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DISTRIBUTED ENGINEERING VIA BROADBAND - A CASE STUDY

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Abstract

Coordination and exchange of information between participants in a distributed product development team is technically difficult and time consuming. Different locations and time zones further complicate communication. It is therefore important to provide tools and methods so that a geographically distributed design team can collaborate as teams in the same location do.

Two partners located 430 km apart, which previously had worked together without distributed engineering tools, were given the possibility to work together using the tools for distributed engineering developed at Luleå University of Technology in cooperation with Alkit Communications AB and SICS. These tools support conferencing, shared multimedia (documents, audio and video) and a virtual reality environment for sharing engineering information. The communication tools were implemented on top of a 155 Mbit SDH network. By using distributed engineering technologies the competence in both places was used better. The distributed engineering tools and methods contributed to better focus and collaboration instead of consulting. The computer tools also simplified all contact and enabled meetings several times a week instead of one every two weeks. A new tool for video annotation is also presented.

Keywords: computer supported cooperative work, computer aided design, distributed product development

1. Introduction

Engineering design is fundamentally social, requiring a lot of interaction and communication between the people involved [1]. Additionally, good design often relies upon the ability of a cross-functional team to create a shared understanding of the task, the process and the respective roles of its members.

The object of the research is an engine development project at Hägglunds Drives AB where the consultant firm Conex AB does computational engineering simulation on engine parts. The two companies are situated about 430 km apart so when they meet physically they need to travel 4-6 hours one way.

The products at Hägglunds Drives are mainly hydraulic motors for high-demand, reliable power within industrial and marine applications. The department of product development at Hägglunds is quite small so in the everyday work the information flow is informal. Documentation is only done when major design decisions are done, although all products are designed in a CAE environment so the final design is always documented. Hägglunds normally do engineering computation in-house but when developing new products they normally outsource some of the simulation to specialists. Conex AB is a small consultant company in Luleå which specialises in product development and simulation. Conex and Hägglunds have previously worked together and all persons involved in the project where familiar to each other.

The two companies are used to working together in the traditional way using e-mail, telephones and fax to communicate between the formal project meetings which are held every second week. Due to the long travel for the project meetings the consultant had to be extremely well prepared for the meeting; it was unacceptable to forget something at home.

2. Related work

Several studies of distributed collaboration have shown that distributed collaborators have problems with information transfer and common understanding [2,3,4]. Time difference, cultural difference, proximity, awareness, communications latency and heterogeneity are also other challenges for distributed teams [5].

Many research systems for asynchronous distributed engineering based on Internet or web solutions have been developed. Wang et al. [6] further explores existing technologies for collaborative conceptual design. One of the largest research projects in integrated product development is the Integrierte Virtuelle Produktentstehung (IVIP) [7]. The IVIP project creates a framework for integrated product development with tools to support product development in a distributed environment. The focus, however, is not on synchronous collaborative design.

Today almost all commercial PDM and CAD systems are also "web-enabled" which enables access to product data via the Internet where it can be used for discussions, collaboration and marketing. Such systems, however, were not originally developed to support collaborative design. For this to take place, synchronous distributed collaboration is required where people can share, interact and communicate product information using Internet based systems in real time. Several research systems such as [8,9,10] have been developed. Some distributed engineering environments are based on a distributed virtual reality environment where different engineers can have different points of interest and active interaction, such as the Distributed 3D Virtual Conference Environment (VCE) [11], and the distributed collaborative engineering environment (DCEE) [12].

Engineering design is not only to exchange and share CAE models. Toye et al. [13] claims that: *"team design is a process of reaching a shared understanding of the domain, the requirements, the artefact, the design process itself and the commitments it entails. This requires communication that is not supported by current CAD tools and PDM systems."*

One way to support this shared understanding is to use audio and videoconferencing [14]. Many of the systems used today are designed to be used in telephone infrastructure such as ISDN-based systems or via the Internet. These systems have the disadvantage that they are optimised for operation in low-bandwidth network environments which, due to the fact that they use highly lossy image compression algorithms, do not scale well when the available bandwidth increases. Bruce [15] suggests a frame rate of 17 fps to convey facial cues, especially lip-movement. He also highlights the importance of a good, dynamic view of the speaker's face to minimise the effect of noise in the audio signal, since even people with normal hearing can lip read to some extent. The audio delay in the system is also very important; Bruce showed that a maximum delay of 80 ms is tolerable without severely compromising the interactivity of conversation.

Perry and Sanderson [16] found that sketches and other physical artifacts are often used to create a common understanding. CAE and CAD software also play a prominent role in engineering and design projects. In collaborative distributed engineering and design, it is therefore important to support shared views and shared control of these systems. Shared application systems enable people sitting in different places to share applications (i.e. windows). All users are forced to share the same view that is controlled by only one user at the same time.

Riesenfeld et al. [4] describe a multi disciplinary design project where a small distributed design group used videoconferencing via a video network and an experimental client server based CAD program. In this project the development time was greatly improved. However the team had problems with spontaneous synchronous meetings, such as distributed brain storming, due to the availability of the videoconferencing system which had to be scheduled in advance. The voice and video lag during teleconferencing was also found detrimental to the spontaneity of the design process. Sclater et al. [3] describes several studies on collaborative design projects; they highlight that a poor physical environment contributed to communication difficulties, and that the right physical environments must be provided to ensure effective work in the virtual one. When using video cameras for communication the quality was poor and that audio/video synchronisation caused dissatisfaction. But their conclusion was, however, that asynchronous communication such as videoconferencing and chat are an important part of the design process.

Törlind et al. [17] presented a distributed engineering environment with high quality conferencing and a distributed VR-environment for sharing geometry. The result was that pure CAD systems are indispensable for doing serious mechanical engineering whilst shared VR-systems provide unparalleled support for visualisation and conferencing in distributed virtual environments. It also demonstrates that high-quality audio/video is invaluable for creating a feeling of presence and contact. This environment was also enhanced [18] with tools for awareness and informal communication.

3. Method

The research described above influenced the initial design of the collaboration tools, and over the course of the study some small adjustments were made to improve the collaboration tools. Ethnographic techniques [19], such as observations, video and tape recordings, informal interviews and field notes have also been used to gain a better understanding of the work activities that the system is supposed to support. This qualitative approach was combined with quantitative data derived from system log files e.g. timestamp, bitrate, video size etc. Also, by taking a screen capture of the computer screen every minute, it was easy to follow a conference, to see how cameras were used, and to check the quality of the video in the conference.

4. Design and Implementation

To enable the distributed collaboration, a broadband infrastructure was realized between the two partners. The network between Luleå University of Technology and Hägglunds in Mellansel was based on a 155 Mbit SDH network from Telia. On this infrastructure an ATM network with classical IP was used. Between LTU and Conex a dedicated 100 Mbit Fast Ethernet connection was used.

The distributed engineering environment that was implemented on top of this infrastructure contained several tools (categorization from Maher and Rutherford [20]):

- A shared workplace width multimedia conferencing, shared applications and distributed VR.
- Data management. Web-based document servers and shared databases for CAE.
- An application domain, FE-programs and other simulation tools.

The computer setup at both places consisted of SGI O2 for videoconferencing and some PCs for word-processing, etc. At Conex a SUN Ultra 60 Unix workstation was used for CAE, an image from the environment can be found in Figure 1.

Figure 1 The physical setup at Conex in Luleå.

The audio for videoconferencing was based on headphones and omni directional conference microphones with duplex audio. The video cameras used in the setup were Sony EVI-D31 which could be remote controlled using the videoconference application.

4.1 Computer tools

The environment used some commercially available tools such as Microsoft NetMeeting, VNC, BSCW and research prototypes such as Alkit Confero and DIVE. In the project several new tools were introduced, and the learning threshold for some tools such as the distributed VR-system and advanced features in the document server was quite high. These functions were therefore gradually introduced in the project.

The conferencing used was the Confero system developed by Alkit Communications AB. Confero [21] is an integrated audio-/videoconferencing system developed to provide the high-quality interaction necessary in a distributed engineering situation. When engineering teams meet to discuss product designs, it is of great value to be able to view animations generated from the CAD systems. Functionality has been included in the Confero system for streaming animations to all members of a conference.

Application sharing was done using SUN Forum, Microsoft Net Meeting, and SGI Meeting which are all use the T.128 Protocol for application sharing [22]. The VNC program [23] was also used.

The distributed VR system DIVE was used to share and communicate geometrical models. It is based on the Distributed Interactive Virtual Environment (DIVE) [24] developed by SICS. DIVE is an internet-based multi-user VR system where participants navigate in 3D space and see, meet and interact with other users and applications. An interface between the CAE system and DIVE gives the user of the virtual environment direct access to the CAE-database [17]. The user can access projects in the CAE-program and access all models (i.e. parts and assemblies) available in the database in the same way as they would access the models when working in the CAE-program.

5. Results

During the project video cameras were used to create an open video link between the collaborators. The result was that the video links enhanced the sense of working in a shared physical environment. During the project, information flow was changed to a more informal way of working; regular formal project meetings were still held about once or twice a week, but now using the distributed tools, so no travel was required. Several people from each company attended the distributed meeting and an agenda was prepared in advance. At these meetings results and findings were discussed, formal decisions on how to proceed were made and the meeting was documented in a regular way. Between these formal meetings several short informal meetings were held to clarify problems, check the results of the latest simulation or just for casual conversation. This kind of informal communication created a better understanding of the real problem in the project. The need for physical meetings was reduced to a minimum; during the case study only one physical meeting was held in the beginning of the project.

5.1 Simulation presentation

In the study the DIVE system was only used a few times. One of the main reasons was that the project was a computational problem that should be solved and no new geometry was created during the project. The users also found the navigation and interaction in the VR-program a little complex. The findings from earlier work [25] show that VR programs are really useful if the collaboration deals with the design of new geometry in a complex product with many parts.

The application sharing program was used successfully when sharing documents and agendas, but not as well for interactive sharing of 3D-geometry and simulation results. This is because the application sharing program did not scale well enough, though the network bandwidth was better between the two sites than within the local network, e.g. the user could not interactively move a result set, instead he interacted and waited for a while until the remote computer had updated the picture. When explaining complex results, animations were created in the FE-application and then streamed from a video server to the remote participant.

5.2 Sketching

When working with electronic documents and drawings, the distributed team used shared whiteboards for mark up and annotation. When the mouse is used for annotation in a figure, the result was only rudimentary sketches; see an example in Figure 2 a.

In Luleå a Wacom digitizer was used instead of the mouse and this simplified the interaction significantly, but there were still usability difficulties because the user has to learn to draw on the digitizer and look at the computer screen.

A normal meeting often used a traditional paper drawing for discussion. The paper drawing was not available in an electronic format; in order to use the drawing in a whiteboard application the drawing must be digitized or scanned and then saved in the right place and finally opened in the shared whiteboard. This process was too cumbersome and the electronic whiteboards were difficult to work with, so instead a drawing was placed on a wall and the camera was zoomed into an interesting area.

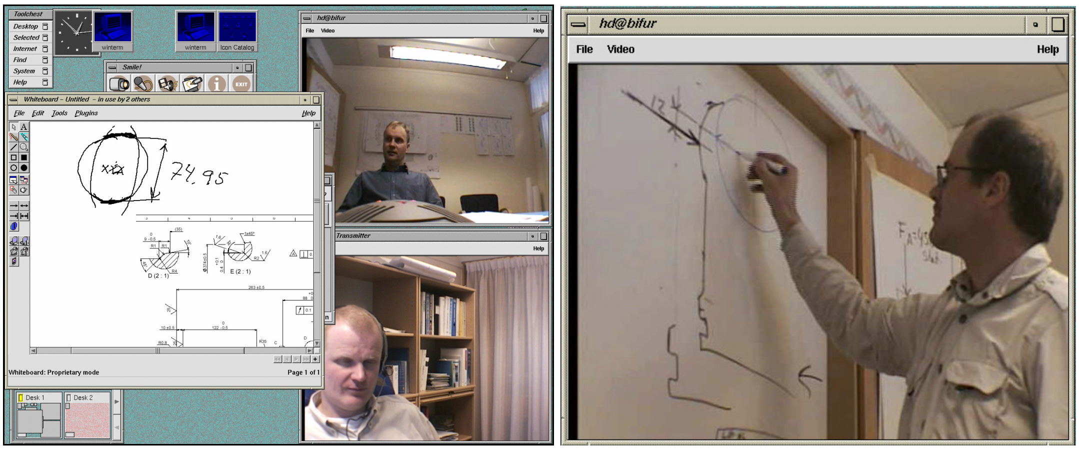

Figure 2 a) An example of annotations in a digital drawing.
b) Using a normal whiteboard, the view from the remote site

5.3 Measured data

During the project video was always used. The average bitrate for video was about 3 Mbit in each direction and the bitrate for audio 512 kb. The average total bandwidth for conferencing was 7 Mbit. The peak level for videoconferencing when streaming video is about 8 Mbit in one direction.

The average frame rate was about 21 fps and the video size used was 540x432 pixels, this size was used so both windows could be tiled without overlapping. Late in the project the function for scaling down the sending window was implemented.

The conferencing system was started 107 times during the period. The system was often left running when no meeting was being held, as an awareness camera or pointing out of the window, thus establishing some sense of "being there".

6. Discussion

There may be a problem of comparing two different methods of working in product development because a project is never the same-different people work together; the quality of the work can depend on several causes not connected to the project, such as the workload of the people involved; personal relations; etc. In this case the two companies had worked together before without distributed engineering technologies, so by comparing the way of working before and after the implementation, some conclusions can be drawn.

The advantage of using the distributed engineering approach was that communication was better than usual, though the conferencing environment enabled a dynamic and flexible personal contact which is much better than phone and e-mail. Fewer mistakes were made and the quality of the work was better.

The amount of travel decreased to almost nil; the consultant from Luleå travelled once to Mellansel for the kick-off meeting, after which all meetings were conducted using the distributed engineering system. In a similar project, the group held meetings every second week; therefore, in a six-month period, about 120 h of travel was avoided.

By storing all information in the project in a document server, all information was accessible for everyone in the project. By using these tools, not only CAE-models and documents but also the knowledge at the company are available. If additional expertise is needed, it's easy to bring another person to the meeting.

6.1 Audio and video

In a meeting with several users, an open system was tested with omni-directional microphones. The problem with this solution was the acoustic feedback. Instead a conference microphone/loudspeaker unit with echo cancellation was used. The audio quality of the conference microphone was unsatisfactory because it clipped audio and made simultaneous conversations (i.e. interrupting someone) almost impossible. Whilst active echo cancellation can be used with an "open" system consisting of omni directional microphones and a speaker system, this is computationally intensive and often requires dedicated hardware support, which is normally designed for ISDN-based videoconferencing and uses a low sample rate which is inadequate for Confero.

The conferencing environment was designed for small groups, and therefore it was not appropriate for meetings with more than three people. The display size (normal 21" CRT monitors) was too small when used in a large group. These problems with audio and video has been solved in another project [26] by using wireless microphone and plasma display or projection systems.

6.2 Sketching

To support the sketching on paper described above, remote camera control was used. A new tool, video annotation, was also developed. With this tool it is possible to annotate within the video window; see Figure 3. The annotations could now be done on paper drawings or other physical objects.

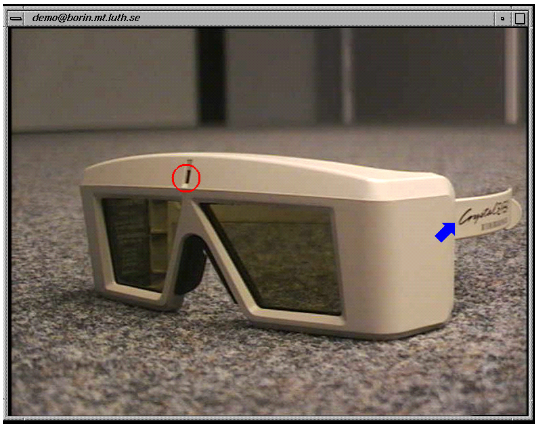

Figure 3 Video annotation in Confero

6.3 Simulation results

Large FEM simulations often consist of very large datasets (elements with node information and result data such as strains and stresses), and they are complex to store and distribute in an efficient way. The distributed VR-system DIVE used in this project could not handle these extremely large datasets. Instead, the programs for application sharing in combination with still images and animations where used for sharing and storing simulation results; see Figure 4 for an example.

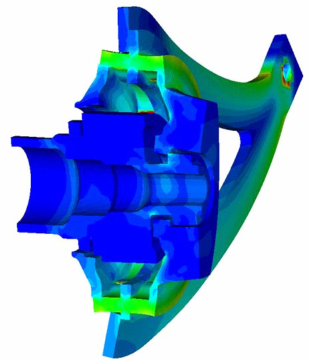

Figure 4 A typical FE-model of the hydraulic motor with approximately 100 000 elements

6.4 Infrastructure

The bandwidth used in the study varied between 10 Mbit and 15 Mbit continuously, with peak transfers up to 80 Mbit. Therefore the need for broadband networks is quite obvious. Since the case study was performed using a dedicated network, in this case a SDH connection, no resource reservation issues had to be considered. In a public networking environment, however, this is a critical factor since the performance of the synchronous collaboration tools (i.e. the audio-/videoconferencing tools and the shared applications) is dependent on the available bandwidth and on transmission delays. On public networks security issues are important. Technologies such as ciphering and VPN (Virtual Private Network) are necessary.

7. Conclusions and future work

This paper presents a case study done over a period of six months where two companies used distributed engineering tools via a broadband network. Several distributed tools and the usage are described. The study confirmed that the use of high-quality video and audio for teleconferencing made it easy to work together for long periods of time. The users of the system consider that the quality of the audio in the conferencing system is much better than using a telephone. To avoid audio feedback it is desirable to use personal microphones instead of using conference microphones.

Computer tools simplified all contact and enabled meetings several times a week instead of one every two weeks. The focus of the project is better when using distributed engineering technologies, and the competence and knowledge at both places were used in a better way because the communication tools simplified communication. It was easy to schedule a new meeting in 30 min to bring in a production specialist.

Also, informal communication within the project was improved. For the consultant the project changed from an ordinary consulting assignment (with design goals, weekly progress reports and a final delivery of a design document) to a flexible collaboration project where there was true cooperation between the companies, where ideas was discussed on a daily basis, problems were rapidly solved and new directions for future work came up. The distributed team could work in the same way as a co-located team.

The system consisted of research applications and commercial applications; some of the function was also duplicated and available in several applications. Some of the tools were difficult to use (e. g. sketching with a mouse in the electronic whiteboard vs. with pen and paper). The knowledge about distributed collaboration tools was very low in the beginning of the project. Applications for collaborative work are not used so much in industry and are not traditionally being taught at universities, so one important future goal is to improve tools and methods and also use these tools in education in the future.

Some general conclusions are that high quality conferencing can improve communication substantially. References to physical artefacts such as sketches in the (remote) room can easily be done. New distributed tools should resemble traditional tools, use well known metaphors or enhance normal tools so they can be used in a distributed settings. A good example is the e-beam application which uses a normal whiteboard were all information is digitized and sent to the remote user.

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