More about MirrorSpace

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ABSTRACT

One of the advantages of video over audio for mediated communication is the ability to transmit non-verbal information. Physical proximity to other people is a form of non-verbal communication that we all employ everyday, although we are barely aware of it. Yet, existing systems for video-mediated communication fail to fully take into account these proxemics aspects of communication. In this paper, we present MirrorSpace, a video communication system that uses proximity as an interface to provide smooth transitions from general visual awareness to very close and intimate forms of communication. After introducing some related work, we provide an overview of the design concept of MirrorSpace. We then present some details of its implementation. Finally, we describe some initial user reactions to this system and conclude with directions for future research.

Keywords

Video communication, proxemics, mirror, visual awareness, intimate communication.

1. INTRODUCTION

One of the advantages of video over audio for mediated communication is the ability to transmit non-verbal information. However, as Grayson and Coventry point out, while many studies have focused on eye gaze and gesture in video-mediated communication, little work has been carried out on proxemics, one of the most fundamental elements of non-verbal communication [1].

The term proxemics refers to the study of spatial distances between individuals in different cultures and situations. It was coined by E.T. Hall in 1963 when he investigated man's appreciation and use of personal space. Hall's model lists four distances which Northern Americans use in the structuring of personal dynamic space [2]: *intimate* (less than 18 inches), *personal* (between 18 inches and 4 feet), *social* (between 4 and 12 feet) and *public* (more than 12 feet)[1]. For each communication situation, there is a distance within these four categories that we find appropriate, based on our cultural background and on the particular context of the situation. If the perceived distance is inappropriate, we become uncomfortable and we usually adjust it by physically moving closer or further away, or even simply turning our head or looking in another direction.

Physical proximity to other people is a form of non-verbal communication employed everyday by us all, although we are barely aware of it. We constantly use space and distance to define and negotiate the interface between private and public matter, particularly during the moments leading up to contact. By altering our physical distance from other people in a space, we communicate subtle messages such as our willingness to engage into dialogue with them, the desire for more intimacy or a lack of interest. As noted by Dunne and Raby, this sense of distance is not only visual but also acoustic and olfactory [3].

The nature of a conversation can often correspond to a particular handling of space. For example, certain feelings or emotions are difficult to share unless the two partners are in the proper conversational zone. Similarly, trying to tell a secret to someone across the street is not only difficult but also somehow negates the confidentiality of the message. Existing systems for video-mediated communication fail to take into account the proxemics aspects of communication. Although some of the people who designed the systems understood the importance of these aspects, they failed to fully provide the support they require.

In this paper, we present MirrorSpace, a video communication system that uses proximity as an interface to provide smooth transitions from general visual awareness to very close and intimate forms of communication. The rest of the paper is organized as follows. After introducing some related work, we provide an overview of the design concept of MirrorSpace. We then present some details of its implementation. Finally, we describe some initial user reactions to this system and conclude with directions for future research.

2. RELATED WORK

Most video communication systems are based on a glass pane metaphor. VideoWindow [4] probably best illustrates this concept, displaying remote people as life-sized images on a large vertical surface and thus making them appear as if they were seen through a virtual window. The glass pane metaphor provides a sense of shared space and supports gesture-based communication. However, the authors of VideoWindow also point out that even with life-sized images, the psychological distance to someone at the other

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[1] 18 inches is about 45cm, 4 feet is about 1,2 meter and 12 feet is about 3,65 meter.

end of the system is still greater than that in a comparable face-to-face situation. They conclude, "In spite of its value, VideoWindow does not provide the same degree of social intimacy as face-to-face interaction".

One of the reasons explaining this is that the commutative properties of face-to-face interaction (i.e. I can see/hear you if you can see/hear me) are usually hard to preserve in video communication systems. In particular, the distance between the camera position and the image of a remote person's eyes can make eye contact and gaze awareness a real challenge. As the camera is usually placed on top or aside the display, the remote people never seem fully engaged as they always appear to bee looking slightly off, in another direction. In order to give the impression of looking into someone's eyes, one has to look at the camera and thus can no longer see where the other person is looking.

A number of solutions to gaze awareness problems have been proposed. MAJIC [5], for example, uses a camera placed behind a large semi-transparent display screen to support eye contact in multiparty videoconferences. In [6], Buxton and Moran relate how Smith and Newman managed to put the camera right in the line of sight by placing a mirror and a half silvered mirror in front of a monitor, creating what they called a Reciprocal Video Tunnel. ClearBoard [7] uses a similar mirror-based technique to put the camera behind the display surface and supports both eye contact and gaze awareness in close collaboration situations based on shared drawing.

As a cultural artifact, the mirror has a prominent position in the creation and expression of aesthetics. Throughout Western culture narratives such as the Narcissus myth, Snow White (the Grimm Brothers) or Through the Looking Glass (L. Carroll), it has come to many different meanings including vanity, deception, identity or a passage to another world. Unsurprisingly, a number of interactive art installations have picked up on these meanings and taken advantage of the universal and irresistible fascination for self-image. Examples of these works include Videoplace [8], Liquid Views [9], Mass Hallucinations [10], the Electronic Mirror [11] and the Wooden Mirror [12].

Instead of the glass pane metaphor chosen by VideoWindow, MAJIC and ClearBoard, several systems have used a mirror metaphor to provide seductive and pleasant-to-use interfaces to video communication services. HyperMirror [13], for example, shows the images of local as well as remote participants on a single screen, making them believe they are all in one room and looking at themselves in a mirror. Reflexion [14] is a similar system that adds audio and video analysis to track which participant is speaking and singularize his or her image. The Well [15] also uses a mirror-like video projection system - but this time, horizontal - to support informal interactions between small distributed groups of people. The mirror metaphor offers an interesting potential to attract people to a video-based system and invite them to interact with it. As demonstrated by [13], it also helps reduce the psychological distance between local and remote participants by displaying them side-by-side.

No matter the metaphor, virtual window or mirror, the interpersonal distance perceived by participants determines in great part the suitability of a video communication system for a particular context. ClearBoard, for example, creates the impression of standing about one meter away from the other person, which corresponds to the personal distance of Hall's classification. This has a number of implications [7]. First of all, although perfectly suited for use with friends and colleagues, this distance might seem too small for a formal meeting with a person of a higher rank. Another consequence is that while ClearBoard makes it easy to establish eye contact, it also makes it difficult to avoid. Users of VideoWindow experienced the same problem and "went to great lengths to avoid eye contact" when they wanted to avoid conversation [4].

ClearBoard authors suggest that the media (i.e. the video communication system) could provide users with some control over the virtual (perceived) interpersonal distance [7]. As noted by MAJIC authors, this distance is influenced by many factors such as the spatial distance from the display, the size and quality of the video images, backdrops or voice fidelity [5]. In [16], Grayson and Anderson show that perceived proximity can be affected by changes in camera zoom. The potential exists for proximity as a form of non-verbal communication to affect behavior in video-mediated interactions. Yet, very little work has been carried out on the control over perceived proximity.

Over the last few years, a number of systems have been designed to support lightweight, intimate and emotional communication over distance. Most of these systems use haptic sensing and feedback to convey information [17, 18, 19, 20, 21]. Some of them also use lighting, sound, temperature or even scent [19, 21, 22]. Surprisingly though, none of these systems uses the images of the participants. According to [23], intimacy deals with the subjective match between the behavior of a device and the operation of that device: when a person has a high degree of intimacy with a device, they can communicate ideas and emotions effectively through it as if it were an extension of themselves. Therefore, in order to support intimate communication though a video system, the challenge might be to create an intimate relationship between the users and the system.

3. MIRRORSPACE CONCEPT

MirrorSpace was originally conceived as a prototype for the interLiving[2] project of the European *Disappearing Computer* initiative. A first video mock-up illustrating its design concept was made in August 2002. Two prototypes were then created and presented to the public as an interactive video installation in four art exhibitions, in February, May, July and November 2003.

The MirrorSpace project aims at creating an original personal video communication system that takes physical proximity into account. Whereas existing systems aim at creating a single shared space corresponding to a particular interpersonal distance, the goal of MirrorSpace is instead to create a continuum of space that will allow a variety of interpersonal relationships to be expressed. Our work focuses on the understanding of how people's interactions can trigger smooth transitions between situations as extreme as general awareness of remote activity where anonymity is preserved to intimate situations where people can look into the eyes of a remote person. By observing behaviors in the real world and conceptualizing distance as a relative variable, we aim at using the existing language of proximity as an interface to the video communication system.

As the name suggests, MirrorSpace relies on the mirror metaphor. Live video streams from all places connected through the system are superimposed on a single display on each site so that people see their own reflection combined with the ones of the remote persons. A real mirror is already perceived as a surface for mediating communication with its own rules and protocols. As an example, making eye contact with a stranger through a mirror is usually considered less intrusive than direct eye contact. Since the mirror is already associated to this idea of reaching out to other people and other spaces, we believe it is the ideal enabling metaphor for establishing a new communication experience.

MirrorSpace prototypes display images of the participants and thus require at least one camera. As we aim to support intimate

[2] http://interliving.kth.se/

Figure 1: MirrorSpace installation at Jeune Création (Paris, February 2003)

forms of communication, it felt important to us that people could actually look into each other's eyes and possibly merge their portraits into one, so the camera was placed right in the middle of the screen. This setup allows participants to come very close to the camera while still being able to see the remote people and interact with them.

In addition to the camera and the display, MirrorSpace prototypes include a proximity sensor that measures the distance to the closest object or person in front of it. This distance is used by MirrorSpace to alter the remote images displayed, and possibly the local one. A blur filter is applied on the images to visually express a distance computed from the local and remote sensor values. Blur is one of the most commonly experienced form of visual perspective: objects in a visual plane other than the one on which the eyes are focused are seen less distinctly [2, 24]. Blurring distant objects and people in MirrorSpace allows one to perceive their movement or passing with a minimum involvement. It also offers a simple way of initiating or avoiding a change to a more engaged form of communication by simply moving closer or further away.

4. IMPLEMENTATION DETAILS

Two MirrorSpace prototypes were built for the first art exhibition where they were presented to the public during 11 days (Figure 1). These units were slightly modified before the second exhibition where they were presented during 24 days (Figure 2). They were not modified before the third exhibition which lasted 20 days. Two new prototypes including minor modifications were made before the fourth exhibition that lasted 51 days (Figure 3). In the following, we describe the hardware and software parts that were used to build and operate these two prototypes.

4.1 Hardware Configuration

Each MirrorSpace unit is made of a 19" TFT LCD flat screen, a camera, a proximity sensor and a computer that runs dedicated software. The prototypes have been designed to minimize their technological appearance so they can discreetly blend in their environment. The screen and its attached sensors are placed into a wooden box, protected by a transparent glass. The computer is hidden in another wooden box. The wires running between the two boxes are tied together. Ideally, the computer box and the wires should be hidden from users, although it was not the case for the first exhibition.

As one can see on Figure 1, the screen was initially oriented in landscape mode. After the first exhibition, we decided to change the orientation to portrait mode and part of the protective glass was covered with a real mirror film. The installations for the second and third exhibitions allowed us to actually hide the wires and computer

Figure 2: Mirrorspace installation at Mains d'Oeuvres (Paris, May 2003)

Figure 3: MirrorSpace installation at the Centre Pompidou (Paris, November 2003)

boxes. Together, all these changes contributed to push further the augmented mirror metaphor.

Standard USB webcams usually consist of a CMOS or CCD image sensor, a lens holder and a lens, and a logic board to communicate with the computer and possibly process the images. The image sensor itself is very small. The size of the lens holder and the lens is also quite small, about 1cm diameter. We took a Philips ToUcam Pro[3], disassembled it and placed the image sensor with the lens in the center of the screen. We connected the sensor back to the logic board using hair thin isolated wires running over the screen surface. As early informal tests quickly confirmed, the lens is hardly noticeable once placed onto the screen since people are generally focused on the images displayed rather than the screen itself.

The proximity sensor used is a Devantech SRF04[4]. It is a compact micro-controlled ultrasonic range finder that measures distances between 3cm and 3m. The sensor was placed at the bottom of the screen and connected to a Parallax BASIC Stamp chip[5] itself connected to the computer via a serial interface. The Stamp chip is programmed to send a normalized distance value between 0 and 255 over the serial line every time a change is detected in the value given by the ultrasonic sensor. Figure 3 shows a close-up of one screen with sensor locations indicated.

The computers used for the first three exhibitions were two Apple PowerMac Cubes each equipped with a 450 MHz G4 processor, 256 MB of memory and an ATI Rage 128 Pro graphics card. They were replaced for the fourth one by 2.8GHz Pentium IV machines with 2GB of memory and an NVIDIA GeForce FX 5200. A 100 Mbits/sec Ethernet network was set up to connect the two prototypes.

4.2 Image Capture and Proximity Sensing

[3]http://www.pc-cameras.philips.com/
[4]http://www.robot-electronics.co.uk/
[5]http://www.parallax.com/

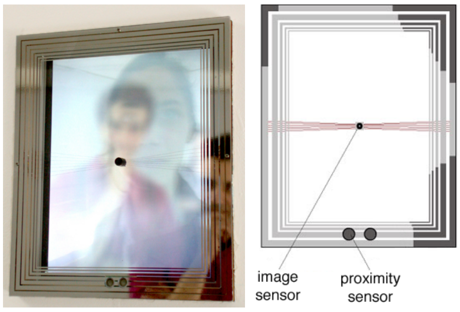


Figure 4: Location of the image and proximity sensors

Figure 5: Sample composition of two MirrorSpace images

The software used by MirrorSpace is written in C++ and uses the videoSpace library [25] to capture SIF images (320x240 pixels) from the camera in real-time. In addition to real-time image sources, videoSpace also supports networked and pre-recorded streams. During the development of the software, this facility was used to test several versions of the blur filter on the same pre-recorded movie. This might also be used in the future to mix live MirrorSpace images with pre-recorded streams or images from other real-time sources.

In a similar way, the software does not make any assumption on the nature of the proximity sensor. In addition to the serial-based ultrasonic sensor, two other classes of sensors were implemented for debugging purpose: a keyboard-based simulator and a random one based on a coherent noise function [26]. In fact, a microphone could even replace the proximity sensor so that the sound level, and not a distance, would control the blur effect. This, however, would radically change the nature of MirrorSpace.

4.3 Networking Aspects

Although only two were used for the exhibitions, the MirrorSpace software doesn't make any assumption on the number of connected prototypes. Each instance of the program uses the Multicast DNS and DNS Service Discovery technologies from the IETF Zeroconf Working Group[6] to automatically find other instances running on the same network. This makes MirrorSpace a plug-and-play networked application: there is no need to specify any IP address or port number and new instances can be added or removed at any time.

A UDP multicast group address allocation server is automatically started by the first instance launched if none was available on the network at that time. When launched, each instance requests an address from this server and announces it through the Multicast DNS service[7]. Proximity sensor values and images captured by the unit are then sent on the network using that address with a best-effort strategy (images are transmitted as JPEG data compressed to fit in a single datagram).

As they are multicasted on a publicly announced group address, sensor data and images from one unit are available to all the other MirrorSpace instances running on the same network. In addition, they are also available to any other program running on that network. This allowed us to develop an application that saves the graphical composition of the MirrorSpace images into a file instead of displaying it on a screen. We also developed another application that makes the composition of a MirrorSpace installation available on the Internet as a set of periodically updated pictures or as a video stream. These two applications helped us monitor the installations more easily and thus eased their documentation.

Multicast DNS is intended for use on small networks with no infrastructure support. Although this approach is very flexible and allowed us to experiment with different configurations including one with 5 instances running, it cannot be used on a wide area network. In order to simplify this, we have implemented another application that can be used as a long distance relay between two MirrorSpace prototypes: this application behaves locally as a traditional MirrorSpace instance but uses TCP connections to forward images and sensor data to and from a similar distant relay. Each relay has to know the IP address and port number of the other one.

4.4 Image Compositing

The MirrorSpace software uses OpenGL to display a graphical composition created from the sensor values and images of the local unit and the remotely connected ones. The compositing process applies a blur filter on the image of each unit and superimposes them using alpha blending (Figure 4). The resulting composition is flipped horizontally before display to produce the expected mirror effect.

The proximity sensors give the MirrorSpace application values between 0 (close) and 255 (far away). A function specified at run-time re-scales these values between 0 and 255. This function provides a way of configuring a MirrorSpace unit for the particular place where it is installed. As an example, the function can reduce the active sensor range by mapping all values greater than a certain threshold to 255.

The blur effect is implemented with a box-filtering algorithm based on a two-pass incremental motion blur (the first pass does a horizontal blur, the second a vertical one). The size of the filter (i.e. the number of neighbors taken into account for one pixel) determines the blur level: the bigger it is, the more blurred the image will be. However, the complexity of the algorithm depends only on the image size and not on the filter size. In other words, blurring a lot does not take more time than blurring a little.

The scaled sensor values of all the connected prototypes are used to compute the blur level to apply to each image. Three computation modes have been investigated so far. Although the software allows us to choose a different mode for each unit, the configurations used for the three exhibitions imposed a strict WYSIWIS condition (*What You See Is What I See*). The first mode uses the distance between people and their screen, the second one uses the sum of these distances, the third one computes a virtual relative distance from them.

4.4.1 Using the distance between people and their screen

[6]http://www.zeroconf.org/

[7]the multicast address allocation server also announces itself through the Multicast DNS service, so it can be found by MirrorSpace instances, whatever machine it's running on

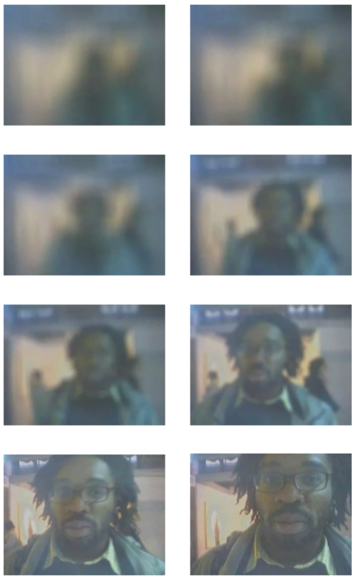
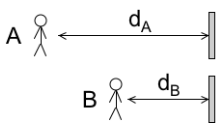


Figure 6: Blur filter of the first kind applied to images showing a person approaching the sensor

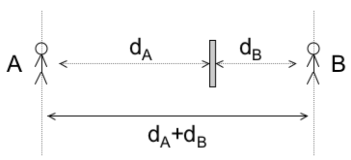
In this mode, the blur level of an image depends only on the corresponding sensor value. Hence, in the situation illustrated below, the image of A would be blurred in proportion to dA and the image of B would be blurred in proportion to dB.



This mode is the one that we used during the four exhibitions. It is quite intuitive as it corresponds to what we expect from our experience with real mirrors: objects and people close to the mirror are better perceived than those far away (Figure 5). It also allows people to slowly disappear as they move away from the screen.

4.4.2 *Using the added distances between people and their screen*

In this mode, the local image is not blurred. The blur level of the other images depends on the sum of the corresponding sensor value and the local one. In the situation illustrated below, A (resp B) would see B (resp A)'s image blurred in proportion to dA+dB.



This mode is interesting because it allows people to move forward or backward to alter not only their own image but also the image of the remote persons. By moving away from the screen, one can still slowly disappear. However, in this case, the other people can follow that person to a certain extent.

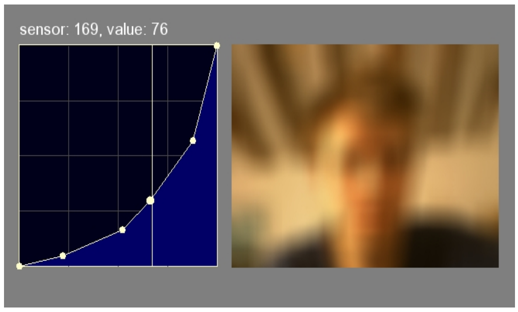
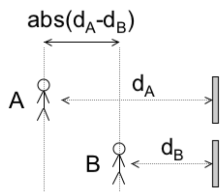


Figure 7: Graphical interface used to specify the re-scaling function. The yellow vertical line indicates the current sensor value. Control points can be added, moved or deleted using the mouse

4.4.3 *Using a virtual relative distance between people*

In this mode, as in the previous one, the local image is not blurred. The blur level of the other images depends on the difference between the corresponding sensor value and the local one. In the situation illustrated below, A (resp B) would see B (resp A)'s image blurred in proportion to abs(dA-dB).



We believe such a mode would allow having multiple "islands" of communication aligned in front of the sensor. However, a lot of space and more than two prototypes are needed in order to experiment with this mode, which is why it hasn't really been tested yet.

4.5 Configuration Management

As we have seen, a number of parameters affecting the software operation can be specified at run-time including the video source, the sensor type, the sensor re-scaling function and the composition method. In order to facilitate the development and testing of the software, a small interface has been written in Tcl/Tk that allows to edit and test a configuration and save it into a file for later reuse.

An OpenGL-based interface has also been developed to allow non-programmer users to specify a re-scaling function by giving a set of points between which the function is linearly interpolated (Figure 6).

5. INITIAL USER REACTIONS

During the first exhibition, the two MirrorSpace prototypes were placed inside a 3x3m cubicle. People in front of one unit could directly see and hear people in front of the other one, which made it easier for them to understand the nature of the system (it was even possible to be seen by the two cameras at the same time). During the second exhibition, the two prototypes were separated by a thin wall so that people could still hear without being able to see each other directly. For the third exhibition, we tried to completely isolate the two prototypes from each other. Finally, for the fourth one, the two prototypes were placed back to back.

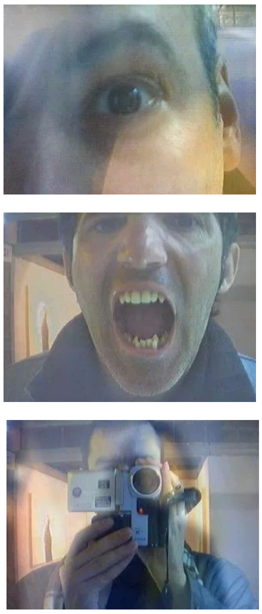


Figure 8: People playing with MirrorSpace

Figure 9: People trying to overlay their faces

Several hours of video were shot during the exhibitions, showing both visitors interacting with the prototypes and what was displayed on the screens. Although the context of these exhibitions is not exactly representative of a traditional remote video communication, a number of observations are worth reporting as they are probably related to the nature of MirrorSpace itself rather than this particular context.

As we mentioned, the prototypes presented at the first three exhibitions were based on two PowerMac Cubes. Although these computers were powerful enough to run our specific software, their modest performance introduced a small delay – up to 500 milliseconds – between the capture and the display of images. As we were testing the software, we tried our best to reduce this delay. However, it turned out that most people didn't pay attention to it and some of them did like it: they were running back and forth to play with their own image and see the blur effect in action. Some even thought the delay had been introduced on purpose. This underlines the important difference between the technical preoccupations usually associated with digital video and a system like MirrorSpace that focuses on the use of the images and user experience.

Artists like Dan Graham already used time-delay mechanisms in mirror-based installations to allow viewers to see themselves as both subject and object [27]. We believe that one of the reasons why people were not bothered by the delay is that it affected both the remote person's image as well as their own and was thus immediately perceived and understood. However, it is not clear whether the understanding would be the same in the case of a real remote communication. This will definitely be investigated in the future.

Almost all visitors of the exhibitions agreed on one point: interacting with MirrorSpace is fun. Proximity sensing helps creating an intimate relationship between users and the system. As we said, many of them played with their own image and the blur effect. One fireman who was there on duty reported that he liked to ”dance in front of the mirror” on his own from time to time. People didn't hesitate to make a fool of themselves and many took pictures or recorded video clips of themselves and other people interacting through the system (Figure 7).

When they saw another person appearing next to them on the screen, many people turned over, looking for that person behind them. This clearly shows that the superposition of the images creates a sense of sharing the same space. It also shows that MirrorSpace is perceived as a mirror and not as a remote video communication system. In fact, the majority of the people didn't think about the camera at all. Only after playing with the system for some time, they suddenly asked surprised ”where is the camera?”. Similarly, many people thought that the blur effect was due to the camera optics and were surprised when we showed them the box containing the computers and explained that was where the magic happened.

The superposition of the images allows not only to share space but also to become one. People who were visiting the exhibitions with friends or relatives immediately understood that and tried to overlay their faces (Figure 8). Some went as far as kissing each other. At the same time, other persons were surprised and even disturbed to find strangers able to come so close to them. In that case, they simply backed away, which made their own image disappear smoothly with the blur effect. This strongly differs from systems such as ClearBoard or VideoWindow where eye contact is difficult to avoid. It shows that MirrorSpace can be used as an intimate communication device and, at the same time, supports at least part of the body language we are used to.

6. DIRECTIONS FOR FUTURE WORK

One important step for future studies of MirrorSpace will be the building of other prototypes that will allow us to experiment the different blur level computation modes with more participants. We plan to deploy and demonstrate the system in various contexts (e.g. other art exhibitions, family households, different buildings of the same research unit). This should help us collect more qualitative and quantitative data about the use of this system. In particular, it should be easy to measure the actual time people spend at each distance according to Hall's classification.

On the software side, we are refining the code responsible for reading ultrasonic sensor values. The basic idea is to interpolate between consecutive values instead of using them directly to prevent fast and big changes and impose smooth transitions instead. This should make the blur effect feel more natural in the future. We plan to add some gamma correction code to deal with poor lighting conditions. We also plan to modify the network bridge application so that it can connect groups of MirrorSpace prototypes instead of only couples.

One thing we learned from the exhibitions is that we still need to improve the industrial design of MirrorSpace. Our ultimate goal is to create a communication appliance that gradually fades from the real physical world to the virtual one. The boxes containing the screen and the sensors are being redesigned in that perspective. Some lighting might be integrated into them. The 19" flat screens are being replaced by 24" ones. We are investigating different technologies that would allow us to embed the image sensor in the protective glass itself.

We are also working on the design of an auditory equivalent to MirrorSpace that might be combined with it in future installations. In its current state, it consists of a program that gets proximity sensor values from the multicast channels, translates them into MIDI commands and sends these commands to a running Max/MSP[8] application. This application is then able to synthesize artificial sounds or process audio signals recorded from a set of microphones. The challenge here is to design an equivalent to the blur effect that would provide general audible awareness of people far away from the sensor and spoken communication with them as they move closer.

7. CONCLUSION

We hope that this paper will help researchers and practitioners realize the importance of the understanding of proxemics for the design of video-mediated communication systems. We have shown that existing systems fail to take these proxemics aspects into account. We have introduced MirrorSpace, a new system that uses proximity as an interface to video-mediated communication. The design concept of this system as well as details of its implementation have been described. We have also described some user reactions to presentations of the system that were made during several art exhibitions. These initial reactions show that MirrorSpace supports smooth transitions from general visual awareness to very close and intimate forms of communication. We strongly believe that the use of proximity as an interface to computer-mediated communication is a promising research direction. We plan to continue this work on image-based communication and to apply the ideas described in this paper to other forms of communication as well.

Availability and Acknowledgments

MirrorSpace software and the videoSpace toolkit are available in source code from http://insitu.lri.fr/roussel/ A video presenting MirrorSpace is also available from this Web page.

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