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A FRAMEWORK FOR DATA COLLECTION OF COLLABORATIVE DESIGN RESEARCH

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ABSTRACT
In design research different methods are used to develop a descriptive understanding of a design activity. One approach is to use video and audio recordings of complex activities such as team meetings in engineering design. Video and audio recordings provide the researcher with a permanent data corpus that can be used to understand events considered difficult to observe in real time. The video approach also has several limitations, especially when observing distributed teams.
This paper describes the needs for a data collection framework of distributed meetings, and how a prototype system has been realized. It also presents a framework on how a physical environment – *the design studio* – can be used to further facilitate design research.
The presented tool is based on a conferencing system where additional video streams from the design environment can be recorded (showing detail views of interesting areas etc.). The tool uses a layered video approach and all video streams can be recorded and replayed for analysis. The tool supports visual and textual bookmarks that can be used to find a particular event in the recorded data. The tool clearly has some advantages compared to traditional data collection methods and enables researchers to follow distributed design sessions.

Keywords: computer supported cooperative work, distributed product development, data collection, design studies.

INTRODUCTION
Ethnographic techniques are often used in engineering design to collect information and data from engineering work where manual observations, field notes and interviews are combined with video and audio recordings of the design session, and later analyzed [1]. This approach has been used in the Polhem Laboratory for the last ten years, when researchers have followed several product development projects [2]. These projects involved both distributed and co-located design teams, and have mainly been of two types, namely *industry projects* and *university projects*. In industry projects [3,4], the researcher follows an industrial product development project over a longer period of time. University projects have followed global student projects within the Sirius course at Luleå University of Technology [5,6,7], i.e. the final-year course in product development for engineering undergraduates studying towards an MSc. in Mechanical Engineering. Sirius involves teams of students carrying out a product development project in close cooperation with industry partners. The global teams have typically consisted of a about four local students and four students from another site with similar courses, both nationally (Royal Institute of Technology, SE; Chalmers, SE) and internationally (Stanford University, USA). The project also includes a large amount of communication between the students and the industry sponsor that provides the industrial context, requirements and funding.
The main advantage of following a university project is that the environment can be controlled more easily, and methods, groupware and technology can easily be deployed. University projects typically last about nine months, when several iterations of technology and tools are implemented and evaluated [8]. Also, the researcher has the advantage of close proximity to at least one group of students.
Following teams in industry gives a more accurate view of an industry related problem, and also an introduction to a more complex environment. Product development in industry is often done in large teams and can be very difficult to follow, even for a large research group. It is also difficult to

instrument the team environment, and the use of video recording is often restricted due to company regulations and is thus limited to interviews, field notes, etc.
As well, it is easier to conduct a descriptive study in industry rather than attempting to intervene and change the work process by introducing new methods. Even more difficult is the issue of implementing new software tools in strictly restricted environments, when the process of deploying a new tool in the existing environment of a large company often follows strict regulations and includes a process of conformance testing, security assessment, etc.
In Luleå, combining ethnographic observations of engineering work in industry with university projects and controlled experiments has solved this dilemma. From descriptive studies in industry relevant issues can be identified and then further evaluated in an experimental setting [9]. An environment for these types of studies was realized through the design of a new collaborative design studio.
This paper describes the advantages and limitations of video based data collection and analysis, along with formulating the needs to overcome some of the existing limitations when following distributed meetings. Finally, the paper describes the development of a prototype system, i.e. a framework for data collection.

DATA COLLECTION IN DESIGN RESEARCH

Data collection from design sessions normally comes from experiments or from the actual engineer's practice. One guiding principle of Ethnography is to study the activities of people in their natural setting [10], without interfering with the ongoing work. In research fields such as CSCW and HCI, the usage of video recording to observe people interacting with different types of technology (hardware, user interfaces, etc.) has been used for many years as one component for interaction analysis [11]. In design research, the Delft second delft workshop *Research in Design Thinking II - Analysing Design Activity* [1] popularised the method of using video and audio to analyse and understand design work. For many years, The Center for Design Research at Stanford University has used the *observe-analyse-intervene* approach initially described by John Tang [12] and developed specifically designed physical environments [13, 14, 15] to simplify data collection in design research.
Several techniques to collect video and audio exist, though data collection is traditionally based on the use of several cameras to record the design work from several angles and microphones to collect audio from the design session. By only recording video data much of the interaction is missed; team members in a design session often interact with different types devices, such as laptops, stationary computers and mobile devices.
Badke-Schaub and Frankenberger [16] differentiates between *direct* methods and *indirect* methods where the direct method uses observation of design work (or analysis of video recording) and the indirect method consists of analysis of, diary sheets (papers with notes from problem solving) containing design rational etc. Badke-Schaub and Frankenberger conclude that this type of indirect data enriches and complements the data collected from the direct methods.
The capturing of meeting information from several sources has been a topic of research in several communities, such as the *Workspace Navigator* [15], *Quindi Meeting Companion* [17], and *Ferret Browser* [18]. These tools are primarily designed to capture information in one specifically equipped room and can store and index multiple streams of data from the work environment, e.g. video, audio, slides from presentations, etc., all of which are time stamped and presented on a timeline.
Screen recording software is also a useful source for workplace analysis. Tang et al. [19] conclude from a study using Camtasia screen recording software that it is *"Unobtrusive but invasive"*, as well as collecting rich empirical data without interfering with their normal work practice (no physical presence of a physical observer or video equipment). However, they also conclude that the disadvantage is its invasiveness replicating all interactions with the computer.

A physical research environment for data collection – the Collaborative Design Studio

The collaborative design studio is designed as a *"rapid-response environment, in which the significance of issues raised through ethnographic observations of engineering work can be evaluated and solutions offered"* [9 p1].
The main goal with the new studio was to *"Create a flexible research environment where new innovative ideas can be deployed, tested and evaluated. The environment will support local as well as*

global creativity. Trough the strong connections with the Faste Laboratory and the Sirius project the new environments will be evaluated in global product developments projects".

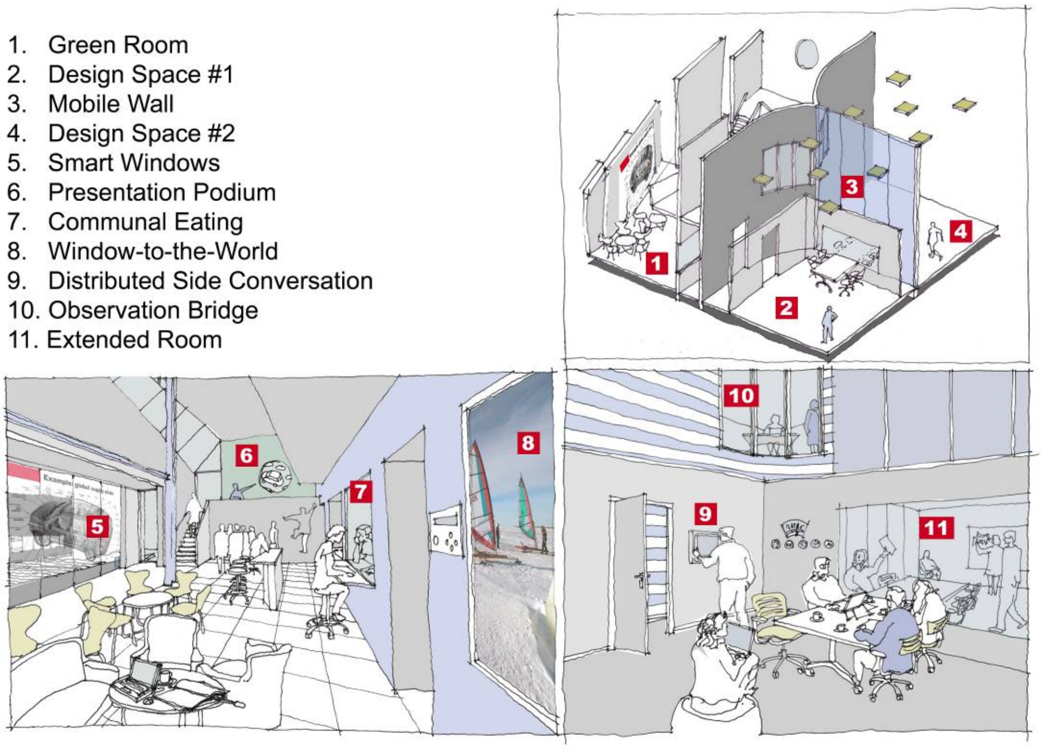

Figure 1 Concept Design Sketches, courtesy of Hans Walloschke, Arkitekthuset Monarken.

The design rational of the collaborative design studio is further described in Larsson et al. [9]. In the studio researchers have the possibility to rig specific experiments that can be carefully monitored and follow design in action via 'real-world' development projects (i.e. the university projects mentioned above). There is also a possibility to restrict one of the design spaces to one team for an extended period of time, thereby creating a team space within the studio.

The studio is inspired by similar approaches, such as the Design observatory [20] at Stanford University. In our approach the design spaces (2 and 4 in Figure 1) can be easily reconfigured similar to a scene in a theatre or a television studio. In the design spaces several HD cameras can be used to record design activities, and the infrastructure can support real time, i.e. down conversion, recording, and recompression of video. Control systems are highly integrated, and researchers have the possibility to route audio and video from the small studios and view all video sources on a large powerwall (i.e. a large high resolution display 7,2x2,2m) in a facility across the corridor (*the Studio*). Here, researchers can simultaneously monitor up to four full HD streams from the design spaces.

The infrastructure provides the researchers with an excellent environment for design observations, e.g. the design spaces can be used in experiments to simulate geographic distance, where the researchers can observe the design session as it unfolds from the observation bridge (10 in Figure 1) or by a larger group in the Studio. This outside view (i.e. the researcher is not inside the design space) has several advantages, specifically if several researchers are monitoring the development in a design session interesting issues can be found, and the discourse between the researchers as the events unfolds can rapidly lead to an improvement of the experiment, change the experimental setup, etc.

In a true distributed project, the researchers in Luleå have limited control and overview over the remote site. To take even greater advantage of the new research studio new tools and methods were needed to simplify observation, documentation and storage of distributed design meetings.

CHALLENGES FOR DATA COLLECTION AND ANALYSIS

Rhuleder et al. [11] present several advantages of using video for interaction analysis, the main one being that video creates permanent data corpus and can capture complex data that is impossible to note by simply observing the event. Finally, it provides several researchers the opportunity to do their own interpretations and a collaborative multidisciplinary analysis can create an unbiased view of the events. The video approach also has several problems, some of which are confidentiality, complexity and the time consuming and expensive analysis.

One challenge is to store *metadata* with other types of information. *Distributed projects* and *real product development* projects further complicate data collection. Finally, the *analysis of collected data* is today poorly supported in existing tools.

The challenge of storing and retrieving additional metadata

A big challenge is to store other types of metadata that enrich the data collection (e.g. storing interactions with computer tools in the environment and quantitative data from system log files). Screen recording can either be done by software (compressing to a video file) or hardware (full resolution or down converted to video). Hardware solutions that save full resolution are expensive and require large storage systems; hence, the software approach is the emerging approach used in design research. Within the HCI (Human Computer Interaction) community the usage of video analysis of user interaction is widely used and is often supplemented with other types of data collection, such as screen recording and the recording of eye movements.

The main challenge is not to store information, but rather replay and analyse the data in an effortless fashion, as well as methods to integrate and aggregate different types of information.

The challenge of distributed projects

The complexity of data capture will increase when following distributed projects, where at least two sites should be monitored. The actual audio and video stream used for communication should also be saved so that comparisons of *what happened* and *what could be seen* (from the remote site) can be done in the analysis. It is important to store the video with the actual resolution and frame rate as the remote collaborators receive.

Many existing conferencing applications, such as Marratech [21], can record a meeting (saving video, audio, whiteboard and application sharing). Several systems are also available to store the content of a normal video conferencing using the H.323/H.320 standard, normally storing only one video stream and one stream for application viewing or document camera (H.239).

In a distributed design study researchers at the sites may observe the design session and use field notes to document additional information. These field notes can save much time in the video analysis because they can highlight a specifically interesting moment within a long session that later can be analysed in detail using the recorded material. An onsite researcher has the possibility to change or adjust the technical equipment to provide a rich data collection.

The challenge of analysing the data

The analysis of raw data is a tedious task and support tools are needed to synchronize the different media stored from a design session (multiple cameras, audio, and field notes). Some systems from the HCI area that support analysis of multiple data types have emerged, such as *d.tools* [22], that record video and other metadata to be later used for comparative analysis. These tools are normally designed to record information from only one user. When following a product development project over time, the amount of raw data soon becomes unmanageable; therefore, it is important that the tool also supports the retrieval and analysis of stored data. To support the researcher it is important that the system supports indexing of the data and provides the possibility to add metadata during the design session and in the following analysis of the collected data. Törlind and Larsson [23] describes three types of indexing, viz. *active indexing* done by the users, researchers or both, *automatic indexing* created automatically by the system and *passive indexing* indexed automatically from the usage pattern of users who re-examine the information.

The challenge of following real projects

When following a design team over a longer period of time the amount of recorded data soon becomes unmanageable, and recording all design meetings is therefore impossible. One challenge of following real projects over time is to have the possibility to record a design meeting with very low overhead and only record data if necessary. If a researcher focuses on interaction with physical objects, it might not be interesting to store long meetings when the team is interacting with project planning software, etc.

However, if the team chooses to skip the planning and instead do some work with mock-ups, the session is relevant for the researcher and video and data should be recorded from the meeting.

DESIGN AND IMPLEMENTATION

Even though the experimental studio is designed to provide an excellent environment for design research, there was a need to simplify data collection and analysis of design work. Hence, from the challenges described above the objectives for the prototype were derived;

- Collect data without interfering the ongoing engineering work
- Capture of distributed meetings with several video streams (both collaboration media and local interaction),
- Possibility to replay entire design sessions,
- Possibility to add research metadata (e.g. notes from the researcher and images),
- All data should be time stamped to allow cross referencing within the recorded data
- An awareness of remote design collaboration work.

The framework for data collection is based on the commercially available conferencing software Alkit Confero, an integrated audio-/videoconferencing system. The Confero system has for many years supported different types of research prototypes at Luleå University of Technology [2], such as mobile conferencing, life size conferencing and stereo videoconferencing. By building the data collection framework on an existing conference tool, a prototype can rapidly be designed and evaluated.
The Confero system also support a vide range of video hardware; Fire wire cameras, USB-cameras and high quality framegrabbers.
Some basic support for data collection was implemented in earlier projects, when the user could locally store a video stream as a QuickTime file, see Figure 2. The video could be combined statistics from the conferencing sessions (bandwidth used, frames per second received, spatial size of video, video compression algorithm, dropped frames, etc.), which are time-stamped to simplify quantitative analysis of video conferencing usage.

Figure 2 Replaying of a stored session (only conferencing video).

Several new functions were added in the prototype, specifically adding support for auxiliary cameras, the possibilities to record all video streams using a layered conference approach, and textual and visual bookmarks.

Using a layered conference approach

A conferencing session is normally *unicasted* (point to point), *multicasted* (multipoint controlled by the network) or transmitted via a *reflector* (client server approach where all users connect to one server that transmits video to all members in the same session); to support data collection the reflector approach was used.
To differentiate conferencing video from auxiliary cameras a layered approach was used in the reflector where a session could inherit another session. The *conferencing layer* contains the conference session used for communication between the remote teams. The above level is the *data collection layer*, where researchers have the possibility to add several other video channels containing the cameras in the room used to monitor the whole group, detailed views at whiteboards, etc. The top level

contains the *research communication layer*, where researchers can have their separate conversations to comment the ongoing design session (normally only audio is recorded in this session). All video and audio from a lower layer is inherited to the next layer so that the designers only see the video and audio from the conference layer, and the researchers see all video and hear all audio from all layers. A typical setup between two remote studios is visualized in Figure 3.

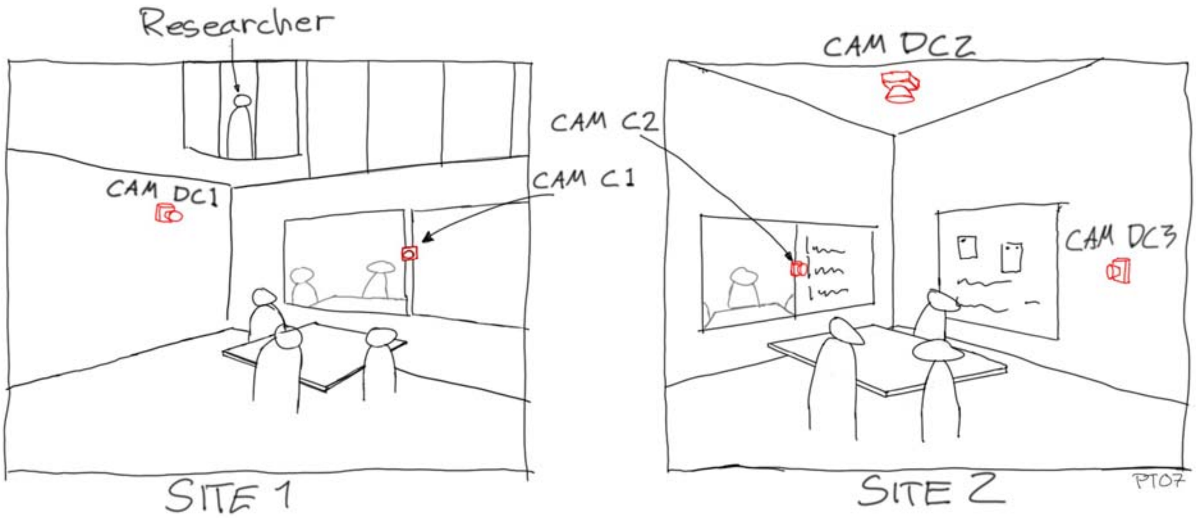

Figure 3 Typical setup for remote Collaboration (in this setup the researcher is at site 1).

In the setup two sites collaborates via video conferencing, *CAM C1* and *CAM C2*. One camera at *Site1* (*CAM DC1*) and two at *Site2* (*CAM DC2* and *CAM DC3*) is used to save video from different views. The different layers are represented in the conferencing application as in Figure 4.

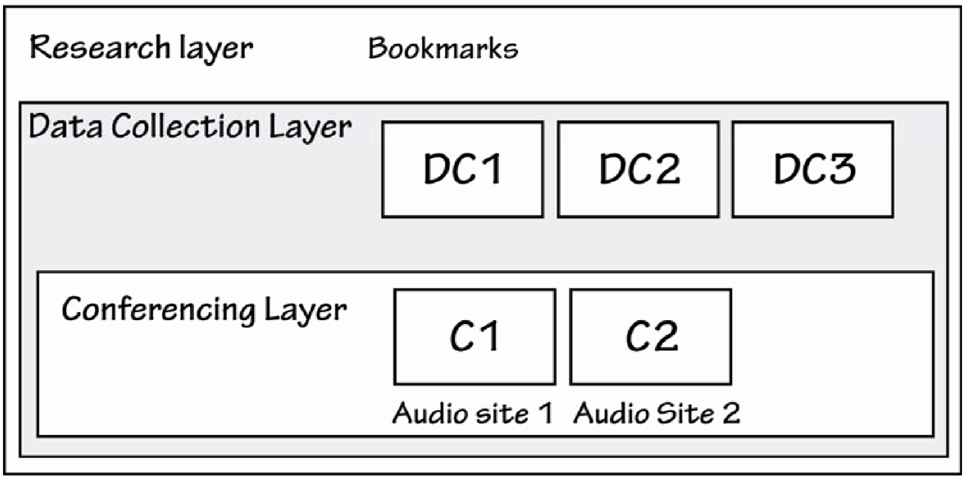

Figure 4 The video streams from the setup above and their corresponding layer.

In the setup the users only see the video from the conferencing layer while the researcher sees the Data Collection layer which inherit the video streams from the conferencing layer (a total of five video streams), the researcher also has the possibility to add bookmarks which is saved in the research layer.
To view all video streams simultaneously, a web interface was designed where all video streams are presented as video thumbnails (low frame rate and resolution). Using this solution the user has an awareness of the complete interaction and can at any time choose to view any stream with full resolution and frame rate. The user can also decide which streams to record for further analysis.
Existing functions such as remote camera control are also very useful, allowing the researcher to control the camera view used for data collection from a remote location. An observing researcher can also invite a remote researcher by mailing an invitation with a session description, SDP (which includes the address to the reflector and the session information). If the Confero software is installed the researcher just clicks on the SDP file to follow the design session.

Simplifying analysis

To simplify analysis the use of *visual* and *textual* bookmarks was implemented. *Visual bookmarks* are snapshots of the video stream or the shared application. *Textual bookmarks* correspond to a short note from the researcher. These bookmarks are stored and time stamped and can be used to rapidly find a specific part in a long session, see example in Figure 5.

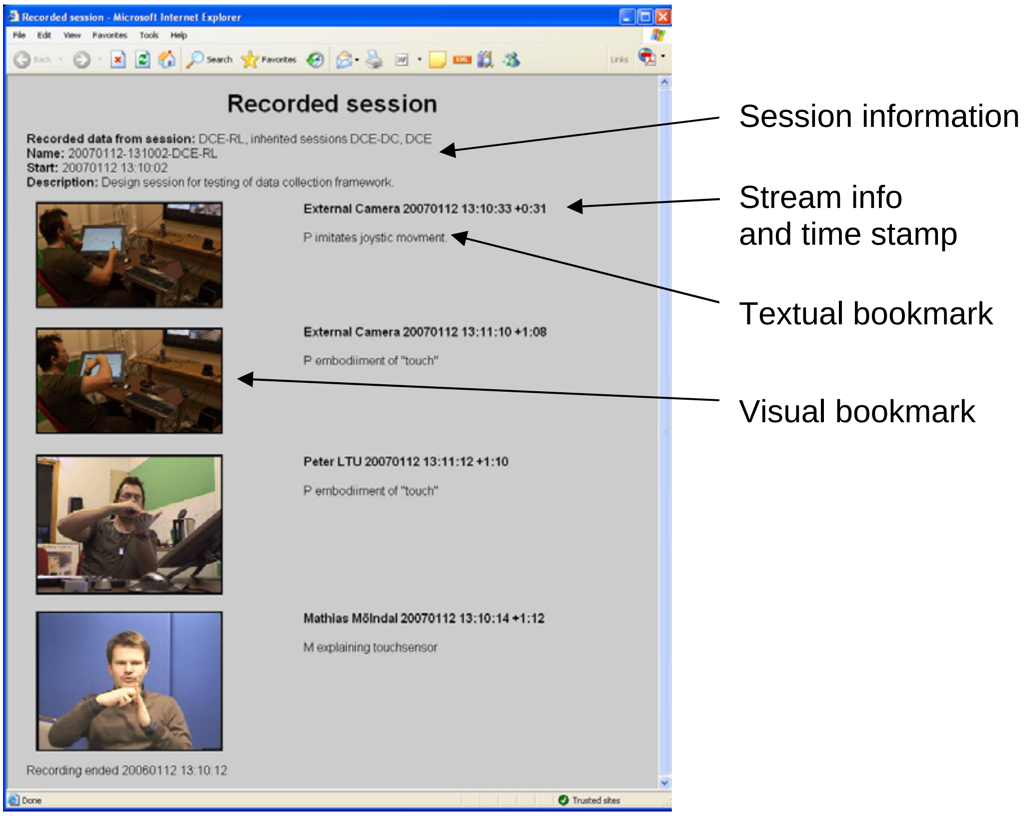

Figure 5 The web interface of the reflector, showing bookmarks in the recorded session.

Both textual bookmarks and visual bookmarks can be accessed from the Confero user interface, or via keyboard shortcuts.

Reducing bandwidth

The reflector also supports the user by limiting the transmission of video to the receiver, i.e. re-sampling (reducing the spatial resolution of each video frame) of video and changing the frame rate (reducing temporal resolution). This enables a remote researcher (with low bandwidth) to follow the design session with reduced video quality, whereas users with high bandwidth can receive high quality video.

The user can also decide which compression algorithm to use; today Confero supports DV, Motion JPEG, MPEG2 and H.264. The complexity of the encoding reduces the bitrate and increases the process load of the computer. JPEG encoding is the most attractive in terms of computational complexity and the H.264 codec provides the best compression performance.

In another project Motion detection was implemented in Confero. After some testing it was apparent that the motion detection algorithm could also be used to reduce the amount of data needed to store the video from a meeting. If a multi-camera setup is used, the amount of data stored rapidly increases (a normal DV-camera needs about 25Mbit/s; therefore, a recording of a distributed session with 3 cameras at each site consumes about 70 GB/h). By implementing a motion detection approach that changes, the frame rate can be changed depending on the motion in the image.

Recording of meetings

By using the layered approach the researcher can decide to record some or all communication streams (video, audio text messaging) that can be replayed later on. Confero also has the possibility to stream a video file from a video server; if a user chooses to stream a video file, it is also included in the recording. Text chat within Confero is also stored and replayed.

The user (conferencing layer) or the researcher (data collection layer) also has the possibility to change the resolution of the video (to preserve bandwidth). This event is also stored and replayed in the replayed session.

CONCLUSIONS

This paper has presented several of today's challenges in data collection and presents a tool that clearly has some advantages compared to traditional data collection methods. It also presents a framework on how a physical environment – *the design studio* – can be used to further facilitate design research.

Recording all video streams at the reflector ensures that the recorded video corresponds to the video sent from the conferencing application (including compression artefacts, dropped frames, video size, delays, etc.). The tool enables remote researchers to follow a local and remote design sessions, and have a parallel discussion when the design session unfolds. As well the researcher can easily invite other researchers if the opportunity arises. After the meeting, the researchers can easily replay the distributed meeting with all video and audio synchronised, regardless of where the researcher is situated. The framework also provides an advantage when following a design team over a longer time, when a researcher may only have a brief awareness of the ongoing design session. By eaves dropping, the researcher can respond if an interesting topic appears, and record the session, if necessary.

One limitation is that the system is dependent on high bandwidth networks between all sites and the reflector and that all storage of video is done at the reflector. Several ideas to limit the bandwidth have been implemented, such as variable frame rate (triggered by motion detection) and the possibility to use high efficiency compression algorithms.

RE-EXPERIENCING ENGINEERING MEETINGS

The framework also supports the design team, which can use recorded data from the conferencing layer to re-experience the meeting [23]. Team members can also use the annotation function to add 'bookmarks' to important moments in the meeting. By using this function a team can rapidly find and recapture the discussions about design rationales regarding a specific concept or function instead of replaying the complete meeting. This function is also useful to share knowledge to absent team members.

The collected information can also be used as a knowledge bank of lessons learnt from previous projects. Törlind and Larsson highlights that *"The need to support rapid context adaptation also includes how to quickly and effortlessly share knowledge with new, often temporary team members who enter the project with little or no knowledge of the previous work. Enabling team members to re-process and ultimately re-experience the dynamism and richness of meetings in which they did not actively take part is a very appealing situation for globally distributed development teams, particularly if they can experience a brief synopsis of the most important parts rather than repeat the entire meeting."* [23 p. 9].

FUTURE WORK

The prototype system will now be evaluated in several research projects in the new collaborative design studio. The system today only has a basic support for storing field notes, bookmarks and other additional metadata. By combining this type of direct data with the possibility to rapidly capture and crosslink additional indirect data (designers note, sketches etc) to a specific moment in time, analysis can rapidly be improved. Another interesting possibility is to add support for different types of protocol analysis methods [1]. A combined framework that combines data from both indirect and direct methods as well as analysis support should substantially simplify the analysis of design activity.

For future work the system will need enhanced support for the analysis of the recorded data, when all data (video, annotations, comments and other indirect data) can be presented at a common timeline. Also the possibility to cross index and structure different sessions is both useful for both design research and project work where users rapidly can find and re-experience past design sessions.

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