1 DISTRIBUTED WORK ENVIRONMENTS FOR COLLABORATIVE ENGINEERING

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Extended and networked enterprises distribute the design of products, planning of the production process, and manufacturing regionally if not globally. The usual face-to-face work is going to be replaced, at least partly, if not totally, by computer mediated collaboration. Awaited are reduced problems of resolution cycle time, increasing productivity and agility, and reduced travel to remote sites, enabling more timely and effective interactions, faster design iterations, and improved resource management. Mixed reality based work environments support distributed collaborative work between remote sites. An application for solving a control task collaboratively is described.

1. INTRODUCTION

Distributed design of products over remote sites is a strong demand of the industry for saving time and therefore costs. Centers for e-design got established at different universities, just to name Pittsburgh University and University of Massachusetts, Amherst (Nnaji, 2004), among others. The communication is mostly done with data-transfer using distributed CAE-systems like CATIA, i.e. a visual access to the products under the design process. Therefore with this trend to extend the designing and processing of products over different and remotely located factories the problem arises how to support an effective collaboration of the involved workforce. The usual face-to-face work is going to be replaced, at least partly, if not totally, by computer mediated collaboration. Collaboration demands a deep involvement and commitment in a common design, production process or service; i.e. to work jointly with others on a project, on parts or systems of parts. Enterprises investing in new information technology and communication infrastructures have also to consider the important issues in developing a culture and shared values that can facilitate the adoption of such technologies. Investment in advanced technologies may not necessarily result in improved communication by and between the employees. Often managers and the developers of IC - technology assume too much about the anticipated use of the technology by the employees. For most employees, interacting in a virtual mode via mediating technologies may be totally new and may cause anxieties. This loss of human contact could be balanced by maintaining continuous communication as well as by holding occasional face-to-face meetings for information sharing and support. The workers or engineers have to negotiate a shared understanding. This is done partly through video conferences. But in the camera and monitor mediated world of videoconferencing the collaboration support is limited to the senses of sight and sound and eliminate the sense of touch. As a result, even in state of the art videoconference rooms using the highest quality equipment, the sense of co-presence enjoyed by individuals in the same room is never fully achieved.

CAVE-technologies (Computer Animated Virtual Environments) are capable of to supporting the feeling of an immersion into a common workspace. Available CAVE´s at the market are very expensive. But cheaper versions with nearly the same performance are possible and therefore also affordable for small enterprises and training institutions. Integrating an analog-digital connection technology called Hyper-Bond into CAVE´s to support tele-design and tele-maintenance can improve collaborative work.

The paper discusses first related developments, then mixed reality concepts helpful for distributed work, and a new development for collaborative task solving.

2. RELATED DEVELOPMENTS

The project "Future Workspaces" (2003), funded by the European Commission, developed the vision: Supported by CAVE's, engineers will be able to work seamlessly in their workspace environment with documents, scientific models and virtual prototypes, both alone and collaboratively with distant colleagues as if they were in the same room. Virtual and hybrid prototypes will be available as a means for engineers to design new products. They will access specialized services via intelligent and secure network infrastructures that can detect, predict and satisfy user demand at any time and any place through location- and device-independent applications, which are able to seamlessly migrate across network technologies. A step-by-step work timeline could be stored, allowing other users to understand the previous course of the work and thus be able to effectively carry on with the tasks in the work process. The diminishing cost of technological equipment will enable companies to implement technologically integrated spaces, housing large embedded displays, networked furniture, wireless devices for tracking people and remote access to supercomputers etc. The integration of technology with physical space will make the present computer systems and interfaces less visible or transparent in the future environment.

The Collaboration@Work-Report (2005) illuminates European future research on new working environments and practices. The report emphasizes the importance of technologies with a mediating role among a distributed workforce and as a glue to bring together diverse technologies (such as mixed reality) to support collaboration among people and by interaction with other artifacts like robots, actuators and sensors.

Schaffers et al (2005) considered mobile and networked workplaces (Figure 1). Different scenarios are described to challenge existing frames of mind in envisaging different types of workplaces than those already existing and to show plausible future directions for innovation. The underlying technology can be called ubiquitous or pervasive computing. The authors develop a critical perspective of ubiquitous computing or ambient intelligence because it could leave the users without control. Only in few cases is the focus of ambient computing on systems supporting humans in the understanding of what is going on at the level they choose, and supporting them in suggesting courses of action rather than automatic action.

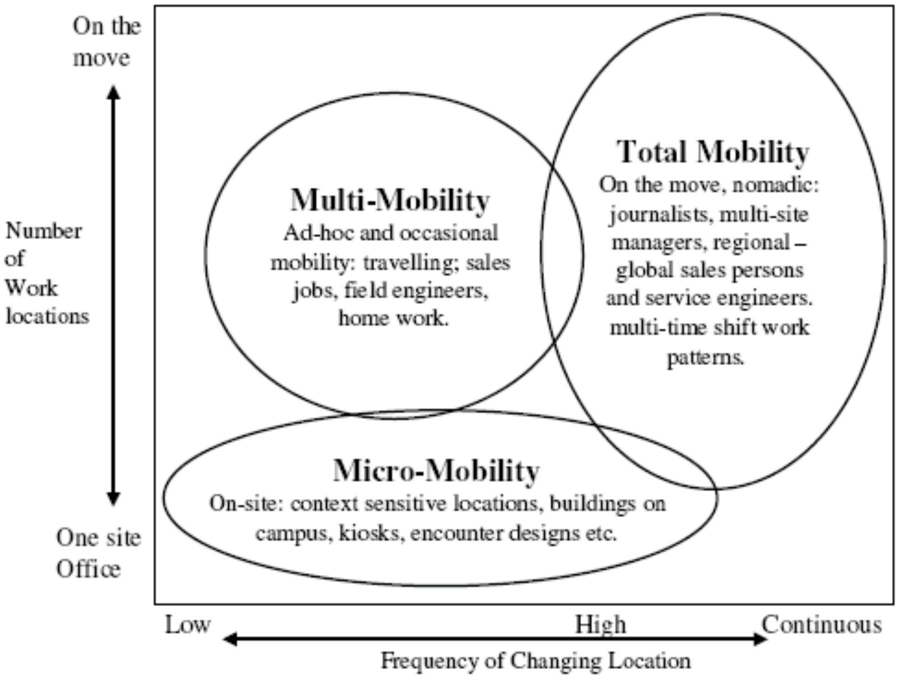

Figure 1 - Mobile workplaces categorization (Schaffers, 2005)

Participants of a workshop held in Aarhus, Denmark (2005) argued: there seems to be a need for a balanced view emphasizing how ambient systems need to be visible, how they can be deconstructed, how coherence can be achieved, how they can provide stability and understandability, and in particular how users can stay in control when dealing with a large number of autonomous components.

Bohn et al (2004) discuss economic effects. Despite the number of potential economic advantages, there are also substantial risks involved when relying on such technologies for large parts of an economy. The increasing automation of economically relevant aspects and the exclusion of humans as decision makers could certainly become a cause for concern. Under “normal” circumstances, automated control processes increase system stability – machines are certainly more dependable than humans for those who have to devote their whole attention to a particularly boring task. But situations that have not been anticipated in the software can easily have disastrous consequences if they are not directly controlled by humans. Other problems might arise from the intricate interplay of several automated processes, which might quickly escalate into an unanticipated feedback loop that gets out of control.

3. MIXED REALITY CONCEPTS

Mixed Reality environments as defined by Milgram (1999) are those in which real world and virtual world objects are presented together on a single display. Mixed Reality techniques have proven valuable in single user applications. Meanwhile, there has been done research on applications for collaborative users. Mixed Reality could be useful for collaborative distributed work because it addresses two major issues: seamlessness and enhancing reality.

When people talk face-to-face to one another, while collaborating on a real world task, there exist a dynamic and easy interchange of focus between the shared workspace and the human interpersonal space. The shared workspace is the common task area between collaborators, while the interpersonal space is the common communications space. In face-to-face conversation the shared workspace is often a subset of the interpersonal space, so there is a dynamic and easy change of focus between spaces using a variety of non-verbal cues (Billinghurst et al, 1999).

Ishii et al (1994) defines a seam as a spatial, temporal or functional constraint that forces the user to shift among a variety of spaces or modes of operation. Seams can be of two types:

Functional Seams: Discontinuities between different functional workspaces, forcing the user to change modes of operation. A functional seam exists when one has to shift the attention from one workspace to another.

Cognitive Seams: Discontinuities between existing and new work practices, forcing the user to learn new ways of working. A cognitive seam is that between computer-based and traditional desktop tools.

Functional and cognitive seams in collaborative work at distant workspaces changes the nature of collaboration and produces communication behaviors that are different from face-to-face conversation. For example, video-mediated conversation does not produce the same conversation style as face-to-face interaction. This occurs because video cannot adequately convey the non-verbal signals so vital in face-to-face communication, thus introducing a functional seam between the participants. Sharing the same physical space positively affects conversation in ways that is difficult to duplicate by remote means. Most current video conference equipment separates the user from the real world.

Mixed Reality concepts can also enable co-located users to view and interact with shared virtual information spaces while viewing or even manipulating the real world at the same time. This preserves the rich communications bandwidth that humans enjoy in face-to-face meetings, while adding virtual images normally impossible to see. Mixed Reality interfaces can overlay graphics, video, and audio onto the real world. This allows the creation of workspaces that combine the advantages of both virtual environments and seamless collaboration with the real environment. Information overlay may be used by remote collaborators to annotate the users view, or may enhance face-to-face conversation by producing shared interactive virtual models. In this way Mixed Reality techniques can enhance communication regardless of proximity and support seamless collaboration with the real world, reducing the functional and cognitive seams between participants. These attributes imply that Mixed Reality approaches would be ideal for multi-computer supported *cooperative* work (CSCW) applications. Roschelle & Teasley (1995) give a widely accepted definition of collaborative versus cooperative work: "We make a distinction between 'collaborative' versus 'cooperative' problem solving. Cooperative work is accomplished by the division of labor among participants, as an activity where each person is responsible for a portion of the problem solving. We focus on collaboration as the mutual engagement of participants in a coordinated effort to solve the problem together. We further distinguish between synchronous (i.e. working together at the same time) and asynchronous activity. Although we do not propose that collaboration cannot occur in asynchronous activity, we focus on face-to-face interactions, which can only occur as a synchronous activity."

When "cooperation" is exchanged for "collaboration," the requirements on Mixed Reality are stronger. Not only vision and sound, but also force and haptic rendering are demanded to providing real immersion in common as well as remote distributed workspaces. More importantly, users (workers, engineers) can see each other's facial expressions, gestures and body language, increasing the communication bandwidth. They can continue doing real world tasks while talking to collaborators in the conferencing space, and it is possible to move the conferencing space with the trackball so that collaborators do not block critical portions of the field of view. While Milgram & Colquhoun (1999) refer to mixed reality as "the merging of real and virtual worlds" such that "real world and virtual world objects are presented together within a single display," Benford et al (1998) broaden this to consider the joining together of whole environments. Milgram's approach, Benford argues, might be suited to a range of applications such as medical imaging, tele-surgery, machine maintenance, and the control of robots, for example. Benford's approach to mixed reality is more comprehensive. He developed the concept of creating transparent boundaries between physical and synthetic (virtual) spaces. Thus, instead of being superimposed, two spaces are placed adjacent to one another, and then stitched together by creating a "window" between them. This is close to a CAVE-like construction.

The approach of Bruns (2005) is close to Benford´s. Bruns' concerns that most existing collaborative workspaces strictly separate reality and virtuality. For example, when controlling a remote process, one can sense and view specific system behavior, control the system by changing parameters, and observe the process by video cameras. The process, as a flow of energy - controlled by signals and information - is either real or completely modeled in virtuality and simulated. In mixed reality concepts distributed environments information flow can cross the border between reality and virtuality in an arbitrary bidirectional way. Reality may be the continuation of virtuality or vice versa. This bridging or mixing of reality and virtuality opens up some new perspectives not only for work environments but also for learning or training environments (Müller, 2005). The next section describes an application of this approach for collaborative distributed work.

4. COLLABORATIVE TASK SOLVING BETWEEN REMOTE SITES

Mejía et al (2004) reports on a collaborative e-engineering environment for product development in connection with the manufacturing process development of a Dry-Freight Van. Both parts were carried out at remote workplaces connected via the internet. AutoCAD and Mechanical Desktop were used for designing. The collaboration was supported by NetMeeting, and for the coordination MS project was used.

4.1 Connections with a Hyperbond

Bruns et al developed and tested a collaborative work scenario between remote sites (Bruns & Erbe, 2005, Müller, 2005). The task was to develop and test an e-pneumatic control circuit (Figure 2) for automatic welding operations: workpieces are fed and clamped; the welding operations are activated. When the welding is finished the clamps open and the workpieces are ejected.

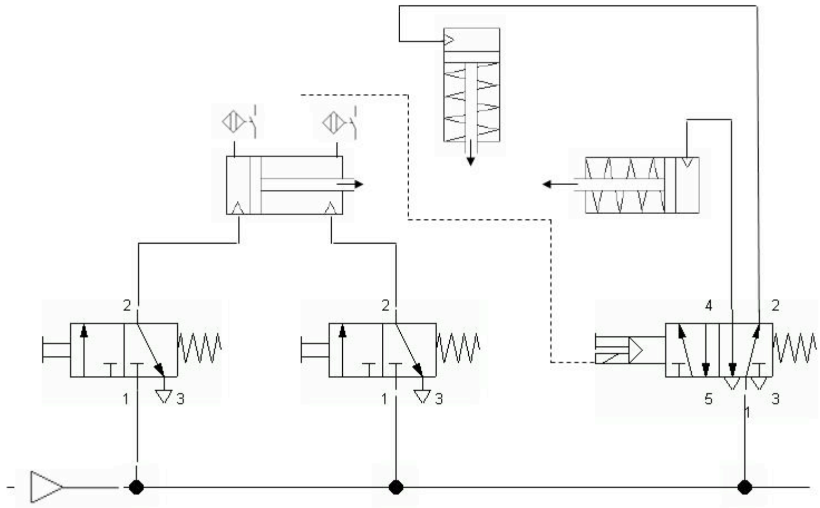

Figure 2. - E-pneumatic control circuit for automatic welding

Within this scenario three enterprises at different locations are involved to perform the following tasks: developing the control virtually, testing it at a real workbench, and manufacturing the device. To solve this task collaboratively work spaces are linked by the Internet. Figure 3 shows the real and the virtual workbench connected with analog-digital and digital-analog converters respectively. This connection is called a Hyperbond (Bruns, 2005). The virtual workbench can be accessed via the Internet so that engineers at remote locations are able to solve the task collaboratively. They have always video and sound feedback of the real workbench and their coworkers at the virtual workbenches. The engineers at the real workbench can also manipulate the components at the virtual workbench, and all can communicate visional and auditorial (Fig. 4 to 6).

When a solution of the control tasks is found at the virtual workbench the solution can be partly or completely exported via the Hyperbond interface to the real workbench. Also, the manufacturer of the welding device is connected to give his comments regarding the feasibility of a solution of the control task. The audio communication uses Internet telephony.

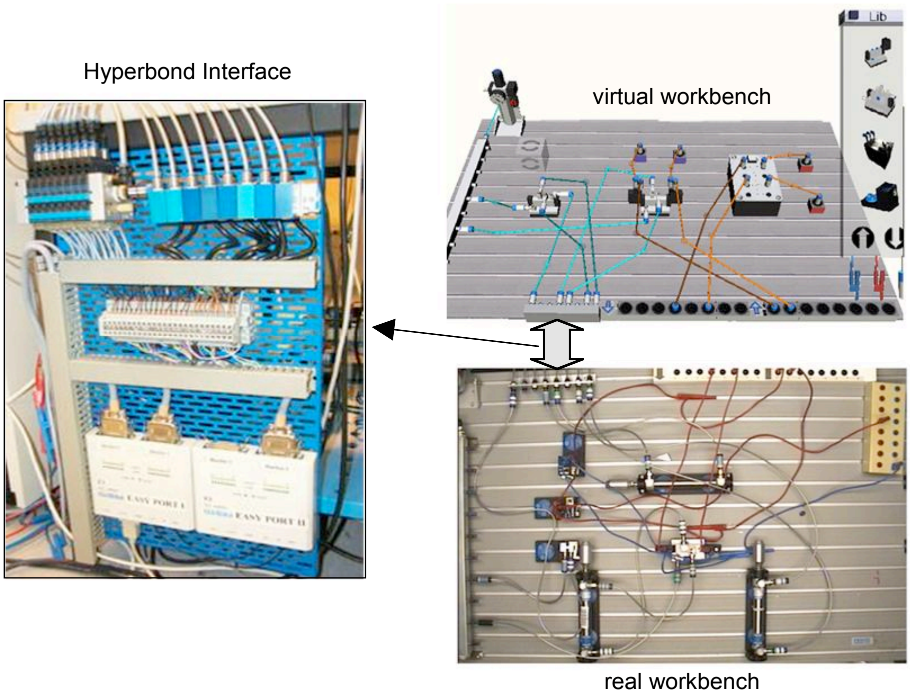

Figure 3 - Real and virtual electro-pneumatic workbench connected with a Hyperbond.

4.2 CAVE´s as workspaces

The connected workbenches are located in CAVE -like constructions. These consist of a scaffolding with canvases where the images of other workspaces with the persons working in it are beamed at. The architecture is shown in Fig. 4. The beamers are controlled by computers connected to the server.

The real and virtual workbenches were implemented as a Web Service to take advantage of the web technology (e.g. easy accessibility, platform independence). A central module is the Mixed Reality (MR) Server which realizes this Web Service. The Web Service itself processes HTTP requests and also manages the sessions of all remote users. Relevant data belonging to a certain work session is stored on the server, like virtual model data, support material and background information. The WWW front end consists of a HTML page including a Virtual Construction Kit (VCK) and a video stream window.

The VCK itself is a VRML based tool for assembling virtual worlds: by dragging and dropping objects from a library onto the virtual workbench new objects (e.g. cylinders, valves, and switches) can be added. Each of these objects has connectors which can be linked to other ones. Links can either be tubes (air pressure) or wires (electricity). Connections between real and virtual workbench elements were realized by the aforementioned Hyperbond technology.

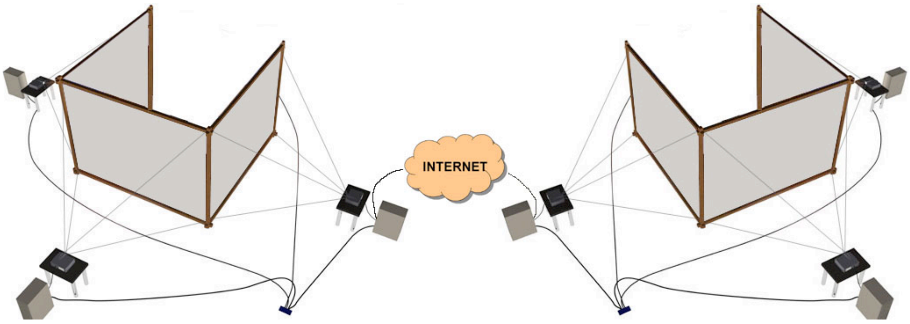

Figure 4 – Sketch of CAVE's (scaffoldings with canvases, beamers and computers)

A Hyperbond consist of two parts: a real and virtual one. Thus any flow through this kind of object is automatically forwarded to reality or vice versa. Changes in reality are distributed by an updated simulation but also by a camera observing the real hardware. The virtual part of a running session can be stored on the server and reloaded later to continue the work task.

Figures 5 and 6 show the arrangements used for the test cases. The common virtual workbench and the real workbench (via video projection) are available via the Internet and visible at an enlarged screen or are beamed at canvases fixed at the scaffolding.

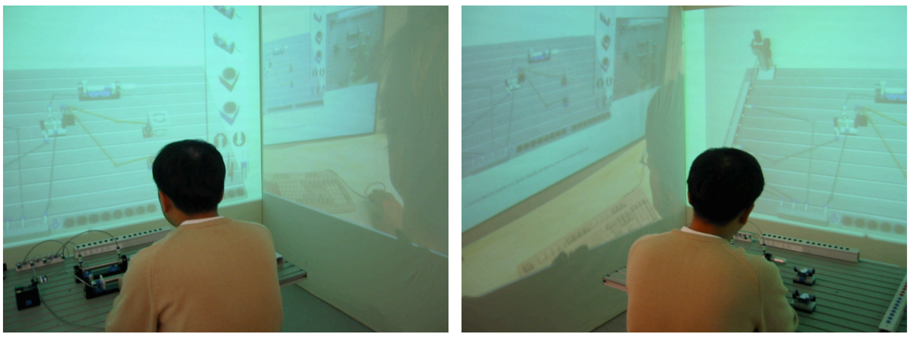

Figure 5 – Workspace with the real workbench and the virtual one in front, and the remote counterparts screened on the left and right canvases

The described mixed reality application for collaborative work is under further development for remote maintenance. Web based service for remote repair, diagnostics and maintenance (RRDM) is meanwhile widespread (Biehl et al, 2004). But it is almost limited to providing only audio and vision. Controls, drives, and sensorized machine parts can be diagnosed remotely through the manufacturers or service providers. For the maintenance of mechanical parts it might be of advantage to touch the parts. This requires force feedback and haptic rendering and is still under research (Yoo & Bruns, 2005). However, the above described application, a real workbench connected to virtual workbenches, can already be used for maintenance training between remote workplaces.

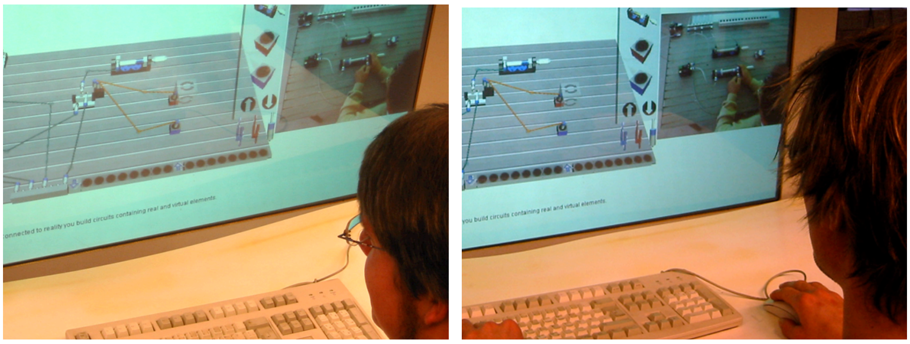

Figure 6 – Two remote workspaces connected with the remote workbench

5. CONCLUSION

Presently some research effort is being done to foster collaborative engineering between remote sites. One of the problems is to seamlessly connect the real to the virtual world. As an example the paper described the connection of a real workbench with the remote located virtual ones. Scaffolding with canvases represents a low cost CAVE, where the remote and local participants can immerse into a common workspace for solving a task. In comparison to other developments for supporting collaborative engineering, that mostly improves only the common work at CAD workplaces, the new approach allows that more than two participants at different remote sites can work together at the same time. They have always access to the real workbench. When some are sitting inside a CAVE and working at the real workbench connected with their colleagues at the remote CAVE´s and virtual workbenches, the test persons got nearly the feeling to working at the same site.

Workplaces providing not only vision and auditory perception but also haptic perception are still in its infancies. It is the goal for future research.

Although the presented development for collaborative work over distant sites has been explained with a simple example, the concept of Hyper-Bond was also developed for continuous events. When enhanced with force feedback it will be a useful tool for remote collaboration. The used CAVE technology has been developed in a project with students of applied informatics. It will be configured and tested to be usable for industrial sites.

6. ACKNOWLEDGEMENT

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