ClearBoard: A Seamless Medium for Shared Drawing and Conversation with Eye Contact

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ABSTRACT

This paper introduces a novel shared drawing medium called ClearBoard. It realizes (1) a seamless shared drawing space and (2) eye contact to support realtime and remote collaboration by two users. We devised the key metaphor: "talking *through* and drawing *on* a transparent glass window" to design ClearBoard. A prototype of ClearBoard is implemented based on the "Drafter-Mirror" architecture. This paper first reviews previous work on shared drawing support to clarify the design goals. We then examine three metaphors that fulfill these goals. The design requirements and the two possible system architectures of ClearBoard are described. Finally, some findings gained through the experimental use of the prototype, including the feature of "gaze awareness", are discussed.

INTRODUCTION

A whiteboard (or blackboard) is probably the most typical shared workspace in an ordinary face-to-face meeting. Fig. 1 shows a snapshot of a whiteboard being used in a design session. Participants are concurrently drawing on and pointing to the whiteboard, while speaking and gesturing.

In a design session, the participants' focus can change dynamically. When we discuss concrete system architectures, we intensively use a whiteboard as a shared drawing space by drawing diagrams, marks, and pointing to them. The whiteboard serves as an explicit group memory that each participant can see, point to, and draw on simultaneously [9]. On the other hand, when we discuss abstract concepts or design philosophy, we often concentrate on the partner's face while talking. In face-to-face conversations, mutual gaze (eye-contact), facial expressions and gestures provide a variety of non-verbal cues that are essential in human-human communication [2]. Through the use of TeamWorkStation in design sessions [6], we realized that a smooth transition between face-to-face conversations and shared drawing activities is essential in supporting a dynamic collaborative process.

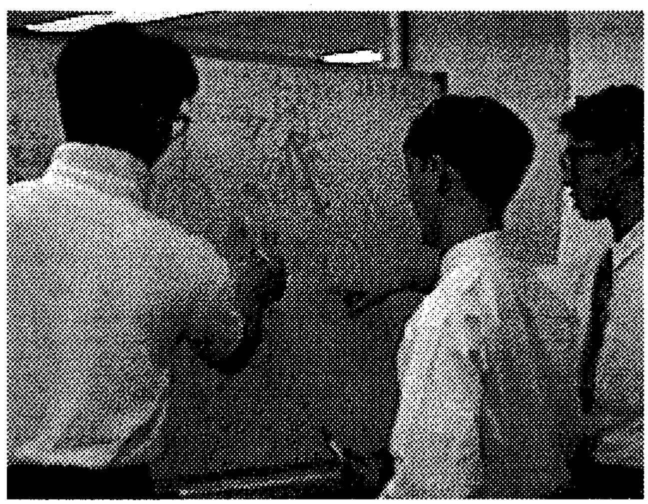


Fig. 1 A Whiteboard used in a Design Session

When we design a medium to support these activities, it is not sufficient to simulate the whiteboard function only, the simple video phone function only, or even both functions. It is necessary to integrate a virtual whiteboard with face-to-face communication channels *seamlessly* so that users can switch their focus smoothly from one to another according to the task contents [3].

In a face-to-face meeting, the room is perceived as a *contiguous* space: there are no physical *seams* between the whiteboard and the participants. By simply moving their eyes or heads, participants can look at both other participants and the whiteboard. However, in existing desktop tele-conference systems with shared drawing functions, the participants' images and shared drawing images are usually dealt with separately. These images are displayed in different windows on a screen, or in different screens. Therefore, there are *seams* between the images of participants and the shared drawing images. The virtual meeting space was segregated into several spatially separated windows or displays.

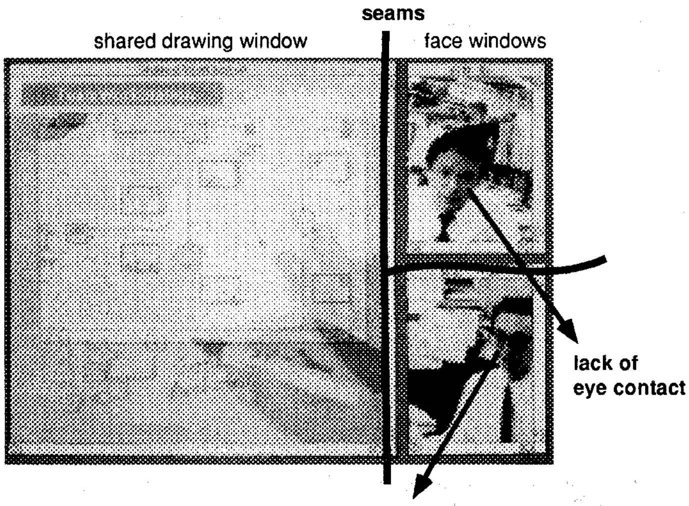


Fig. 2 Seam and Eye-Contact Problems in TeamWorkStation

Lack of *eye contact* has been another problem of existing desktop video conference systems. People feel it difficult to communicate when they cannot tell if the partner is looking at him or her. Eye contact plays an important role in face-to-face conversations because "eyes are as eloquent as the tongue." Fig. 2 illustrates these two problems: seams between windows and the lack of eye-contact in a shared screen of TeamWorkStation [8].

In order to solve these problems, this paper presents a novel shared drawing medium, ClearBoard. ClearBoard realizes both (1) seamless shared workspace and (2) eye contact. ClearBoard is designed to support realtime and remote collaboration by two users. Therefore, it can be called a "pairware" instead of "groupware" [11].

This paper first reviews previous work on shared drawing support and clarifies the goals of this research. We then examine three metaphors that fulfill these goals. The design requirements and system architecture of ClearBoard prototype are described. Finally, some findings gained through the experimental use of the prototype are discussed.

PREVIOUS WORK

As shown in Fig. 3, there have been several systems proposed to support face-to-face conversations and shared drawing activities. However, there has been no system that fulfills both of the following two requirements: (1) a contiguous space that includes both shared drawings and user image, and (2) eye contact.

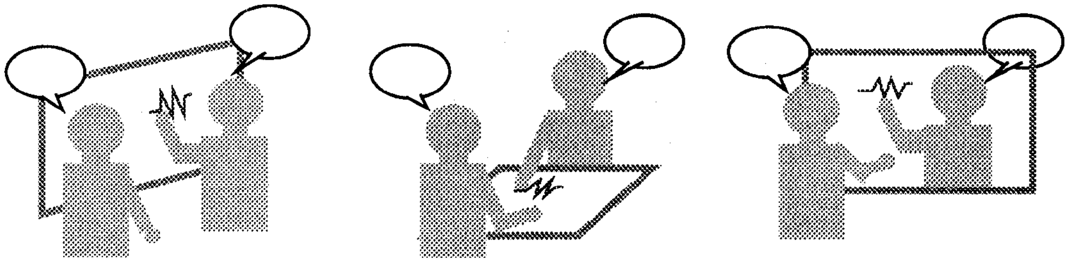
Video Tunnel

Video Tunnel [2] is a kind of video phone developed in EuroPARC for a computer-controlled video network. It supports eye-contact between two speakers using the well-known half mirror technique.

	shared drawing	facial expression	eye-contact	seamlessness: contiguity of drawing and user images		
Video Tunnel		O	O		EuroPARC [2]	only for face-to-face conversation
VideoWindow		O			Bellcore [4]	
VideoDraw	O *1	O		*5	Xerox PARC [13]	for shared drawing and face-to-face conversation
Commune	O *2	O			Xerox PARC [1, 10]	
VideoWhiteboard	O *1	*4		△ *6	Xerox PARC [14]	
TeamWorkStation	O *3	O		*7	NTT HI Labs [6, 8]	
ClearFace on TWS	O *3	O		*8	NTT HI Labs [7]	
ClearBoard-1	O *1	O	O	O	NTT HI Labs	

*1 direct drawing with whiteboard marker
*2 direct drawing with digitizer
*3 indirect drawing with pen and computer tools
*4 shadow image of user
*5 different screens
*6 shadow and drawing are contiguous.
*7 different windows
*8 translucent face windows over drawing window

Fig. 3 Previous Work and ClearBoard-1



(a) in front of white board (b) over a table (c) through a glass window

Fig. 4 Three Metaphors of Seamless Space for Shared Drawing and Face-to-Face Conversation

VideoWindow

VideoWindow, developed in Bellcore, is a wall-size screen that connects remote rooms to support informal face-to-face communications [4].

Neither Video Tunnel nor VideoWindow support shared drawing activities.

VideoDraw

VideoDraw [13], developed in Xerox PARC, is a pioneering work that supports shared drawing activity using video. It allows a user to draw with a whiteboard marker directly on a transparent sheet attached to the video screen that shows the drawing surface image of the partner. For face-to-face conversations, VideoDraw provides users with another screen.

Commune

Commune [1, 10] is a shared drawing tool based on a digitizer and multi-user paint editor developed in Xerox PARC. It is used with another screen for face-to-face conversation as VideoDraw.

VideoWhiteboard

VideoWhiteboard [14] developed in Xerox PARC, utilizes the shadow of users to convey the gestures of collaborators. Since the marks on the wall-size screen and the shadow of the user are captured by a single camera, it provides remote collaborators with a virtual space in which the marks and the shadow of drawing gestures are contiguous. However, because only shadow images are sent, no facial expression is conveyed.

TeamWorkStation

TeamWorkStation [6, 8] developed by the authors at NTT enables the simultaneous use of heterogeneous tools such as computer tools, printed materials, handwriting and hand gestures in a shared drawing space. Facial images are displayed in different windows on the same display.

ClearFace on TeamWorkStation

ClearFace [7] developed by the authors lays translucent facial images over shared drawing images to utilize the limited screen space more effectively. However, as with TeamWorkStation, the facial images are not contiguous with the drawing space.

THREE METAPHORS FOR SEAMLESS SPACE

In order to design groupware that achieves the two goals of (1) contiguous (seamless) space, and (2) eye contact, we first investigated the following familiar metaphors, and clarified their problems.

(a) talking in front of a whiteboard, and
(b) talking over a table.

(a) is an exact whiteboard metaphor. The advantage of this metaphor is that all the participants can share the common board orientation. However, because two participants share the same space in front of the whiteboard, it is hard to implement a mechanism that can coordinate the use of this shared space. The only way we found of realizing this metaphor is to employ "virtual reality" technology. However, we do not think it is a good idea to force users to wear awkward head-mount displays and special gloves and a suit just to share some drawings. This solution lets users dive into a computer-generated virtual world which definitely increases cognitive loads.

(b) is another quite familiar metaphor, sitting on opposite sides of a table and talking over the table. This metaphor is quite suitable for face-to-face communication because two participants can easily see each other's face. However, the orientation of a drawing becomes upside-down for one of the parties[1]. If we could develop an "L-shaped display", this metaphor could be realized to some extent. However, it is hard to give users a natural sense of sharing the same space over the table.

In order to overcome the problems in metaphors (a) and (b) while utilizing their advantages, we devised the new metaphor (c) as the foundation of our groupware design in September 1990.

(c) talking *through* and drawing *on* a *transparent glass window*[2].

1 VideoDraw [11] and Commune [1, 8] took the human interface close to this metaphor letting users share a common orientation. However, physical seams existed between the separate screens, one for the partner's facial image and the other for shared drawings.

2 VideoWindow [3] and VideoWhiteboard [12] are close to this metaphor. However, as described in Fig. 3, both fail to achieve the two goals of seamless integration and eye contact.

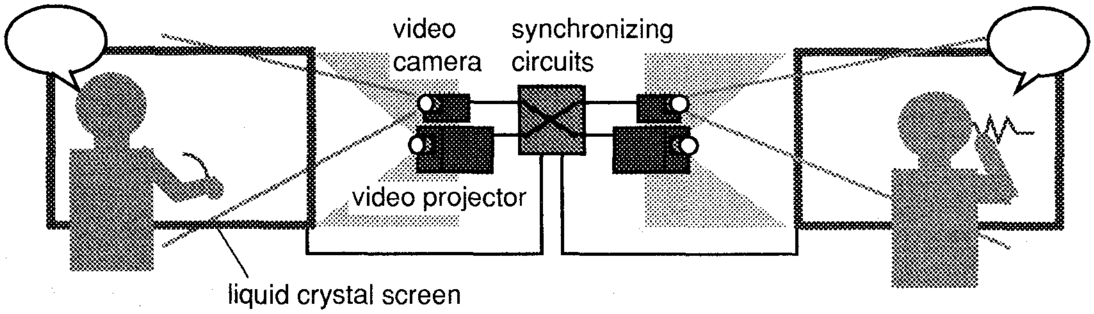


Fig. 5 Liquid Crystal Screen Architecture

Metaphor (c) does not produce any confusion or conflict about shared space use, since each participant's space is isolated from the other partner's space by a transparent glass window. This metaphor has the following advantages. First, as with the table metaphor (b), participants can see the partner's face easily. Second, since the partner's face and drawings are closely located on the board, switching the focus between the drawing and the partner's face requires less eye movements than (a) or (b).
One problem of this metaphor is that participants can not share the common orientation of "right" and "left" of the drawing space. However, this problem can be easily solved in implementing the prototype by mirror-reversing the video image.

We chose this metaphor (c) as the base for pairware design because of its simplicity and the advantages described above.

We coined the name "ClearBoard" for the pairware based on this metaphor (c). There can be several technical approaches to implement this ClearBoard concept. In the following section, we discuss two possible implementations of ClearBoard.

PROTOTYPE IMPLEMENTATION

Design Requirements

In order to implement a ClearBoard prototype which supports remote collaboration, we identified the following three design requirements.

(1) direct drawing on the display screen surface must be supported[3],
(2) the video image of a user must be taken through (behind) the screen surface (to achieve eye contact), and
(3) common orientation of the drawing space, not only "top" and "bottom" but also "right" and "left", must be shared at both sites.

The video tunnel architecture based on half-mirrors satisfies requirement (2). However, the combination of a half-silvered mirror and a CRT display produces the problem of parallax, and does not satisfy requirement (1).
Requirement (3) is important to provide both users with a common orientation of the drawing space. Especially for words, the partner must be able to read the text in its correct orientation. The strict implementation of the transparent glass metaphor does not allow this.

In order to realize a ClearBoard prototype that satisfies all these requirements, we investigated two alternative system architectures based on different techniques.

Liquid Crystal Screen Architecture

In order to take a frontal image of a user who is drawing on a screen, it is necessary to take his or her image through the screen by a video camera placed behind the screen. A liquid crystal screen, which can be rapidly switched between the transparent and light scattering state by the application of a suitable control voltage, can be a key device to fulfill this requirement. Fig. 5 illustrates the system architecture of ClearBoard based on this technique.

Fig. 6 illustrates how this architecture works; the liquid crystal screen is switched between the two states, (1) light scattering

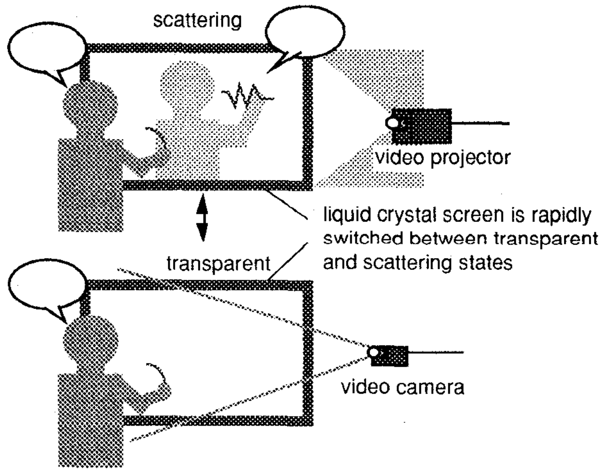


Fig. 6 Light scattering and Transparent States of Liquid Crystal Screen

3 Although we had taken the indirect drawing approach in TeamWorkStation [6, 8] to incorporate variety media such as printed materials into shared drawing space, in the design of ClearBoard, we took the direct drawing method to realize the metaphor of glass window illustrated in Fig. 4 (c).

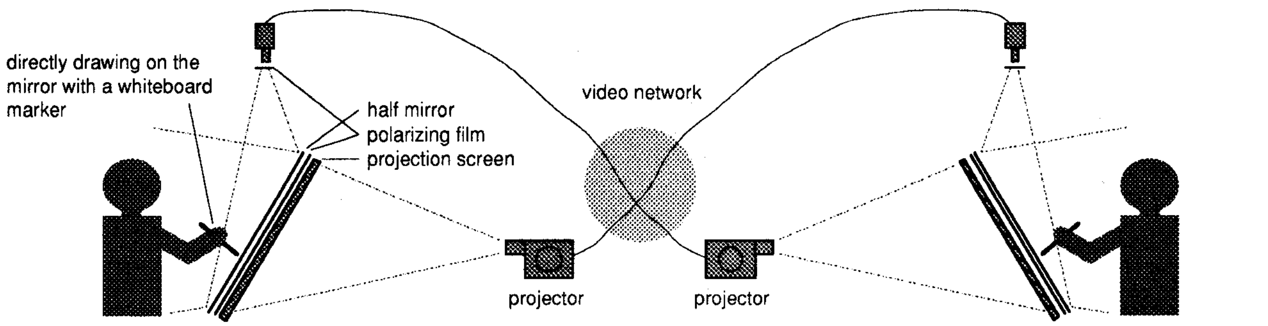


Fig. 7 "Drafter-Mirror" Architecture of ClearBoard Prototype

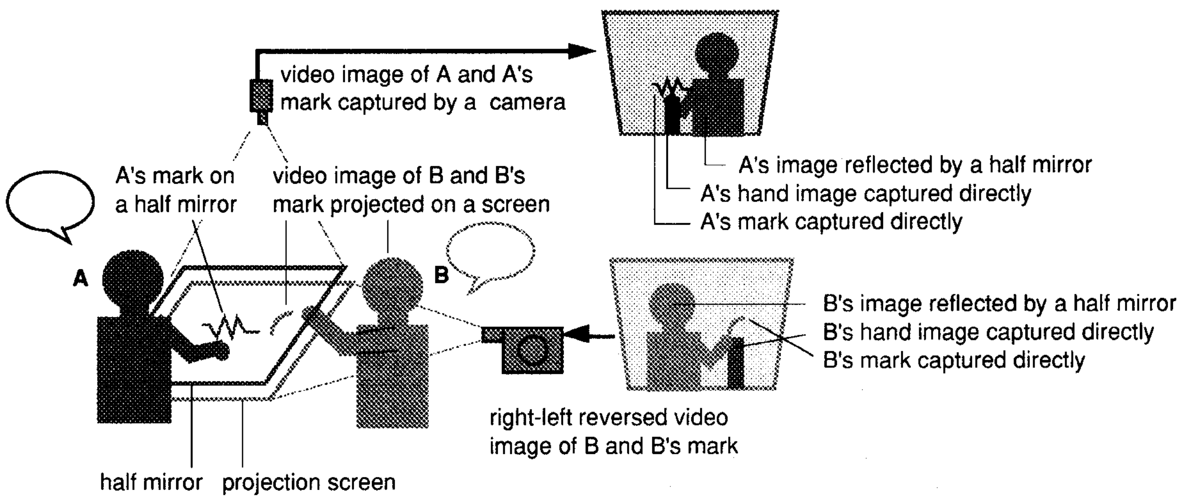


Fig. 8 How Drafter-Mirror Architecture Works

and (2) transparent. In state (1), the screen works as a rear projection screen on which the image of the partner and his or her drawing is displayed. In state (2), the user's image is captured by a video camera located behind the transparent screen. The timing of image capture and image display is synchronized to the switching of liquid crystal display states.

This technique was demonstrated by Shinichi Shiwa [12] at NTT in order to enable eye contact without any shared drawing support consideration. This architecture can be utilized to implement the ClearBoard concept if users are allowed to draw directly on the screen.
The transition frequency of the liquid crystal screen depends on its size. High frequencies, which decrease the physical load on user's eyes, are hard to achieve with large screens. Flickering images can be a serious disadvantage. The high cost of the liquid crystal screen is another drawback. Because of these shortcomings, we devised the next solution, which we refer to as "Drafter-Mirror architecture".

"Drafter-Mirror" Architecture

In order to implement the ClearBoard concept with a *flicker-less* and simpler technology, we devised the new system architecture illustrated in Fig. 7. We call it "Drafter-Mirror" because it looks like a drafter (a desk for architectural drawing) and it uses a half-mirror technique to enable eye-contact.

Each Drafter-Mirror terminal is equipped with a tilted screen, a video projector and a video camera. The screen is angled back at about 45 degrees and is composed of a projection screen, a polarizing film and a half-silvered mirror. Video feedback between the two cameras and screen pairs is prevented by a polarizing filter on each camera lens and a nearly orthogonal polarized filter that covers the surface of each screen. Users can write and draw on the surface of the screen using color paint markers. Water-based fluorescent (luminous) paint markers were used in our experiment because these colors are easy to distinguish from the background images including the user and the user's background. Markers can be erased with a cloth.
Fig. 8 illustrates how this Drafter-Mirror architecture works.

The video camera located above the screen captures the drawings and the image of the user reflected by the half-mirror as a continuous video image. This image is sent to the other terminal through a video network, and projected onto the partner's screen from the rear. The partner can draw directly on this transmitted video image. Because of this architecture, the video camera captures double hand images, one being the direct image, and the other being the image reflected by the half-mirror. The image of the user and his or her drawings is projected on the partner's screen so that both users can shared common orientation of the drawing space.

The drawing image captured by the camera is trapezoidally distorted due to perspective because the screen is at an angle. In order to support shared drawing on the screen, the drawing image must be recreated with the original shape and size on the partner's screen. In the current implementation, the distortion is offset by the opposite distortion caused by projecting the image onto the tilted screen. In order to give a suitable distortion rate, the camera and the projector should be symmetrically arranged with respect to the screen.

EXPERIMENTAL USE OF CLEARBOARD-1

We implemented the prototype of a Drafter-Mirror system in November 1990. (We call this prototype "ClearBoard-1".) Since then we have used this prototype in experimental sessions such as icon design, direction of the routes in a map, and discussions about diagrams for this paper. We informally observed the use of ClearBoard-1 by ourselves and our colleagues.

Fig. 9 shows the appearance of the Drafter-Mirror prototype in one of the experimental sessions.

We realized that users can easily achieve eye-contact when needed. This is because the partner's face and drawings are closely located on the board. Easy eye contact even in drawing-intensive activities increased the feeling of intimacy.

We observed that users often worked collaboratively to coordinate the limited shared drawing space. For example, when a user started drawing over some part of the partner's drawing, the partner often voluntarily erased his or her drawing from the screen.

Unlike ClearFace [7], users do not hesitate to draw over the image of the partner's face. In ClearFace, the partner's image was mixed with the drawing image behind it, and users found it difficult to draw over the facial image. In ClearBoard, we assume that users recognize the partner *behind* the drawing on the glass board, and thus feel no difficulty drawing on the board *in front of* the partner. The transparent glass window metaphor seems to make users sensitive to the distance between the drawing and the partner. Even with this overlapped image, users did not report having trouble distinguishing drawing marks from the video background.

Gaze Awareness

The most novel feature of ClearBoard, and the most important, is that it provides precise "gaze awareness" or "gaze tracking." A ClearBoard user can easily recognize what the partner is gazing at on the screen during a conversation. Precise *gaze awareness* can not be easily achieved in an ordinary meeting environment using a whiteboard because both users stand on the same side of the board. We conducted collaborative problem solving experiment on ClearBoard

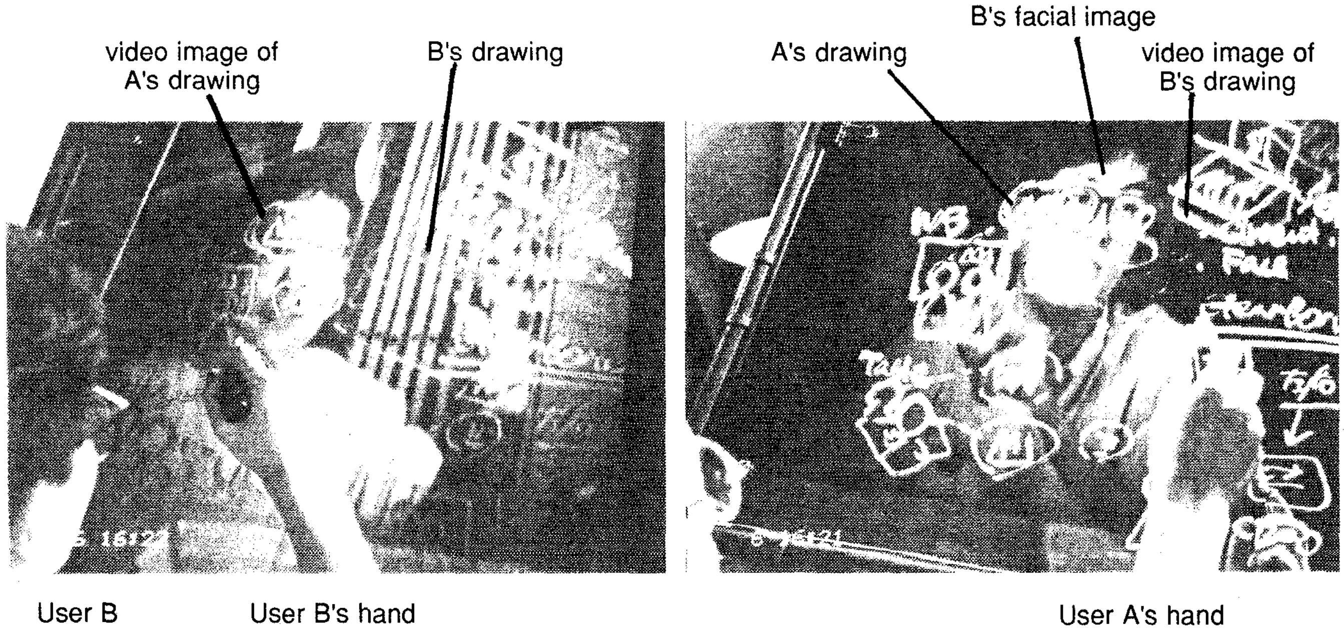


Fig. 9 ClearBoard-1 Prototype in Use
(See also Ishii and Kobayashi, Plate 1 and 2)

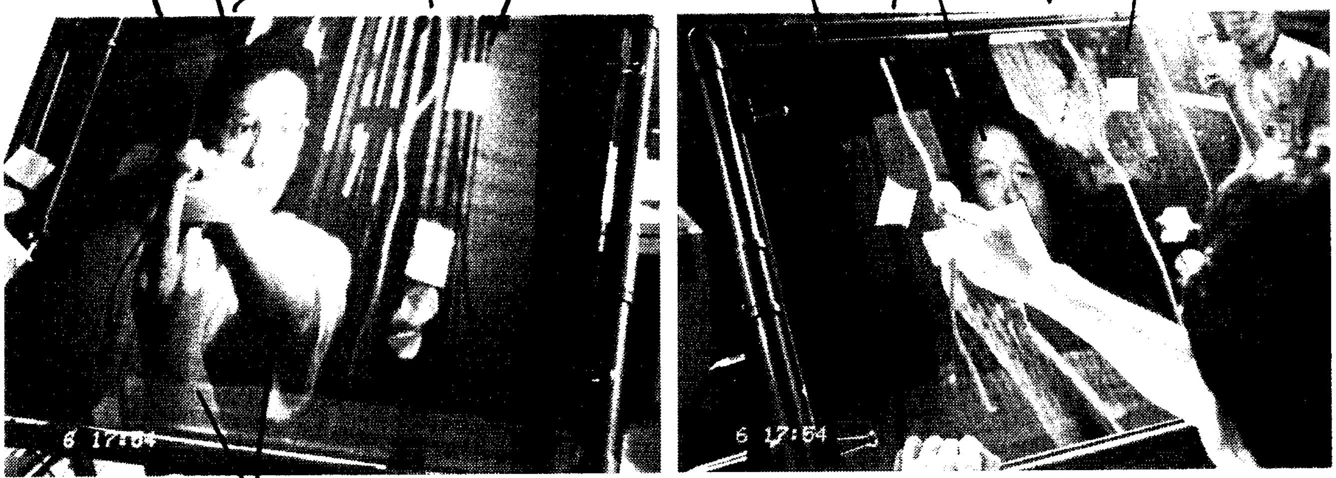


Fig. 10 ClearBoard-1 used for solving the "River crossing" problem
(See also Ishii and Kobayashi, Plate 3 and 4)

using the "river crossing problem[4]."
A separate psychological experiment has determined that the success of this game depends heavily on the *points-of-view* of the players [5]. It is thus advantageous for the collaborative players to know what the partner is gazing at.

Through this experiment we confirmed that it is easy for the players to say which side of the river the partner is gazing at and this information was quite useful in advising each other. Fig. 10 shows a snapshot of one such experiment. User A is gazing at side X of the river, and user C is looking at the face of user A to read his *gaze*.

The importance of *eye-contact* is often discussed in the design of face-to-face communication tools. However, we believe the concept of *gaze awareness* is more generalized and is a more important notion. *Gaze awareness* lets a user know what the partner is looking at, the user's face or anything else on the shared workspace. If the partner is looking at you, you can know it. If the partner is gazing at an object in the shared workspace, you can know what the object is. Eye contact can be seen as just a special case of *gaze awareness*.
We think the notion of *gaze awareness* will be an important goal of the next generation of shared drawing tools. It can not be easily obtained in conventional meeting environments, and only CSCW technology can provide it. ClearBoard-1 is the first system that provides distributed users with the capability of *gaze awareness*.

4 The "river crossing problem" is a puzzle to get group A members and group B members across a river using a boat. (In the most traditional case, the groups were missionaries and cannibals.) The boat can hold only two members at a time, and must have at least one member in it to cross the river. The number of group A members must be larger than that of group B members on both banks. We played the puzzle on ClearBoard drawing the river on it and using some pieces of sticky paper (Post-it™) to represent the members of each group.

Problems of ClearBoard-1
Through the experimental sessions using this prototype, we found the following problems.

(1) clarity of images on the screen
It is hard to achieve sharp focus on all the marks on the screen and on the user's face. Since the screen is tilted, the bottom edge is about 40 cm further from the camera than the top edge. In the current prototype, the camera focuses at the center of the screen, so that the user's face and the edges of the screen are slightly out of focus. The quality of the projected video image is not as sharp nor bright as an ordinary computer screen. Because half-mirrors and polarizing films are used, the screen image of Drafter-Mirror architecture is inevitably darkened.

(2) erasing partner's marks
Since the marks drawn by each user exist on their respective screen surfaces, a user can not erase the partner's drawing.

(3) double hand images
As illustrated in Fig. 8 and Fig. 10, each user "sees" two hands for each actual hand with this arrangement. At first glance, a few users said they were disturbed by this. However, they got used to it soon and had no further complaints.

(4) recording of work results
We mainly used a Polaroid™ camera to make a record of work results. However, if we use the appropriate computer input technologies, it will be easier to record and print the work results.

CONCLUSION

This paper has presented a novel shared drawing medium, ClearBoard. ClearBoard realizes (1) a seamless shared drawing space and (2) *gaze awareness* to support realtime and remote collaboration by two users.

We devised the key metaphor of ClearBoard: "talking *through* and drawing *on* a transparent glass window." We compared this metaphor to the traditional concepts of *whiteboard* and *table*. We implemented a prototype of ClearBoard based on the "Drafter-Mirror" approach and confirmed that the prototype fulfills the two goals.

In addition, through the informal use of ClearBoard-1, we found its most important feature to be *gaze awareness*. By referring to the role of gaze in human communication, ClearBoard is shown to provide a new environment for collaboration. We are planning to conduct empirical studies to understand the effects of gaze awareness in collaborative problem solving.

We are also designing a computer-drawing version "ClearBoard-2" to offer several new functions: recording of working results, easy manipulation of marks (move, shrink, erase, etc.), and the use of data in computer files.

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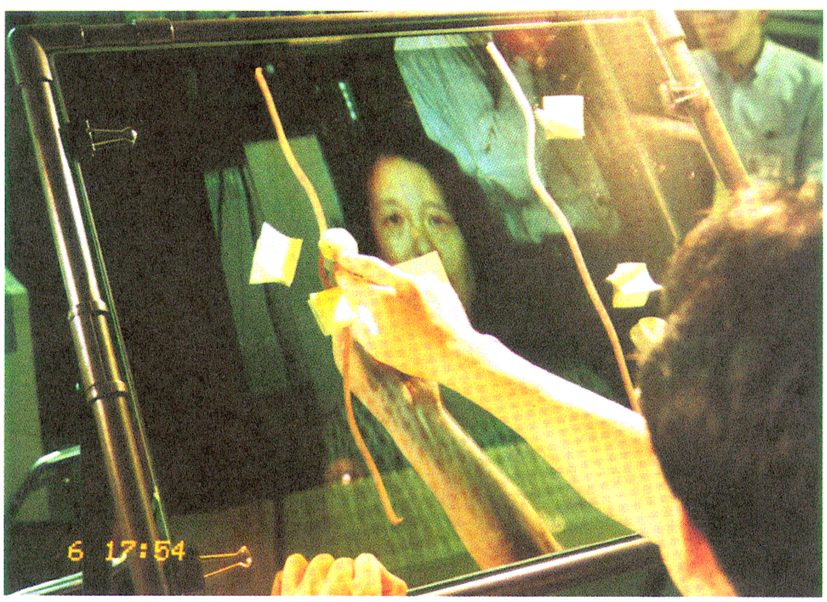
Ishii and Kobayashi, Plate 1

Ishii and Kobayashi, Plate 2

Ishii and Kobayashi, Plate 3



Ishii and Kobayashi, Plate 4