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COMMUNICATION MEDIA IN DISTRIBUTED COLLABORATION – ANALYSIS OF DESIGN EXPERIMENTS

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1. Introduction

Increasing globalization affects design processes, as e.g. in global companies more and more design teams are working locally distributed. Since face to face meetings are usually time and cost consuming, members of distributed teams are at least partially obliged to communicate via electronic media. The communication in these teams has been observed less efficient compared to collocated teams [Kristensen 2004]. Ruiz-Dominguez states that communication media in distributed teams slow down cognitive synchronization and shared understanding [Ruiz-Dominguez et al 2004].
On the one hand the usage of electronic communication media in non collocated teams bears problems, on the other hand the communication in these teams is important for the success. That leads to the conclusion that the communication media and the use of these media should be paid attention to. The objective of the experiments that are presented in this paper is to get a deeper understanding of the role of communication media in distributed design teams. The experiments were designed to look at the question: "Which communication media are used in what combination depending on the design process?" A minor question was: "Can the application of desktop virtual reality improve the communication?" This paper covers the setup of the experiments, the capture and analysis of the data and the presentation and discussion of the results.

2. Method

The examination of "real life" distributed working teams in industry is very difficult. Beyond severe restrictions due to confidentiality, it is hardly possible to control the boundary conditions or to carry out the same design process more than one time. To enable a detailed observation of the communication and the designers during the distributed work, design experiments with students were set up. This made it possible to carry out the experiment six times under similar conditions and capture all design processes on video tape.

2.1 Experimental setup

The experimental setup for the distributed design process is based on a combination of electronic communication media, which were identified as typical communication media in distributed development in German industry [Grieb and Lindemann 2005]. Additionally an infrastructure to capture the processes on video was installed. A suitable configuration of the media was determined in a one day pilot experiment. The majority of the media was implemented in the form of independent software tools. Shortcuts for easy access to these tools were placed on the desktop of the computers. The handling of these tools can be a quite demanding and complex task that requires some time to

learn how to use these tools fully (see for example [Toerlind 2005]). Therefore a preparatory training of the participants and the correct configuration of the tools were required prior to the experiments. The workplaces were located in the same building about 20m apart from each other. They were connected via a 100 Mbit LAN. Figure 1 depicts the arrangement of the main display, webcam and pen tablet display.

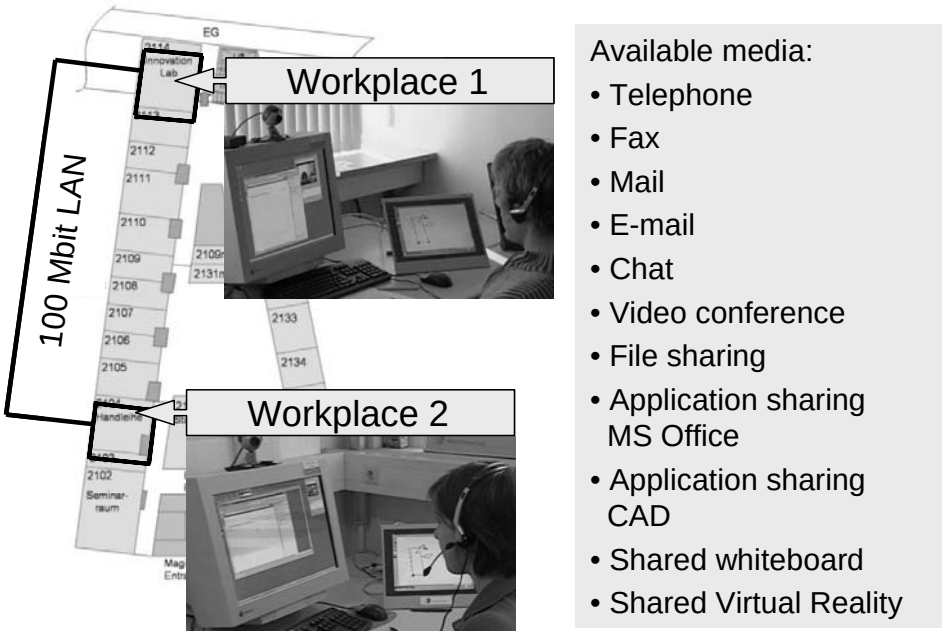

Figure 1. Setup of design experiments

The actual implementation of the different communication media was done in the following way:
Mail and fax were ”simulated” by the possibility to dispatch paper or hardware from one location to the other. The pilot experiment had shown that it was necessary to have both hands free during the experiment. Considering this aspect, telephone was implemented using the Voice over IP (VoIP) software Skype™ and a microphone/headphone combination. E-mail and chat were enabled by using web mail services and NetMeeting™ respectively. A video conference was set up using webcams and Netmeeting™. Application sharing was made possible using VNC™. Even though we used the same application sharing program we regarded shared application of e.g. MS Office™ programs and shared application of CAD e.g. CATIA™ as two different media. In the first place CAD programs can be more problematic when using shared application software (due to graphics acceleration), secondly the kind of information transferred is different, as text and graphs are considered a different kind of information compared to CAD product models. File sharing was implemented using a server based shared directory in the Windows Explorer™. The shared whiteboard was based on the software NetMeeting™ in combination with a pen tablet screen (Wacom™). In addition to these typical media, a desktop based Virtual Reality (VR) media, the “3D Shared Whiteboard” was provided. A 3D impression could be created with the help of shutter glasses. SpaceMouse™ input devices provided a “virtual” handling of artifacts.
During each of the six similar experiments a group of two students had to work on the same design task. Each of the experiments lasted for three days (about 5 to 8 hours a day). The task was a new design of a mechanical component. It represented a distributed design problem and was divided into three parts according to three different process situations: “Task Clarification”, “Concept Generation” and “Embodiment”. Each part had to be carried out within one day. There was no exact time limitation given.

2.2 Data Analysis

Tang describes video based analysis of design processes as a suitable method to examine group design activity [Tang and Leifer 1991]. Valkenburg mentions, that video analysis is particularly qualified if the objective is to explore the behavior of people during design processes. One should be aware, that the observation can only last a limited time and that the very rich video data needs to be processed and anlayzed to gain results [Valkenburg 2000]. Since the objective of this project was to analyze how the designers use communication media and a limited time span was guaranteed by the experimental setting, the authors agreed that the examination should be based on video analysis of the design process. Similar to Maher [Maher et al 2005], who measured the percentage of time on communication content during a distributed design experiment, we measured the percentage of time on communication media use, based on a video analysis.

All experiments were videotaped with two cameras, each located in one workplace. The two videos were digitally merged into a double video which showed both sides of the distributed team. The videos were played using the software "Ergoplayer". This software enables the researcher to put down time stamps of certain actions (e.g. begin or end of telephone use) into an MS Excel™ table while viewing the video. This way the time and the duration of usage of the media were captured. The tables provided the data to generate a quantitative usage-profile of each medium dependent on the one day process situation "Task Clarification", "Concept Generation" and "Embodiment". To obtain more detailed information about the change of usage profiles over time, profiles for every hour and every 15 minute interval were created (Figure2). Altogether about 100 hours of video were analyzed this way. In the future an even more detailed evaluation might be useful, but should be limited to specified, interesting sequences, due to the vast amount of data and the corresponding effort needed for the analysis.

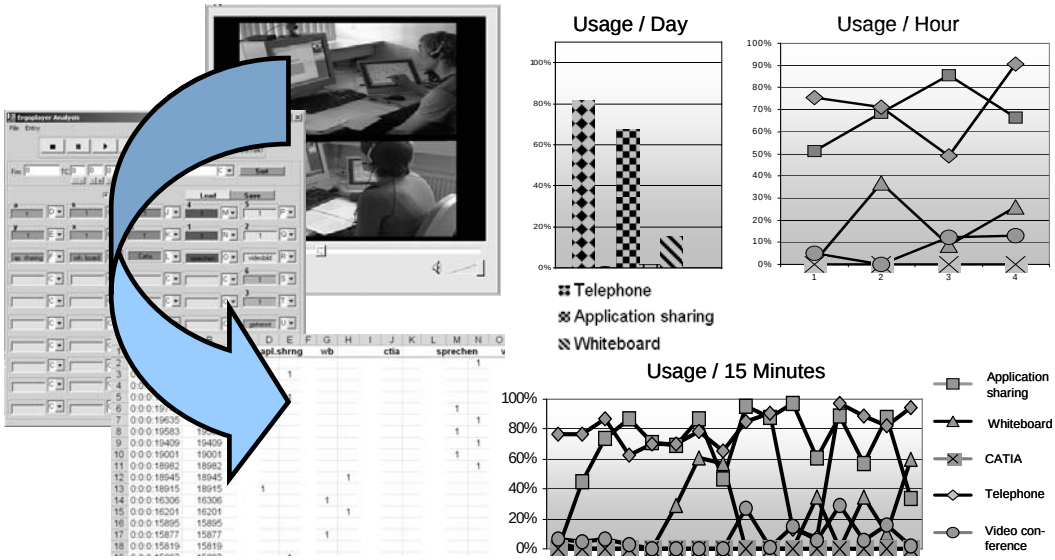

Figure 2. Setup of video data examination

As video analysis reveals the use of the media, but makes no statement about the motivation to use this media, the video data needed to be supplemented. Additionally one has to consider that the usage of media might not in all cases be directly related to the relevance of the media. Therefore it was decided to use a questionnaire and an interview to collect supplementary data.

The questionnaire was used to gain additional information about the importance of the communication media, independent of the amount of time they were used. The subjects were asked to rate how important the media were to accomplish certain tasks, which were related to the phases: "Task Clarification", "Concept Generation" and "Embodiment" on every day of the experiment.

The interviews were held after the last day of each experiment. The subjects were separately interrogated about the distributed design process and particularly the used communication media. The subjects had the possibility to speak about the advantages and disadvantages of the communication media and their motiviation to use specific media. The objective of these interviews was to support the reasoning from the observation and to gain information about the cause of actions during the process. Additionally we wanted to obtain indications of what an ideal combination of communication media for distributed working might look like.

3. Results

Even though the media mail, e-mail and chat were available, they were not used by the subjects. Obviously these media were substituted by other available media, as could be assumed according to the media richness theory [Daft and Lengel 1986], and/or were not suitable for this kind of synchronous design task. File sharing was used during the whole design process as the participants were working with a server based shared directory. Since this tool was not used for actual acts of communication among the subjects, it was not possible to do a video analysis on the use of this tool similar to the analysis of the other tools. Fax does not appear in the video analysis, because it was used only a couple of times for a few seconds. The role of the communication media telephone, application sharing, shared whiteboard, CATIA (CAD application sharing) and video conference during the design process can be observed on the basis of the media usage profiles. Figure 3 shows the average usage of the communication media during all of the six experiments. The columns display the average percentage of usage time, the standard deviation is indicated using a T-bar.

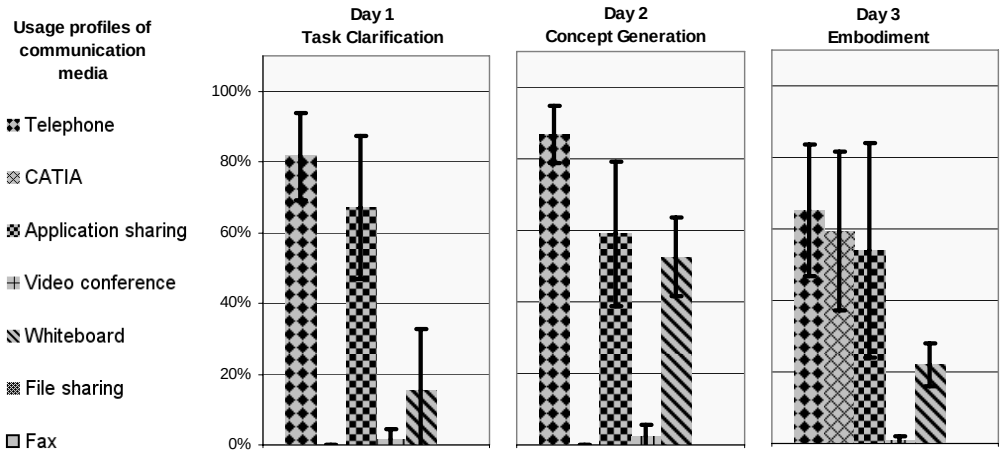

Figure 3. Average usage of communication media

It can be noticed, that telephone has the highest amount of usage time in all process situations. Especially during the phases of Task Clarification and Concept Generation the position of telephone seems to be exceptionally high. Measured by usage time, application sharing is the second important communication medium. Application sharing of CATIA was considered a different communication medium as mentioned in section 2.1. and is very strong during the phase of Embodiment, closely followed by the non CAD application sharing. Shared whiteboard was used very differently during Task Clarification depending on the preferences of the various teams. The very pronounced usage during the phase of Concept Generation is clearly observable. Even during Embodiment and extensive CAD work all teams used the shared whiteboard to support their communication. The encircled episodes in Figure 4 show that this happened together with an increase of telephone use in four out of the six experiments. The video conference tool in contrast was used very little.

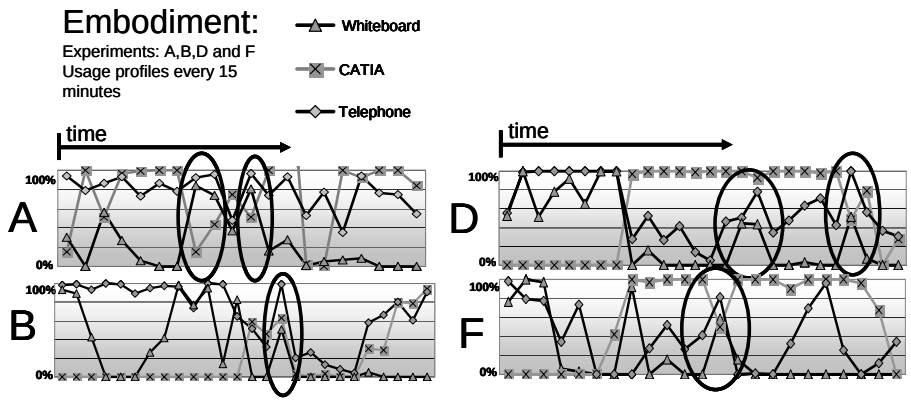

Figure 4. Detailed (every 15 minutes) communication media usage during embodiment

The questionnaire was used to obtain additional information about the communication media beyond the usage profiles of the videotapes as explained in section 2.2. The subjects were asked to rate the importance of the media. The results are shown in figure 5, where 100% is very important and 0% is not important at all. The Columns show the average values, the standard deviation is displayed using a T-Bar.

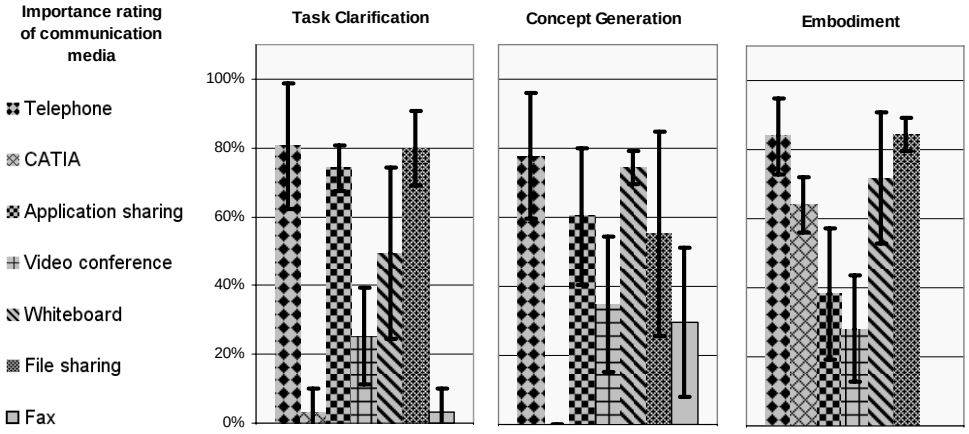

Figure 5. Rating of importance of communication media

Considering the rating of telephone and application sharing (both MS Office™ programs and CATIA) it appears that these are similar to the usage profiles. The shared whiteboard is rated very important. It is remarkable that in the phase of Embodiment it is considered even more important than shared CATIA (looking at the communication aspect). File sharing which did not appear during the video analysis due to reasons mentioned above was considered very important during all phases, especially Task Clarification and Embodiment. The hardly used video conference was considered medium important. Fax, which was used rarely by some of the groups was rated little important during Concept Generation.

The interviews were carried out as stated in section 2.2. The main statements (statements which were mentioned in at least half of the interviews) are summarized in table 1. Looking at the statements regarding the design process it is remarkable that especially the social contact and the exchange of ideas was considered more difficult than during collocated work. The subjects felt that the formal information exchange and the "formal design process" itself were not affected by the distributed setting. The statements considering the media generally support the results of the video analysis and questionnaires. In this setting the VR based communication medium did not supply the extra value

which was needed to compensate the additional effort to use it. The uncomfortable shutter glasses were especially disliked.

Table 1. Main statements of interviews

Design process	
Design problem	• Despite some inexplicit formulation general design task easy to understand, adequate scale of task • Predetermined general process helpful and realistic
Collaboration in distributed team	• Distributed partner not known prior to the experiment • Social contact and informal get to know handicapped, but estimated important • Exchange of ideas handicapped • All in all very few difficulties caused by the distributed setting
Communication media	
Mail, fax, e-mail, chat	• Usually replaced by faster and better suited media
Telephone	• Used at all times, considered crucial for collaboration • Supports social and informal communication, too
Video conference	• Mostly to check if the partner is there, what he is doing • Because of bad quality facial expression and gestures of partner hard to see, proposal: Extra big monitor for videoconference • Real eye contact not possible, proposal: Integrate camera in monitor
File sharing	• Used at all times, no problems
Application sharing MS Office	• Used frequently, slow update of shared desktop
Application sharing CAD	• Used frequently (during embodiment), slow update of shared desktop • Well suited to discuss electronic product model • Enables quick help and hints during operating problems while working with the complex software
Shared whiteboard	• Very efficient, capable of replacing paper and pencil completely • Supports “real” same time collaboration, what you see is what I see
Shared Virtual Reality	• No increased value generated by 3D impression, compared to application sharing CAD • Shutter glasses very uncomfortable • Might make sense when working with extreme complex geometric structures

4. Discussion

One has to keep in mind that even though the experiment was carried out six times, the data still needs to be considered an experimental case study as opposed to a statistical field study. The experimental setting influences the design process strongly. The outcome will be different depending on participants (experience, personality), number of participants, task, duration etc. Thus the results can not be presented as universal for distributed design processes. Nevertheless we think that these results can give some general hints about communication media in distributed design, which might be transferable to other settings to a certain amount.

The usage profiles of the communication media (especially the detailed ones), show that the media have been used quiet unequally during the design process, even on the same day. The detailed usage varies a lot between the different groups, too. This is believed to be caused by the differences of the design processes. Even if the main design process goals and structure was given, no process was exactly like the other. Additionally the different subjects have variable ways to use the media and varying likes and dislikes for specific media. Nevertheless the authors believe that some observed facts can be generalized over all groups.

The audio communication via telephone (VoIP) seems to be one of the crucial media. Telephone played an essential role during all phases of all experiments. Usually it had been the most used media and was rated the most important media. It was normally used in combination with other media.

Beyond the support of formal information exchange, telephone seemed to support the informal and social communication at least to some extent.
Another very important medium is application sharing. Whereas application sharing of MS Office™ programs was used a lot and was rated very important during all phases, application sharing of CAD was only used during Embodiment. In this setting CAD was not needed during Task Clarification and Concept Generation, but this depends on the design task, as it could be necessary to discuss a CAD model during Task Clarification under certain conditions (New design vs. redesign of an existing product). An interesting aspect is that application sharing was not only used to discuss the product model, but additionally to support the partner during the operation of the quite complex CAD system.
The shared whiteboard showed to be more important than the authors had expected prior to the experiments. It was heavily used during Concept Generation and even during Embodiment rated similar important to CAD (for communication). The usage time was less during Embodiment, but on the other hand the use of telephone seemed to rise when shared whiteboard was used as opposed to CAD (Figure 4). It is believed that during some discussions in Embodiment sketching was more helpful than CAD. The subjects stated that it was capable of replacing pen and paper completely. This might be related to the available pen tablet hardware which appeared to be very intuitive to use. It appears that the communication via (shared whiteboard) sketches is very important when developing conceptual solutions as well as during elaborating the product model with the CAD system. This conclusion is supported by the observations of Pache, who identified sketches as one of the main tools while working on concepts. In this context sketches were used mainly for communication (and to generate ideas) [Pache 2005].
Video conference was used very little during all phases of the experiment. Anyhow it was rated medium important for the communication. The assumption, that video was used mainly to create the feeling that there is a human being on the other side of the communication media, than for transferring formal information was supported by the interviews of the subjects. It seems to support mainly the social contact and very little the formal information transfer. Keeping in mind that distributed design processes can be affected very much by problems concerning the social contact, this medium should be considered important.
File sharing was not used for direct communication between the participants like the other media. There is no usage time for communication via file sharing. Nevertheless it is rated very important to support the collaborative work. The subjects stated that it is necessary to have common access to their files.
Fax was used only a few times by some of the groups. It was mainly employed to send non digital hand sketches during Concept Generation. When the teams changed to the digital whiteboard sketching, which all of the teams did, fax became obsolete.
Mail, e-mail and chat were not needed in this setting. The subjects stated that these media were replaced by better suited and faster media.
Although the VR based communication media was used and considered “interesting” during the preparatory training sessions, it was not used at all during the design experiments. It is assumed that the mechanical engineers, whose spatial sense is trained to some extent, can deal perfectly well with the two dimensional images of CAD 3D models in most cases.
Comparing the results of these design experiments with the results of a survey in industry about communication media in distributed design [Grieb and Lindemann 2005] one can notice some interesting facts. Telephone is used very much in industry, too, but e-mail was not used during the experiments at all where it is identified as the most frequently used communication media in industry. This can be probably related to the experiment setting. An all time synchronous collaboration is presumably not the most common kind of collaboration in industry. Furthermore, the better suited communication media which were used in the experiments to replace e-mail (e.g. application sharing) are not available throughout industry. These media are restricted by security (firewalls) and performance (bandwidth) restrictions, which were not present in the experiment setting.
The applied method to evaluate experiments by analyzing video tapes becomes problematic because of the vast amounts of data and the time consuming interpretation. Especially if it is planned to

observe longer periods, an automatic logging of the usage of the communication media should be considered, like it is proposed in [Campbell et. al 2005].

5. Conclusions and Future Work

Beside of the confirmation that telephone plays a central role in design communication, the experiments showed that more complex communication media like application sharing and electronic sketching are very important media for design communication. Especially during Embodiment the combination of sketching via shared whiteboard and shared application of CAD is important. Videoconferencing seems to be important to support the feeling of working together and is used for personal communication rather than formal information transfer.
In future work we want to use these findings to model communication in distributed design and optimize the usage of media according to situations in such design processes.

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