i2i" (HOE and filters) approach**

Instead of shuttering we are minimizing this effect by using polarizing filters in front of the projector and the camera (Figure 7). These are oriented perpendicular to each other so that the camera does not capture portion of the projected image and light send by the projector. Because the filters as well as the screen do not allow for 100% of the light to pass through we apply simple post processing filtering to increase contrast and brightness to the desired level. Together with carefully positioned lights we achieve a good conferencing quality.

**Figure 8. Our i2i system**

We have produced two identical systems based on our HOE and filters approach. The systems (called "i2i") were tested in symmetrical (i2i connected to i2i) and in asymmetrical constellations (i2i connected to standard desktop videoconferencing systems).

As depicted in Figure 8 we designed a special metal frame construction to hold the holographic optical element (HOE) screen. The used 40" HOE screen can be used in landscape and portrait mode and requires a back projection from a certain, manufacturer specified angle (38 degrees in our case). We can adjust the height of our HOE screen within the frame, either to be used at desks (lower positions) or for standing users (higher positions).

The entire aluminum frame construction is portable on wheels.

Behind the frame/screen a standard PAL camera is positioned on a tripod at eye level and equipped with a polarizing filter. Under the tripod (between the legs) a DLP projector with XGA resolution projects the video stream onto the HOE screen at an angle. Here too, a polarizing filter is used in front of the lens omitting the projected light to be visible for the camera. The projection is sized and keystone corrected appropriately. Projector and camera are connected to a PC running the videoconferencing software. An echo cancelling microphone-speaker system is used for audio communication (black device on desk in figure 8).

To date, there seems to be no ideal solution which maximizes all desired qualities for a certain setting and scenario. We developed a novel solution, which optimizes environmental and interaction space while being affordable and delivering an almost artifact-free, 1:1 scale, eye-to-eye contact videoconferencing solution.

## EVALUATION

In a series of informal and formal, qualitative and quantitative studies we investigated whether the effect of eye-to-eye contact can be achieved with our system and what possible factors might be affected by this.

Our system proved to be technically sound and reliable and to provide life-sized eye-to-eye contact. On the basis of those earlier studies and observations we designed an experiment. We were particularly interested to investigate our main dimension of interest: the influence mutual eye gaze on perceived trust. Is our system able to affect trust ratings and therefore might be suitable for "serious", business-type videoconferencing situations?

To test this we installed our two i2i systems in different locations: one system in Dunedin and the other in Christchurch.

### Task

The task was adapted from Regenbrecht and Hoermann (2008) and Bekkering and Shim (2006): The participants were required to discuss current events (e.g. championships in rugby or soccer) in (a) an honest and (b) an in-honest way. I.e. they had to lie or to tell the truth. This gave each participant something to judge the other participant on and also gave the users enough time to evaluate the communication quality during the session. By making the participant lie or tell the truth, it was assumed that this would contribute to whether the one participant felt trustful or not of the other participant.

### Experiment Design

Twenty people participated in a within subjects experimental design. Each of the participants performed an eye-to-eye and a non-eye-to-eye videoconferencing trial in each experimental session. The eye-to-eye or non-eye-to-eye setup was randomized for both trials of the experiment with the setup (i2i or non-i2i) being switched to the opposite setup for the second trial. Whether the participant lied or told the truth was also randomized with and overall equal number of participants telling either lies or the truth. We investigated the influence of eye-to-eye contact and deception on trust as measured by the ITS (Wheeles & Grotz, 1977) and perceived communication quality as measured by (modified, see below) ITU scales (ITU, 1999).

### Procedure

The participants were recruited using Facebook, word of mouth and by sending bulk text messages. The experimental sessions were scheduled to be carried out over two weeks; each session taking about 30 minutes.

Each participant was positioned by adjusting the position and height of the chair at the table; this was relevant to guarantee the best position within regards to the camera and consequently to guarantee the best eye-to-eye experience for the participants. Once the facilitator determined (initially by flipping a coin) whether the participant was to tell lies or truth, the participants were asked to begin the discussion. The participants were not made aware whether their communication partner was instructed to lie or to tell the truth. The participants were told that they would have at least 5 minutes to discuss their chosen topic, thereafter they were asked by the facilitator to stop their conversations which would end the first trial of the session.

Each participant was then asked to fill out a perceived communication quality and perceived trust questionnaires for that trial, while the facilitators would change the setups of the systems on both ends. Once the participant had completed the questionnaires, they were told by the facilitator whether they would be lying or telling the truth for the next trial. The participants would then perform another discussion of about 5 minutes and once they had reached 5 minutes they were asked to stop the discussion which would end the trial. They were then given the same two questionnaires as after the first trial, with an additional questionnaire about the entire experiment.

### Results and Discussion

The reported trust between the conditions (eye-to-eye; non-eye-to-eye) was not statistically significant ($p = .096$). However, this result gives a slight indication in support of the hypothesis that the implementation of direct eye-to-eye contact in videoconferencing might improve perceived trust. Since we only found a trend, the first assumption made was that due to the small number of participants used in this study the results did not reach statistical significance. Therefore the results have to be corroborated with a larger sample.

The second assumption that we made was that asking the participant to lie or tell the truth would have an effect on the level of perceived trust between participants. To test this assumption we compared the eye-to-eye setup against the non-eye-to-eye setup separately for being lied to by and for truth being told by the communication partner. On one hand, there was no significant difference between eye-to-eye and non-eye-to-eye when the participants were being lied to ($n=11$, $p = .109$). On the other hand, when participants were told to tell the truth there was a marginal significant difference (n=9, p = .052).

There was no significant difference for perceived communication quality (p = .396) between eye-to-eye and non-eye-to-eye. These results do not support the hypothesis that the implementation of direct eye-to-eye contact in videoconferencing will improve the perceived communication quality. We assume that even after making changes suggested by Watson and Sasse (1998), the questionnaire was still not suitable for measuring the perceived communication quality of the system. This was supported by comments from participants asking the meaning of the image impairment and listening-effort and how to use the scales during the experiments. This indicated that there was some confusion when participants were answering the questionnaire on perceived communication quality.

We found some initial support for the notion that the i2i implementation of direct eye-to-eye contact can improve perceived. Our results indicate trends for increased overall perceived trust and perceived trust when participants were being told the truth. However, an improvement of perceived communication quality was not supported by the results of this study. However, the questionnaire might not have been suitable to measure the perceived communication quality of this system.

## CONCLUSION AND FUTURE WORK

We motivated the necessity for the support of trust in business-type remote communication and presented a survey on existing approaches to implement eye-to-eye contact in life-sized videoconferencing. We introduced our own i2i system approach using a holographic optical element screen in combination with polarizing filters implementing 1:1 scale videoconferencing with mutual gaze in high quality by reducing artifacts that were visible in other eye-to-eye videoconference systems. We evaluated our presented system in a real remote communication scenario.

We could show that our implementation does provide eye contact amongst other optimized factors. Supporting earlier work, we could illustrate that perceived trust will increase with eye-to-eye contact in “truthful situations”.

To date we examined two-party situations only, but it would be very interesting to test it with three or more parties. In particular three party conferencing should be considered, because the majority of meetings are held with two or three parties (Wainhouse, 2002)

One could also think of a constellation where the reflection on the screen surface itself, normally an annoyance for users, is used as a mirror. For instance, if an LCD screen is used (e.g. a reflective iMac computer screen), which is inherently polarizing the light, a camera with a polarizing filter properly positioned near the user in a certain angle to a slightly titled screen could deliver the desired effect. This would be an affordable solution, needing not much space and leaving the space in front of the screen unoccupied. The main challenge is the reduction of unwanted artifacts though.

In a not too distant future, technical solutions might arise which implement eye-to-eye contact in a more elegant way (e.g. by placing light sensors in-between light emitting elements in computer displays; Uy, 2009). In the meantime we can and should apply one of the techniques described here and elsewhere to improve the quality of our videoconferencing experiences. We hope that our i2i approach presents a valuable alternative here.

## ACKNOWLEDGMENTS

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