

Sharing the Unshareable – Distributed Product Review using Tangibles

Mattias Bergström¹, Peter Törlind¹, Mathias Johanson²

¹ Luleå University of Technology, Computer Aided Design,
971 87 Luleå, Sweden
{mattias.bergstrom, peter.torlind}@ltu.se
<http://www.cad.ltu.se>

² Alkit Communications AB, Aurorum 2
977 75 Luleå, Sweden
mathias@alkit.se
<http://www.alkit.se>

Abstract. Due to the ongoing globalization of businesses and the collaboration occurring between geographically dispersed organizations, distributed collaborative work using computer based support tools becomes increasingly important. When trying to perform design work while relying heavily on the use of physical artefacts such as early mock-ups, a need to share the unshareable, i.e. physical objects, will inevitably occur in a distributed setting. In an attempt to realize this, the authors studied a design team during their design reviews where a physical mock-up was used. A wearable conferencing unit (the Boblebee computer) was then developed to give remote collaborators a first person view of the mock-up using a head mounted video camera. With the Boblebee computer, remote collaboration with large tangible objects can successfully be realized. This paper relates experiences from the design of the system, and reports on early observations of its use.

1 Background

Globalisation is frequently used as a term to describe the trend of doing business globally. Product development in a global context requiring intense collaboration is standard practice in most industries today, and includes all parts of the product development process, such as brainstorming, concept generation, detailed design, manufacturing and support. Throughout these processes different collaboration tools are used, including telephone conferences, video conferences, shared applications, e-mail, ftp, shared databases and portal solutions for communicating and sharing information.

In product development the common view/common ground of the design artefact is very important; traditionally a physical mock-up was used where designers could manifest the design and use it for design review. Today, Digital Mock-Up's (virtual presentation of the product) are slowly becoming established as best practice. Computer based models are removing the need for many physical mock-ups, though they are still being used, i.e. people need to interact with the product by, for example,

seeing if they can reach an interface in a vehicle or feel the texture of the product. Many research projects have tried to enhance the virtual model by introducing haptics, stereoscopic rendering, etc., but these solutions are cumbersome and difficult to use in a collaborative setting, since the head mounted displays, stereo glasses and haptic interfaces prevent easy access to standard design tools, such as documents, telephones and other people in the room [1].

Physical mock-ups are still important in the product development process. Physical objects provide a rich source of information and can be more useful than other more abstract forms of product information [2] as well as enabling the design team to discuss the product and share the same perspective. Unfortunately, *physical objects live in one place* [3] and their sharing in distributed groups is a great challenge.

2 Objectives

The goal of the research presented in this paper is to enrich the design process and assist designers in their work to be more effective by introducing a computer tool as a means of communicating tangibles in their work, e.g. to interact with a large physical mock-up of a vehicle in a remote work shop. The design of the system is based on the actual needs of the designers at the company.

The results are based on a study conducted of a design team at Land Systems Hägglunds AB that often use a full size mock-up of a combat vehicle in their design meetings. However, due to space constraints at their main office, some team members were forced to move to another site, prompting the introduction of several computer supported collaboration tools to support the collaboration between the design teams. With the introduced tools, conducting formal meetings and sharing documents and digital mock ups of the vehicle could be easily done. However, working with a prototype is an integrated part of the design process and enhancing the distributed collaboration with virtual “visits” in the remote physical prototype is desirable.

By studying how co-located users worked at the physical prototype, a system was designed enabling this type of work from a remote setting, this system was designed and tested in four design iterations with inputs both from actual use of the system with design engineers at the company and technical testing.

The goal of the case study was to investigate how a co-located design meeting at the prototype was done and attempt to recreate the same experience in a distributed setting. Drawing from the concept of ethnomethodology [4], it was important to try to understand things in the context in which they occur without making assumptions about what modes of communication could be useful for successful collaboration. The study was performed using ethnographic methods such as observations, field notes and videotaping. The testing of the concept systems was recorded via the hand held video camera, and comments from the video were transcribed and analysed.

3 Related Work

To prepare for the research, the concepts of design, grounding, use of video for shared understanding and the use of a head mounted camera have to be expanded upon.

3.1 Design and the Concept of Grounding

Given that design is not just a systematic method, but also a social activity, creating a consensus, i.e. a shared understanding, is then important for the design team. A team that does not reach a consensus does not work as a team, but rather as a set of individuals working towards their separate goals without a common agenda. According to Bucciarelli design is:

“...as much a matter of getting different people to share a common perspective, to agree on the most significant issues, and to shape consensus on what must be done next, as it is a matter of concept formation, evaluation of alternatives, costing and sizing.” [5]

Arias et al. also stress the importance of a shared understanding

“Bringing different and often controversial points of view together to create a shared understanding among stakeholders can lead to new insights, new ideas and new artefacts” [6].

The term *grounding* refers to the mutual understanding between conversational participants, ensuring that what is communicated is also correctly understood. Physical objects can provide assistance with the crucial concern of successfully negotiating a shared understanding of the design and task [7].

Due to the importance of physical objects in design, the sharing of physical objects within distributed teams is necessary. Larsson [8] found it appealing to provide global design teams with collaborative environments that allow the team to successfully negotiate a shared understanding of a physical prototype.

3.2 Using Video for Sharing Tangible Objects

Videoconferencing is a common tool used for collaboration and a natural starting point when working with tangibles. Conferencing is usually done from specialised conference rooms and used mostly for formal meetings. Systems built for an ordinary desktop computer has the advantage of being used at any time and does not require a system built specifically for videoconferencing.

Research within the DTI-project [8,9] showed how global design teams do not have any shared space for physical artefacts. The team studied worked in a global product development project concerning the novel design of a new pedal system. The distributed team (Luleå, Sweden and Stanford, USA) used videoconferencing for brainstorming, formal meetings, etc. During the project the team built many hardware prototypes and could easily share the geometry of a pedal concept (using a shared 3D-modelling tool), but could not share the “feeling” and “experience” of driving with these pedals without having physical prototypes at each site. If the physical object was small, it was moved to the conferencing room, but if this was not possible (i.e.

pedal concept mounted in a car), videotaping the prototype and sharing the video clip via a video server was the solution. This type of communication shares information about the artefact and its use, but supports no interaction.

Videoconferencing is normally done by using one camera and sending the video signal to the remote participant where the video is rendered on a two-dimensional display. The viewpoint of the camera from this approach is fixed. By controlling the pan/tilt/zoom of the camera, some conferencing systems facilitate changing the viewpoint by the remote participant. Other systems used several viewpoints from the same physical space (i.e. multiple video streams) [17, 18]. Yamaashi et al. [10] presented a system with multiple viewports, one wide angle (scene camera) and one controllable detailed view. The navigation was simplified by using sensors and a point to zoom interface.

Stereoscopic videoconferencing can further enhance the view of tangibles. Johanson [11] proposed a system using a static viewpoint with only two cameras at each end. In the Office of the future vision, Chen et al. [12] presented a telepresence project with high-end 3D-conferencing utilising an array of cameras, depth acquisition and motion tracking to create a 3D-environment with a dynamic viewpoint. Office of the future is a mixed reality [13] concept where real world and virtual world objects are presented together on a single display,

The commercially available Zaxel [14] system can be used for remote collaboration by using an array of cameras that create a virtual viewpoint where the user can chose their own (monoscopic) viewpoint. Billinghamurst et al. [15] suggested a system based on the Zaxel imaging acquisition system, which augments the real world with video from a remote site.

These systems with virtual viewpoints (office of the future and Zaxel) are technically interesting, but need several high-end computers to function and an array of stationary cameras at the remote site.

Everitt et al. [3] presented “the Distributed Designers’ Outpost”, a system where tangible objects (i.e. Post-it notes) can be shared by a global design team. The system enables synchronous remote collaboration via two back screen projections, with one at each location. The designers use the screen to share tangible Post-it notes; a physical artefact at one side appears as a virtual object on the other screen. The system also enables a sense of presence as the shadows of the remote collaborators are displayed on the screen.

3.3 Head Mounted Camera

Another approach is to use computers (stationary or wearable) combined with a head mounted camera (HMC), either to augment the real world or to document or broadcast one’s own personal experiences. Steve Mann developed EyeTap [16] and described in Cyborg [17] how it can be used as a way of communicating. *“While I am grocery shopping, my wife – who may be at home or in her office – can see exactly what I see and help me pick out vegetables”* further *“It allows the individual to fully enter – to communicate and be a substantive part of – the video graphic world of images that dominates everyday existence”*.

Drugge [18] proposed the use of a wearable computer as a video conferencing node to share the experience of visiting a fair with remote colleagues. The user of the wearable computer allows remote participants to connect to the wearable device and communicate with the user and share the experience at the fair. They found that a single user at the fair could represent the research group situated at the home site, while the remote users experienced some sense of being at the fair.

Several research projects have focused on assisting a user from a remote site [19,20,21] through the use of different types of HMC. Fussell et al. [22] clearly demonstrate the value of a shared view for remote collaboration of physical tasks, by comparing the communication between two subjects with a given task (assembly of a robot) in five media conditions, viz. side-by-side, audio-only, head mounted camera, scene camera and scene plus head cameras. The efficiency and communication was highest when side-by-side, and significantly higher with a scene camera and head mounted camera than with audio only. Fussell et al. [23] also showed that a remote controlled cursor pointer, visible in the head mounted display (HMD) further enhanced the collaborative process.

Kurata et al. [24] compared remote assistance using a traditional HMD/HMC combination with a shoulder worn Wearable Active Camera/Laser (WACL), concluding that the WACL is more comfortable to wear, more eye- friendly and causes less fatigue to the wearer, though there is no significant difference in completion time.

4 Interacting with the Physical Mock-up

Situated in Örnsköldsvik, Sweden, the company Land Systems Hägglunds AB designs and manufactures military land systems such as tanks, tracked vehicles and turrets. The authors studied a design team and their work on the AMOS mortar system – a twin barrelled 120 mm mortar turret built as a module to be fitted on a variety of vehicles. The design team comprises of seven engineers and a mechanic working with the physical mock-up of the mortar system. Land Systems Hägglunds AB use a physical mock-up as a part of their design process; at the co-located setting, the design team gathered at the physical mock-up for design reviews. Such meetings were held at least once every week.

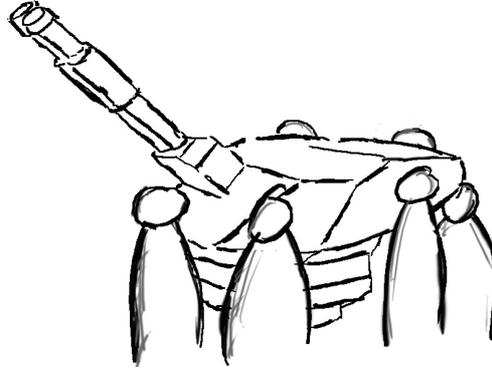


Fig. 1. An Illustrated figure of a typical design review at the mock-up (for confidentiality reasons actual pictures from the mock-up can not be published)

The entire design team meets for a design review at the mock-up every week, when the design and potential problems with the design are discussed. The mock-up supports the discussion by giving visual and tangible cues to the team members. Although the mock-up is a large object, it becomes crowded when the entire design team gathers around a specific object of interest, with some members usually getting their views blocked by either other members or by the panes of the mock-up itself. Hence, all team members cannot always participate in the discussion due to a lack of visual cues. Typically, the topics deal with how a specific detail should be built, if the passenger envelope is enough, if the space to fit a communication device or some other electronics is sufficient, issues of wire placement, etc. During the week the mock-up is used as a reference and to clarify any questions during the design. The design team needs a system to support this type of meeting from a remote location, since most of them are a 30-minute drive away from the mock-up itself. The time now spent on travel could instead be spent on design, thus speeding up the design process.

5 Initial Demands on the Collaboration Tool

From the studies of the co-located design review the first demands of a tool to support remote collaboration with the mock-up was formulated. Initially, the goal was not to use a wearable computer, but to realize a collaboration tool that could communicate the visual cues given by a tangible to the remote collaborators. The system was intended to be a tool for a specific industry application, i.e. to be able to share and interact with a remote physical prototype in the design process.

The system is also intended to support the product development process at Land Systems Hägglunds AB. Therefore, the focus has been on providing the design team with a tool to support the visual information from the mock-up and the visual cues between the team members as they examine and discuss the mock-up on site. The work is primarily concerned with a system to support the design team's virtual visit to

the workshop (where the mock-up is built and situated) and to support the collaborative work between the mechanic and the designers in the workshop.

A visual communication system is needed to communicate visual information about the surrounding environment of a mobile user and to share the view of physical artefacts in that environment. The required functionality can be seen as a specialized form of videoconferencing; a live video signal is to be transmitted from the person using the wearable computer to one or more recipients, while one or more incoming video signals (optionally) are presented to the mobile user using some kind of head-mounted display. Working with the prototype often involves being able to focus on specific details; therefore, a video conferencing system must support as high video resolution as possible (at least PAL quality video). The right lighting conditions are also necessary for the camera to capture the video accurately.

Live audio (voice) should also be transmitted between the participants. Further requirements on the audiovisual communication system are:

- The network protocol IP (Internet Protocol) should be used to transport media signals over the Internet.
- The user interface must be easily customizable to fit the usage situation.
- Audio and video must be of sufficient quality for the intended usage situation.
- A reasonably lightweight software implementation must be possible on the wearable computer.

6 The Conferencing Node

As a part of the system development to fulfil the requirements, a total of four concepts were built and tested, each building on the experience and lessons learned from the preceding concept. The initial requirements were also altered and improved as testing of the concepts were conducted at Land Systems Hägglunds AB.

6.1 Conferencing Software

To realize the audiovisual communication needs, a commercially available videoconferencing system called Alkit Confero was used as a building block. Alkit Confero is a desktop videoconferencing system based on IP and RTP for media transport and SIP for session setup signalling. Since the source code of Confero was available to our developers, and since the user interface parts of Confero were written in the scripting language Tcl, customizing the GUI for the mobile application was a reasonable effort.

Media Encodings

Confero has a variety of media encodings to choose from. For the usage situation in this research, it was important to meet the audio and video quality requirements at a

reasonable cost in terms of computational complexity and bandwidth requirements. Audio communication was rather simple here, and a wideband G.722.1 audio codec readily available in Confero was found to give satisfactory results. The video communication, however, required more careful consideration. Four different video codecs are available in Confero: JPEG, MPEG-2, H.264 and DV. A detailed description of these compression algorithms is beyond the scope of this paper, though some general observations can be pointed out. The H.264 codec can deliver high quality video at low bit rates, but at the cost of very high computational complexity. The JPEG codec, however, can deliver high quality video at low computational cost, though with significantly higher bandwidth requirements. The MPEG-2 video codec is somewhere in between the JPEG and the H.264 codec, both in terms of compression efficiency and complexity. The main advantage of the DV codec is that it allows transmission of high quality video streams at high bandwidths, directly from affordable digital cameras, without re-compression. JPEG and DV are less sensitive to packet loss compared to MPEG-2 and H.264, since they employ intra-coding only, and hence do not suffer from propagation errors.

For our application, the selection of video compression algorithm was guided by the CPU performance of the wearable computer, the available network bandwidth and the requirements on visual quality that the application posed. Because the DV codec is very bandwidth demanding (25 Mbps) and the transcoding from DV to another compression introduces high computational complexity (and coding delay), the DV codec was ruled out. A performance analysis was conducted to find out the CPU and bandwidth requirements for the three remaining codecs: JPEG, MPEG-2 and H.264. The results are shown in Figure 2.

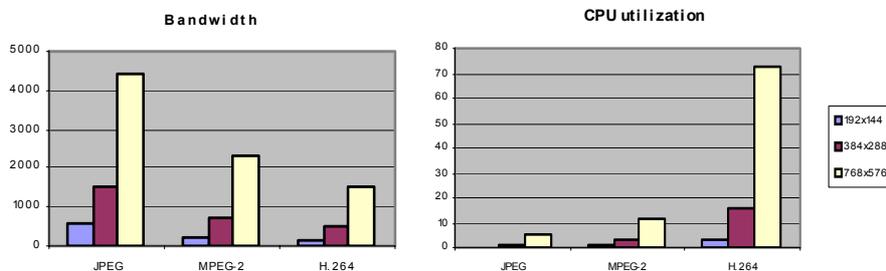


Fig. 2. Bandwidth requirement and CPU utilization for JPEG, MPEG-2 and H.264 respectively

The performance analysis was performed by running Confero on a 2.8 GHz Pentium 4 computer and measuring the bandwidth and CPU consumption, while keeping the subjective video quality constant at an acceptable level for the intended application. The measurements were performed using three different video frame sizes: 192x144, 384x288 and 768x576. The bandwidth measurements correspond to a frame rate of 25 frames per second (fps), while the CPU utilization measurements were recorded at a frame rate of 5 fps. (This was done because the CPU could not sustain 25 fps for the H.264 codec at the highest resolution.) It is evident from Fig. 2

that the JPEG codec is the most attractive in terms of computational complexity, with the H.264 codec clearly providing the best compression performance. Since the available bandwidth in the network to be used for our particular application is generally high, and the CPU on the wearable computer is limited to 2.1 GHz (Pentium M), it was concluded that the JPEG codec is in most cases the most useful video coding. In situations when the network bandwidth might become more restricted, the MPEG-2 codec is a viable alternative. The H.264 codec was seen to be too computationally expensive, especially since a high spatial resolution (i.e. 768x576) is needed for the video in most situations.

6.2 User Interface Customization

As previously mentioned, the GUI of Confero is written in Tcl/Tk [25]. Tcl/Tk is a “quick and dirty” scripting language, ideal for rapid prototyping of graphical user interfaces. Because a mouse and keyboard are inconvenient when using a wearable computer, the Twiddler (a combination keyboard and mouse that fits in the palm of your hand) was presented as an input device. Lyons et al. [26] stated that it takes an average user 25 hours of practice to use the Twiddler. However, the users did not find it to be a helpful tool for this application. The traditional WIMP (Windows, Icons, Menus and Pointing device) user interface model was abandoned, and a single toggle button was instead chosen as the main input device. Due to the limited size of the head-mounted display, full-screen renderings of the video signals and shared applications (such as CAD systems) were sequentially switched between using the toggle button.

6.3 Session Setup

To simplify the setup of a conference session, the media streams are always sent through a reflector, regardless if two or more participants are in the conference. The conferencing system on the wearable computer was preconfigured to connect to the reflector at the startup and set up the session using SIP (Session Initiation Protocol) signalling [27].

6.4 Application Sharing

Besides video communication, the system also supports the sharing of applications, through a shared view of a 3D geometry model in a CAD system, or some other visualization system. The application sharing tool integrated into Confero is based on the VNC software, originally designed for remote control of a computer. On the wearable computer, the mobile user can toggle between full screen renderings of the transmitted and received video signals, and a full screen rendering of a VNC window with a shared application.

6.5 The Wearable System

All concepts consisted of a computer, head mounted display, camera, headset and videoconferencing software. Commonalities between the concepts were the software used (Alkit Confero) and the HMD (MicroOptical SV-6).

Two kinds of camera configurations were tested. The first camera was mounted on a pair of glasses; the advantage being that the person wearing the equipment had both hands free and could use them as if he had no additional equipment. The camera was supplemented with a laser pointer to indicate where the camera was pointed and to provide a pointer for the user as he shifted the attention of the remote users to discuss a certain object of interest. Without the laser pointer the user needed to reach over and point to the object, thereby obstructing the view of the remote collaborators. The second camera was an ordinary, off-the-shelf DV-camera. This option offered an unexpected advantage, namely making it possible to put the camera behind panes and other obstacles, enabling the team members to discuss parts of the vehicle that were usually not visible due to obstructing panes of the mock-up. The advantage of being able to view behind panes with a handheld camera was found to dominate the disadvantage of not having both hands free.

The wearable computer did not have to be equipped with any specialized hardware due to Confero being a software-only system, except initially for a PCI-based video grabber board (Matrox Meteor II) to digitize an analogue video signal. This was subsequently replaced with a USB-based analogue to digital conversion device (GrabBee X). The IEEE 1394 interface was also tested, but because an analogue head-mounted camera was chosen, the USB device was still needed. The handheld DV camera was used to complement the head-mounted camera. Analogue input was preferred due to the ease of switching cameras during the session, when the user can choose to transmit the signal from the hand held DV camera or put it away and continue by transmitting the signal from the camera mounted on the bow of the spectacles.

Concept 1: The Barebone

Since the videoconferencing software demands high CPU utilization, the first concept was built on a small form factor stationary computer (operating on a Pentium 4 3.4GHz). The goal of this concept was proof of concept; is it feasible to use video conferencing in the workshop work for a distributed design review. The system consists of two main parts, i.e. the wearable unit and the computer. The wearable unit consists of the HMD and a camera mounted on the bows of a pair of spectacles and a headset, all of which were connected to the stationary unit (i.e. computer) via a cable. However, due to the cable, the system had a range of approximately ten meters and the system turned out to be cumbersome to work with as the cable was dragged around on the cluttered workshop floor, allowing for the possibility of it becoming entangled in something on the floor or inside the mock-up. Its limited range was also a disadvantage.

Concept 2: The Light Weight Laptop

Due to the difficult mobility with the barebone, a wearable computer using an IEEE802.11a wireless network was built. This concept consisted of a light weight computer (Pentium M 1.2GHz) mounted in a backpack, leading to serious overheating problems and insufficient cooling. However, the functionality of the wearable computer was much better than a stationary due to the ease of mobility in and around the mock-up. Still, there was a need for a faster computer to achieve full frame rate and quality of the video.

Concept 3: The Performance Laptop

The next concept was also laptop based (Pentium M 1.7GHz), but mounted on a rucksack frame for heat dissipation. The computing capabilities were enough for the application, though a laptop mounted in this manner is not feasible in an industry application due to its vulnerability if the user hits something inside the mock-up.

Concept 4: The Boblbee Computer

The final concept, Figure 3, combines the best qualities of the previous systems. To accommodate the need for a protected computer a hard shell backpack (Boblbee Peoples Delight) was used. To optimise the cooling a customised system was built on a micro-ITX motherboard with a Pentium M 765, chosen due to its low power consumption. The hard shell of the backpack became the case for the computer with fans mounted inside for heat dispersal. To accommodate glass-wearing users the camera and HMD are mounted on the headset instead of on a pair of spectacles. The headset used in previous concepts was replaced with a professional type headset to accommodate the HMD and head mounted camera/laser. The new headset also protected the user from unwanted noise coming from the workshop.



Fig. 3. The Boblbee Computer, left picture: close up on the head worn equipment. Right picture: The wearable computer in use at a mock-up

7 Evaluation of the System

It was found that the system could be run under three modes of operation: collaborative mode, tangible sharing mode and application sharing mode.

1. *Collaboration* - remote video to the HMD:

The system could be used as a video conferencing tool, enabling users to communicate via audio and video for discussions and to communicate visual cues.

2. *Sharing of the tangible object* - local video from camera to HMD:

The camera is pointed at the tangible object, i.e. the mock-up, letting the users share the view of the object and discuss it as they would if they were co-located.

3. *Sharing of virtual documents*:

The tool can also support the sharing of applications normally run on a remote desktop computer (e.g. CAD-data, drawings, etc.). The design team found it useful to share and discuss the CAD models of the mock-up with the mechanic.

Due to the simplified UI of the wearable system the user could instantly switch between these modes using a toggle button, figure 4 gives an example of what is shown in the HMD.



Fig. 4. The three modes of operation, from left to right; the transmitted video, the received video (remote collaborator) and CAD data received via VNC

8 Conclusions

A design review at the mock-up was usually overcrowded, with designers peering through manholes to get a glimpse of what was currently being discussed. The introduction of the Boblebee computer has changed the reviews, allowing everyone to get the same visual view of what is currently being discussed. The distributed design reviews are actually *better than being there*, as Hollan and Stornetta discussed in their article of the same name [28]. It is here thought that a collaboration tool successfully supporting remote collaboration this way will lead to the traditional co-located counterpart being abandoned, since this method for remote collaboration is better and more efficient.

The handheld camera, though having the disadvantage of occupying one hand, gave an unexpected advantage, i.e. the ability to see what otherwise cannot be seen behind the panes of the mock-up. The head mounted display's primary use is showing the mechanic exactly what is transmitted to the designers. The introduction of a head mounted camera combined with a laser pointer has the advantage of allowing the mechanic to use the head mounted display to view other information than what is transmitted, e.g. CAD data. The laser pointer enables the mechanic to use the real world as a display, as is indicated to him by the red dot on what is transmitted to the designers.

The conference node is not intended as an assistance tool for augmented reality (AR) [29], thereby adding to the mechanics experience by enriching the real world by overlaying virtual objects. However, the authors acknowledge that AR can be introduced in this system. The system supports virtual data through VNC embedded in the conferencing software, Alkit Confero. This enables the designer to share his virtual data with the mechanic as the mechanic shares his real world visual cues of the mock-up. The sharing of CAD data with the mechanic also speeds up the design process, since the mechanic previously had to examine drawings sent to him to understand what to do next.

Confero can easily handle several video streams permitting a remote controlled 'scene camera to be easily implemented. This was not implemented during testing and might not be as useful as reported by Fussell et al. [22], due to most of the

communication being performed inside the mock-up where the view from the camera will be blocked by the mock-up itself. The camera would have the same poor view as most designers had before the system was introduced. Land Systems Hägglunds AB found that the system enriches their collaboration so much that they will use the system on a daily basis, as well as desiring their collaborating partner companies to invest in a compatible system so that the collaboration may flow as easily as the internal collaboration.

9 Acknowledgements

The research is done within the ProViking programme funded by Swedish Foundation for Strategic Research. The project is also supported by the Kempe Foundation and the Wallenberg Foundation. Special thanks to the designers at Land Systems Hägglunds AB.

References

1. Green M. and Halliday S.: A geometric modelling and animation system for virtual reality, *Communications of the ACM*, vol. 39, No. 5 (1998) 46-53.
2. Harrison, S., and Minneman, S.: A Bike In Hand. In Cross, N., Christians, H. and Dorst, K. (Eds.): *Analysing Design Activity*, Chichester, UK, John Wiley & Sons (1996) 417-436.
3. Everitt, K. M., Klemmer, S. R., Lee, R. and Landay, J.: A Two Worlds Apart: Bridging the Gap Between Physical and Virtual Media for Distributed Design Collaboration, In *Proceedings of CHI'03*, ACM Press (2003)
4. Dourish P. and Button G.: On 'Technomethodology': Foundational Relationships between Ethnomethodology and Interactive System Design, *Human-Computer Interaction*, Vol. 13, No. 4 (1998) 395-432.
5. Bucciarelli, L. L. Reflective Practice in Engineering Design. *Design Studies*, Vol. 5, No. 3 (1984) 185-190.
6. Arias, E., Eden, H., Fischer, G., Gorman, A. and Scharff, E.: Transcending the individual human mind—creating shared understanding through collaborative design, *ACM Transactions on Computer-Human Interaction (TOCHI)*, Volume 7, Issue 1 (2000)
7. Clark, H. H. & Brennan, S. E.: Grounding in communication. In L. B. Resnick, R. M. Levine, & S. D. Teasley (Eds.). *Perspectives on socially shared cognition*. Washington, DC: APA (1991) 127-149
8. Larsson A.: Making sense of collaboration: the challenge of thinking together in global design teams, *Proceedings of the 2003 international ACM SIGGROUP conference on Supporting group work*, ACM Press (2003)
9. Larsson, A., Törlind, P., Karlsson, L., Mabogunje, A., Leifer, L., Larsson, T., Elfström, B. Distributed Team Innovation - A Framework for Distributed Product Development, In *Proceedings of ICED 03*, Stockholm, August (2003)
10. Yamaashi, K., Cooperstock, J. R., Narine, T. and Buxton, W.: Beating the Limitations of Camera-Monitor Mediated Telepresence with Extra Eyes, In *Proceedings of CHI 96*, ACM Press (1996)
11. Johanson, M.: Stereoscopic Video Transmission over the Internet. *Proceedings of IEEE Workshop on Internet Applications (WIAPP '01)*, (2001)

12. Chen, W., Towels H., Nyland, L., Welch G., and Fuchs, H.: Toward a Compelling Sensation of Telepresence: Demonstrating a portal to a distant (static) office. In Proceedings of the IEEE Visualization 2000, IEEE Computer Press (2000)
13. Milgram, P., and Kishino, F. A taxonomy of mixed reality visual displays, IEICE Transactions on Information and Systems, Special issue on Networked Reality (1994)
14. Zaxel Virtual Viewpoint- Remote collaboration, URL: <http://www.zaxel.com>
15. Billingham, M., Cheok, A., Kato and Prince, S.: Real World Teleconferencing. IEEE Computer Graphics and Applications, 22 (6), (2002) 11-13
16. Mann, S.: Continuous lifelong capture of personal experience with EyeTap, Proceedings of the 1st ACM workshop on Continuous archival and retrieval of personal experiences (2004)
17. Mann S. and Niedzviecki, H.: Cyborg: Digital destiny and human possibility in the age of the wearable computer, Doubleday Canada (2001)
18. Drugge, M.: Wearable Computer Interaction Issues in Mediated Human to Human Communication. Licentiate in engineering thesis, Luleå University of Technology (2004)
19. Kuzuoka, H.: Spatial Workspace Collaboration: A SharedView Video Support System for Remote Collaboration Capability. In Proceedings of CHI 92, ACM Press (1992) 533-540
20. Fussell, S. R., Kraut, R. E., & Siegel, J.: Coordination of communication: Effects of shared visual context on collaborative work. In Proceedings of CSCW 2000, ACM Press. (2000) 21-30
21. Kraut, R. E., Miller, M. D., & Siegel, J.: Collaboration in performance of physical tasks: Effects on outcomes and communication, In Proceedings of CSCW'96, ACM Press. (1996) 57-66
22. Fussell, S. R., Setlock, L. D. and Kraut, R. E.: New directions in video conferencing: Effects of head-mounted and scene-oriented video systems on remote collaboration on physical tasks, In Proceedings of the conference on Human factors in computing systems, (2003)
23. Fussell, S. R., Setlock, L. D., Parker, E. M. and Yang, J.: Assessing the value of a Cursor pointing Device fore Remote Collaboration on Physical Tasks. In Proceedings of CSCW 2003, ACM Press (2003) 788-789
24. Kurata T., Sakata N., Kurogi M., Kuzuoka, M., Billingham, M.: Remote Collaboration using a Shoulder-Worn Active Camera/Laser, In Proc. 8th IEEE International Symposium on Wearable Computers (ISWC2004) (2004)
25. Ousterhout, J., Tcl & the Tk Toolkit. Addison-Wesley, New York (1994)
26. Lyons, K., Plaisted, D., and Starner, T.: Expert Chording Text Entry on the Twiddler One-Handed Keyboard, October 31 - November 03, Arlington, Virginia (2004) 94-101
27. Handley M., Schulzrinne H., Schooler E. and Rosenberg J., SIP: Session initiation protocol, IETF RFC 2543 (1999)
28. Hollan, J. and Stornetta, S.: Beyond being there, In Proceedings of the CHI'92 Conference on Computer-Human Interaction, ACM Press (1992) 119-125
29. Barakonyi, I. Fahmy, T. and Schmalstieg, D., Remote Collaboration Using Augmented Reality Videoconferencing Proceedings of Graphics Interface 2004 (2004)