GETTING PHYSICAL – INTERACTING WITH PHYSICAL OBJECTS IN DISTRIBUTED COLLABORATION

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Abstract

Due to the ongoing globalization of businesses and the collaboration occurring between geographically dispersed organizations, distributed collaborative work using computer-based support tools is becoming 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 physical objects will inevitably occur in a distributed setting. In an attempt to realize this, the authors studied a design team during design reviews in which a physical mock-up was used. The study of co-located design reviews gave valuable input to the design of a wearable conferencing unit. The system allows remote collaborators a first-person view of the mock-up. The paper also discusses how the design process changed when distributed reviews were used. With the new tools, the remote engineers can share their "virtual" CAD data simultaneously with the mechanic situated at the prototype, who shares his "physical" data with the engineers. The new tools also provided support in a co-located setting, even enabling users to look behind panels and view items that are normally hidden from the user's sight.

Keywords: Distributed collaboration, collaborative design tools, globalisation, physical artefacts and video conferencing.

1 Introduction

The design of complex products is an increasingly collaborative task among engineers working in teams. There is a growing demand in industry for the ability to work in teams and in close collaboration with experts and colleagues dispersed around the globe. Traditionally distributed collaborative work is performed via teleconferences, videoconferencing, e-mail, etc. and travel to the remote partners. When collaborating at a distance, all aspects of the work must be preformed to some extent. Due to the limitations of distributed collaboration tools, a distributed team cannot work as co-located teams. Unfortunately, *physical objects live in one place* [1] and sharing them in distributed groups is a great challenge.

In a co-located project, the team is rarely confined only to their office or a specific team space. The team can change location or visit the machine shop or prototyping area. Artefacts (e.g., objects, prototypes, or mock-ups) are often used to convey thoughts and ideas. Small artefacts are usually brought to the team space while larger and heavier artefacts, considered impractical to move, force the design team to relocate the meeting to the object.

When a design team works in a global setting, problems of conveying the artefact exist. Synchronous meetings in distributed teams can be held using telephone conferencing or video conferencing, these meetings are normally held in specifically designed conference rooms. In a videoconferencing session, smaller artefacts can be conveyed to the remote team members by displaying them in front of the camera. Visiting a workshop to view a large item such as a mock-up has yet to be explored. Mobile solutions for videoconferencing exist; i.e., PDA with conferencing software [2] and third-generation mobile phones. However, these solutions have

poor frame rate and quality and are inadequate for conveying artefacts. Other technical solutions are used to recreate a physical object in another place; e.g. augmented virtual reality, 3D scanning or multiple cameras and advanced image reconstruction. These solutions are presently stationary and very complicated to manage and are therefore not considered useful in industry today.

This paper presents tools and methods for interacting with large prototypes in distributed collaborative work.

2 Related work

Even though the modern computer tools can be used to visualise the complete product [3], the tangibility of a mock-up is still preferred at some stage of the product development process.

2.1 Artefacts in Design

In *The myth of the paperless office,* Sellen and Harper [4] describe paper versus its digital media counterpart. It was believed that with the introduction of the computer to the office, paper would become obsolete, since all documents could be accessed through the computer. But it seems that, with the introduction of the computer, paper has been used to an even greater extent. The advantage of paper over a digital document is that it is easily manipulated and tangible. Reading a paper is often preferred to reading a computer screen. The same argumentation can be used when it comes to computer models of a product.

Otto et al. [5 p. 834] define a prototype as *"a physical instantiation of a product, meant to be used to help resolve one or more issues during the product development".* Prototyping cycles offer an opportunity to bring together the various functions, determine the progress made to date and consider how alternative solutions might play together. [6]. As Ulrich and Eppinger [7] state, prototypes are used for four purposes;

- *Learning* – Prototypes are often used to answer questions such as "will it work?" and "does it satisfy the needs of the customer?"
- *Communication* – Prototypes enrich the communication of a project, especially for people on the outskirts of the project. The visual and tactile, three-dimensional representation of the prototype makes the concept much easier to understand.
- *Integration* – Prototypes are also used to ensure that components and subsystems fit together and work as intended.
- *Milestones* – Particularly in the later stages of product development, prototypes are used to prove that a desired level of functionality is achieved.

Larsson further stresses the importance of objects; the built-in versatility in physical objects can be used as *"shared objects to think with"* [8]. Various objects can be used to explain a concept or idea. The object itself does not need to be the finished product, but it still inspires the design team to imagine the finished product. Due to the importance of physical objects in design, the sharing of physical objects within distributed teams is necessary. Research within the DTI-project [8, 9] showed how global design teams do not have a shared space for physical artefacts. The team studied worked in a global product-development project concerning the novel design of a new pedal system. During the project, the team built many hardware prototypes. If the physical object was small, it was moved to the conferencing room, but if this was not possible (e.g., a pedal design concept mounted in a car), videotaping the prototype and sharing the video clip via a video server was the solution. This type of

communication enables sharing of information about the artefact and its use, but supports no interaction.

When following the design of components for trucks, Axelsson [10] pointed out the importance of physical objects. In co-located meetings, the team often went out to the workshop to inspect a stamping tool or analyze problem areas in the production process. To some degree, these issues could be solved in a distributed meeting by using a camera to document a specific issue before the meeting and send the photo to all participants before the meeting. However, the comprehension of the problem was much better when the team visited the workshop.

Harrison and Minneman [11] conducted a study on how objects or early mock-ups are used in conceptual design. They found that objects give the designers information that cannot be gained or is difficult to gain in other ways than to build and test certain concepts. Physical mock-ups are important in the product development process. Objects provide a rich source of information and can be more useful than other more abstract forms of product information, as well as enabling the design team to discuss the product and share the same perspective, to create a common ground.

2.2 Common ground

The term *grounding* refers to the mutual understanding between conversional 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 [12]. 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." [13]

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" [14].

Perry and Sanderson [15] found that sketches and other physical artefacts are often used to create a common understanding. Without a shared understanding of the task, the design team has little or no chance of success. The shared understanding can be reached through many things, but objects that support the ideas a team member is trying to communicate can be very important tools. CAE and CAD software also play a prominent role in engineering and design projects. They can act as a physical object does and, as a way of communicating thoughts and ideas, CAD models are more exact than the random physical object described by Larsson [8]. Though CAD models do give the design team something to discuss and form consensus about, the tangibility of a physical object is more easily communicated.

2.3 Mobility

Synchronous communication between distant team members is traditionally carried out from fixed locations; video conferencing is done from a conferencing room or from the team member's desktop machine. Few communication tools allow for user mobility. Luff and Heath [16] classify mobility in three different categories: micro mobility, local mobility and

remote mobility. *Micro mobility* is when an artefact can be mobilized and manipulated in a circumscribed domain, such as by moving a document or a handheld device so that another person can see the context. *Local mobility* refers to moving within the company, e.g., visiting another office or going to the coffee machine. Systems that support local mobility are usually interconnected using wireless LAN technology, or by direct interaction between wearable or otherwise mobile devices. *Remote mobility* is when geographically distributed users interact with each other over a distance using communication technology. Examples of remote mobility systems are third-generation mobile phones that support video calls, and in some cases, wearable computers if the network connection is sufficient.

Due to the limited size of its display, the mobile phone is best suited for synchronous voice communication and simpler asynchronous applications such as reading e-mail and SMS text messages. The limited bandwidth on video communication, even with the third-generation mobile phones, limits the usage of video for communication of artefacts.

Johanson and Törlind [17] presented a framework for informal, spontaneous communication between mobile team members. These tools include meeting-scheduling tools, awareness tools that can be used to check if remote users are available for ad hoc synchronous communication sessions, and transition tools to initialise synchronous communication (i.e. conferencing).

Wearable computing comprises a small body-worn computer that is always on and always ready and accessible. In this regard, the new computational framework [18] differs from that of handheld devices, laptop computers and personal digital assistants.

Some use the wearable computer as a communication tool. Steve Mann developed EyeTap [19] and described in Cyborg [20] how it can be used to aid communication. *"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 [21] uses a wearable computer at a public fair. Remote users can to some extent follow the person at the fair in a first-person perspective and interact with people at the fair via the wearer of the computer who is a mediator of the conversation. The wearer can even act as an expert in fields he knows nothing about through the help of remote experts that tell him the answers to any questions he may have or solve any problems he may face.

Several research projects have focused on how a user can be assisted from a remote site [22, 23, 24] using different types of head-mounted cameras. Fussell et al. [25] clearly demonstrate the value of a shared view for remote collaboration of physical tasks. Fussell et al. [26] also showed that a remote-controlled cursor pointer, visible in the head-mounted display (HMD) further enhanced the collaborative process.

3   Method

The method used in the research presented in this paper is based on descriptive/prescriptive studies similar to the Design Research Methodology of Blessing et al. [27]. This includes stages of description, followed by prescription with a second descriptive study used to validate the results of the prescription and description. The goal of the first descriptive study (section 4) was to investigate how a co-located design meeting at the prototype was realized

and attempt to recreate the same experience in a distributed setting. In the prescriptive phase (section 5), a new tool for enabling distributed product review was built. The following descriptive study (section 6) considered the effects on the implementation of the new method and tools.

Drawing from the concept of ethnomethodology [28], 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 system was recorded via the handheld video camera at the mock-up and another video camera was set up at the collaborating site, either in a conference room or at the desk of an engineer. Comments and the course of events from the videos were transcribed and analysed.

The case study is based on a 6-month case study at Land System Hägglunds AB, situated in Örnsköldsvik, Sweden. The company 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.

4   Co-located design review at Land System Hägglunds

The design team of the studied project comprised seven engineers and a team of mechanics working with the physical mock-up of the mortar system. Due to space constraints at their main office, some team members were forced to move to another facility. The mock-up was built in a workshop at the main plant, 7 km from the city centre where the engineers were situated.

In the design practice at LSH, prototypes are built to verify the design. The main purpose is to make sure that every part fits together and works. Parts or subsystems do not always work as intended, which means that the engineers and the mechanics building the mock-up have to work in close collaboration with each other to solve any problems that occur.

The prototype also gives the design team a physical mock-up that is an aid to discussing further improvements as the design progresses. The prototype also ensures the fit of subsystems. At least once each week, the entire design team (including the mechanic responsible for the assembly of the mock-up) gathers around the mock-up for a design review. A typical design review has an agenda consisting of current design issues. Usually, one designer is responsible for each point of the agenda and the other members advise him on how to resolve the issue in question. The mechanic also points out problem areas for the design team to discuss. Often, aspects regarding the interface between different subsystems may involve the entire design team.

A difficulty occurs when the problem resides within the vehicle; due to space constraints, only one or two of the design team members can be inside the vehicle at the same time. The other team members are left outside and have to peer through openings and manholes. Since they have difficulty seeing the object of interest, they are not always able to follow the discussion and are therefore unable to contribute to solving design problems.

Between these design reviews, the mechanics at the workshop may encounter problems that need attention. The mechanic will call the engineers to discuss the problems over the phone,

which is often an inadequate means of communication for describing the problem. To clarify the mechanical design and describe the problem, the mechanics sometimes fax visual information in the form of CAD images. In attempting to reach a common ground and solve the problem, these drawings and pictures are often hard to interpret. Explaining the problem usually takes too long or is too frustrating, so the issue is postponed until the next physical visit to the mock-up.

As the LSH design team was used to working in close proximity to the prototype, going to the prototype was not a big issue. But when some of the engineers were located roughly 7 km from the prototype, visiting it took a lot of time. Visits to the mock-up usually took about two hours. Of that time, five to ten minutes where spent negotiating at the mock-up with the mechanic and other engineers, the rest of the time was spent travelling. Due to the fact that they had to travel to the mock-up site, the engineers had a tendency to accumulate problems, so that all problems could be addressed at the same time when visiting the workshop. Though postponed design issues were not documented, they could sometimes be forgotten.

5   Design of the Mobile Conferencing Node

The team needed some type of tool that could support the distributed design review (without relocating to the physical prototype). The overall goal was defined as: *"a mobile collaboration tool for distributed design review"*. From the first study, design requirements were derived. These requirements also correspond to the measurable criteria in the Design Research Methodology [27]:

- Local users must be able to share their view of the physical artefact with remote users.
- The node must enable virtual visits at the mock-up, at any time from anywhere.
- It must enable sharing of digital information (i.e., drawings, CAD-models, documents) between users.
- It must be easy to use.

The detail design of the mobile conferencing node is further described in Bergström et al. [29], the following sections briefly describe the design rationale used.

5.1   Sharing the view of the physical artefact

To conduct a distributed design review the tool had to be mobile, so the user could move around freely in the workshop. Arrangements with fixed cameras or cameras with cables were therefore inadequate. A mobile solution involved some type of computer, display and camera. The solution had to be accessible without interfering with normal work (in essence, a wearable computer). By utilizing a wireless network, the user was able move around freely within the reach of the wireless network. The solution had to be robust, so the user could interact inside the prototype without damaging the communication equipment; therefore, the computer was mounted in a hard-shell backpack.

Different types of cameras were tested and the final design of the wearable computer had two cameras:

- The first camera was mounted on the headset, giving the remote users the same view (first-person view) as the user at the mock-up, the advantage being that the person wearing the equipment had both hands free. The camera was supplemented with a laser pointer to indicate in which direction the camera was pointed. The laser also

provided a pointer; without the laser pointer the user needed to reach over and point to the object, thereby obstructing the view for 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 mock-up that were invisible due to obstructing panes. The advantage of being able to view behind panes with a handheld camera was sometimes found to be more important than having both hands free.

The user could choose to transmit the signal from the handheld DV camera or transmit the signal from the camera mounted on the headset. For display of the remote video from the other users, a head-mounted display (HMD) was used and mounted on the headset, which also protected the user from unwanted noise coming from the workshop. The mobile conferencing node can be seen in Figure 1.

Figure 1: The wearable computer in use

5.2 Enable virtual visits

Communication between the workshop and one or several remote users should be easy; therefore, a commercially available video conferencing system, Alkit Confero, was used. This is IP-based conferencing software that supports point-to-point conferencing as well as multipoint conferencing with audio and video. By using multicast, any number of users can connect to the mobile conferencing node from any computer with proper software installed.

5.3 Sharing of "virtual" information

In the design reviews, it is important that everyone in the team can participate in the discussion and share important information with all other members of the design team. The mechanics can view CAD models remotely by sharing an application, i.e., a CAD program. Together, they can discuss different design issues and clarify the design.

5.4 Ease of use

One important issue was the ease of use; the system had to be as simple as possible to use. Wearable computers normally have a general input unit, a combination of a miniaturized keyboard and mouse e.g., Twiddler. With such devices, the wearable computer is more flexible. However, it takes time to learn to use these devices [30].

The system had to support three basic modes of operation: *collaborative mode, tangible sharing mode* and *application sharing mode.*

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. The main purpose of the wearable computer was to give the remote partner a view of objects.

Collaboration - remote video to the HMD. The system could be used as a videoconferencing tool, enabling users to communicate via audio and video for discussions and enabling the remote partner to communicate visual cues, Figure 2. The drawback of the system is that it is hard for the user of a wearable computer to use the tool to make himself visible to the remote partner.

Sharing of virtual documents. The tool also supports the sharing of applications normally run on a remote desktop computer (e.g., CAD-data, drawings, etc.), see Figure 2.
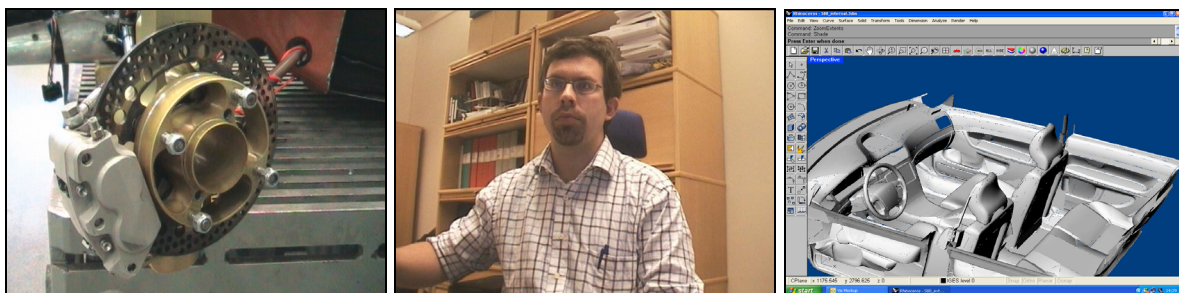

Figure 2: The three modes of operation, from left to right: the transmitted video, the received video (remote user) and CAD data received via VNC. For reasons of confidentiality, actual pictures from the mock-up cannot be published; hence, all pictures are illustrated or taken outside Land Systems Hägglunds AB.

A simplified user interface of the conferencing system was developed to switch between these modes. The user interface consisted of a single button that allowed the user to instantly switch between the modes. All modes are displayed in full screen in the HMD.

6 Communication of Physical Objects in Distributed Design

After implementing the mobile conferencing node at the workshop at LSH, the effects of the new tools and methods were studied. After a period of test and evaluation, the setup was used instead of visits to the workshop.

The remote users visit the mock-up in a first-person perspective through the wearable computer; the wearer of the equipment takes the remote user on a tour of the mock-up and can discuss objects of interest, see Figure 3.
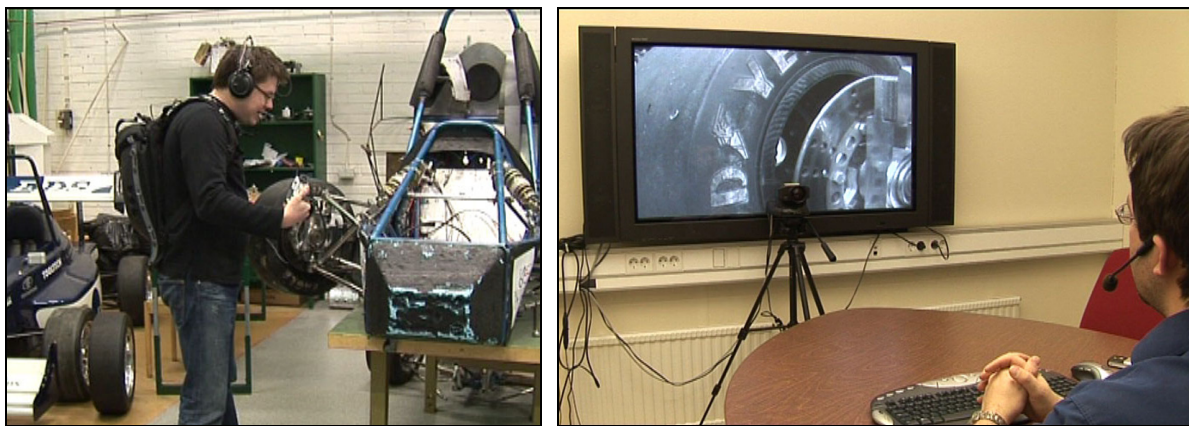

Figure 3: Left, the wearable communication node in action. Right, the view from the remote site [i].

A schematic figure of the setup can be found in Figure 4. The usage of the communication system can be divided into three distinct set-ups. In all set-ups, the mechanic is wearing the mobile conferencing node;

1. *Workshop – Office:* The engineer sits at his desk and wants to communicate with the workshop. A session is started and the mechanic and the engineer can discuss matters of interest with the visual support from the mock-up and visual support from the engineer's CAD data.

2. *Workshop – Conference room:* The design team can assemble in a conference room and view the video. With a shared perspective, everyone can participate in the discussion.

3. *Workshop – Workshop:* A local conference is initiated. Persons at the workshop can view what is happening inside the vehicle while at the mock-up. This is somewhat like workshop-to-conference room; the difference is that it is less organized.

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[i] A video clip demonstrating a distributed design review, *http://www.cad.ltu.se/media/GettingPhysical.wmv*
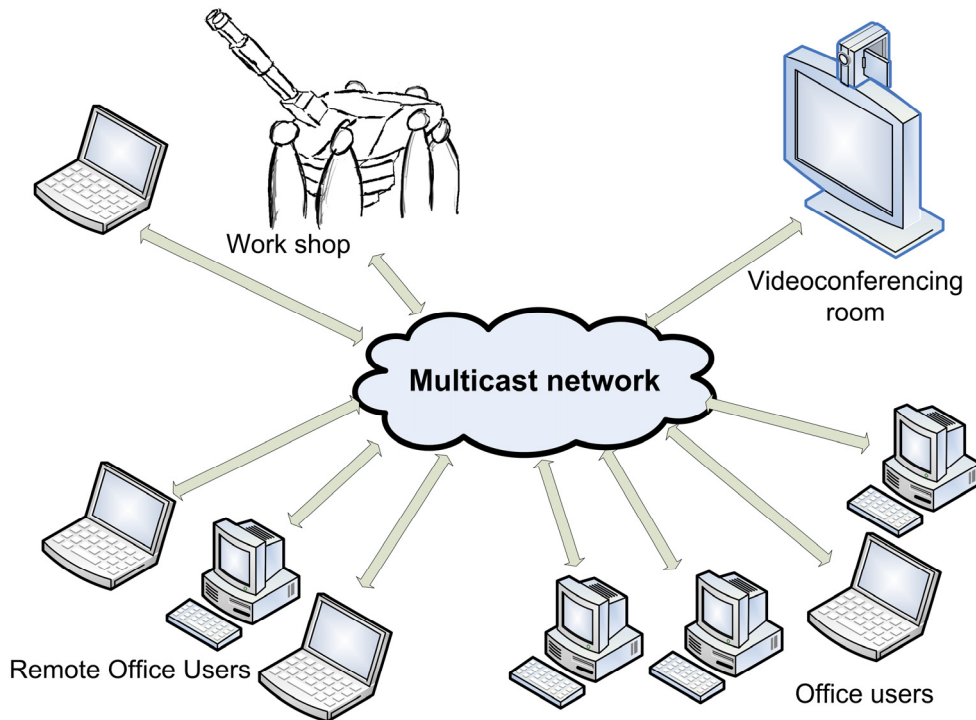
Figure 4: Schematic illustration of the system in use over a multicast network.

Sometimes, the set-up varied over time or was adapted to suit specific situations:

Example 1: *The mechanic has problems in fitting two subsystems. As he knows that one of the engineers just has finished the design of one of the systems, he gives him a call to discuss the problem. The engineer wants to see the problem for himself, so they start a videoconferencing session. The two subsystems do not fit together in real life. Together they view the CAD model to figure out what is wrong. The engineer shares his view of the CAD system with the mechanic. Via application sharing, the mechanic views the CAD model at the mock-up through the HMD. The engineer asks the mechanic to measure parts of each subsystem to figure out which subsystem does not correspond to the CAD model. They conclude that something must have gone wrong with one of the subsystems in the production phase. Subsequently, the system must be produced again.*

Example 2: *The mechanic sets up a videoconference with an engineer to start discussing a problem. After the discussion has been in progress for some time, the engineer asks a colleague to join them from his desk. At the same time, one of the design team members visiting the mock-up joins in on the conversation on-location.*

Example 3: *A distributed design review is going on in a conference room; the mechanic is wearing the equipment and showing the people in the conference room something. The engineers in the conference room discover that, to solve the problem, information from the electrical engineers is needed. The electrical engineering project manager is contacted over the phone and can immediately start up the videoconferencing application on his regular desktop computer and join in the meeting to supply the necessary information to resolve the issue.*

7 Conclusions

This is an initial study on the impact of a tool for distributed collaboration allowing remote users to receive remote video and audio from a physical object. The new tools allow remote users to enter a first-person conferencing mode (the remote user does not see the remote collaborator, but shares his view of the world). The tool also fulfils all of the requirements stated in section 5.

With the introduction of the wearable conference node, the engineer can contact the mechanic on the phone and ask him to start a videoconferencing session, have the meeting and solve the problems in a ten-minute timeframe. Without the tools, the same design issue included travel to the remote prototype and could take two hours to resolve. Sharing of information is important for the success of a project. Application sharing enables the mechanics to view CAD data remotely with the engineers and they can discuss the information either via telephone or via the videoconference system. Application sharing is also implemented in the wearable computer; hence, *the engineers can share their "virtual" CAD data simultaneously with the mechanic, who shares his "physical" data with the engineer*. This gives all members of the design team access to information regarding the project within minutes without requiring them to relocate. The advantage for the mechanic is that he will no longer have to explain to the designers what has gone wrong but can simply show them. The engineer can decide if he needs to go to the workshop; the advantage of not leaving his desk is that all the information is available to him (at his desk or in the computer, e.g., post-it notes, Word documents, CAD models, catalogues). Still, he has the opportunity to relocate to the workshop if he feels that it is beneficial. Likewise, the mechanic does not need to rely on the next visit by the engineer to get the information he needs; he can simply contact the engineer at any time to invite him on a virtual visit to the workshop.

Design reviews at the mock-up were usually overcrowded, with designers peering through manholes to get a glimpse of what was currently being discussed. The introduction of the wearable computer has changed the reviews, allowing everyone to get the same visual view of what is currently being discussed. The users can even look behind panels and view items that are normally hidden from the user's sight. Hence, a co-located design review can also benefit from the new tool. The distributed design reviews are in some ways *better than being there* [31]. The mobile collaboration tool enables users to do remote design reviews. Potentially, this might lead to the abandonment of the traditional co-located counterpart, since this method for remote collaboration is more time-efficient.

By utilizing multicast, any number of users can connect to the mobile conferencing node from any computer with the proper software installed. Engineers can connect to the session and "eavesdrop" on meetings that might be of marginal interest, hearing what is discussed in the session while continuing to work at their desk.

Sometimes, seeing the physical objects is not enough; the user might need more information, such as weight of objects, friction between objects, etc. In the DTI project [9], a distributed team designed new pedal concepts for vehicles. Team members could easily share the geometry of a concept (using a shared applications and CAD models), and discuss the physical object in a videoconference. They could, however, not share the "feeling" and "experience" of driving with these pedals without having physical prototypes at each site.

It is still difficult to share tactile properties remotely, such as the response of a mechanical prototype. Potentially, these types of communication could be beneficial in many settings.

Another important issue is the possibility to record a shared design review. Such recordings can be used to document the design rationale and to store decisions made in the design process.

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