FROM REMOTE LABS TO COLLABORATIVE ENGINEERING WORKSPACES

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Abstract: Research results of improving remote collaboration are presented. Individual, social and cultural aspects are considered as new requirements on the employees of networked and extended enterprises. New developments on cost-effective connections are providing not only vision and auditory perception but also haptic perception.

Keywords: e-learning, simulation, remote experiments, hyper-bonds, distributed workspaces

1. INTRODUCTION

Collaboration is working together towards a common goal at different times, in different locations, at different companies in different functions. Principles are: support collaboration within the entire working team including external suppliers and partners, support flexible team participation to minimize collocation as a team requirement, benefiting individuals by making their job easier and helping to achieve work-live balances, providing a collaborative environment, allowing the team to tap into their inherent creativity and power of sharing ideas, focusing on people, process, communication and relationships in addition to technology. This sounds like the intentions of sculpting a learning organization/enterprise as it was presented by Senge (1990) and theoretically developed by Watkins & Marsick (1993). But now the challenge is to extend this theory to globally distributed enterprises. The benefits of collaboration are: reduced problems of resolution cycle time, increasing productivity and agility, reducing travel to remote sites, enabling more timely and effective interactions, faster design iterations, improving resource management and facilitate innovation.

Collaborative work over remote sites in so called virtual teams is therefore a challenge to developers of information- and communication technology as well as to the involved workforce. 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

(Acosta & Moreno, 2005; Erbe, 2005). Information mediated only via vision and sound is insufficient for collaboration. In designing and manufacturing it is often desirable and in maintenance it is necessary to have the parts in your hands. To grasp a part at a remote site requires force (haptic)-feedback in addition to vision and sound.

Engineering education has to consider this development with providing learning environments for students to train collaborative work over distances where face-to-face work is excluded.

Ferreira et al (2002) and Cooper et al (2002) demonstrated the use of remotely controlled experiments of biochemistry, fundamental physics, automatic visual inspection and digital electronics in the EU-project PEARL (2003). Mueller & Ferreira (2003) reported about remote-lab development of the EU-project MARVEL – a mixed reality learning environment for vocational training in mechatronics.

Most remote-lab developments strictly separate reality and virtuality, energy and information. One can sense the remote process, view specific parameters, control them by changing parameters and observe the process by video-cameras. The process, as a flow of energy controlled by signals and information, is either in reality or completely modeled in virtuality by simulation.

Bruns (1999) developed a concept of Complex Objects being a unit of various closely coupled virtual and real representations and Hyper-Bonds, a universal interface type as a basis for learning environments.

2. LEARNING ENVIRONMENT FOR REMOTE LABS

2.1. Technological arrangements

A learning environment was developed where on-site and remote components merge into a cooperative learning process. The envisaged system allows working together with complex real and virtual systems, consisting of parts which may be remotely distributed. The learning environment includes a supportive web-database with multimedia learning sequences providing theoretical background information, exercises and help to handle training tasks. Hardware equipment can be connected to the virtual environment with a special bi-directional sensor-actor coupling called Hyper-Bond. The learning environment smoothly integrates equipment and supports full hardware-in-the-loop functionality, allowing building up real systems from subsystems of complex virtual systems.

Real and virtual workbenches of electro-pneumatic components are located in CAVE -like constructions. These consist of 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 (Figs. 1 and 2).

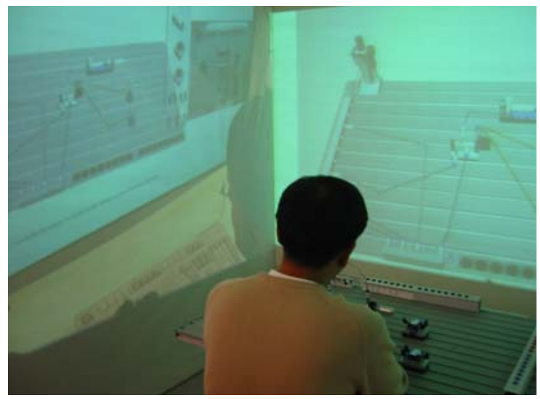

Fig. 1.

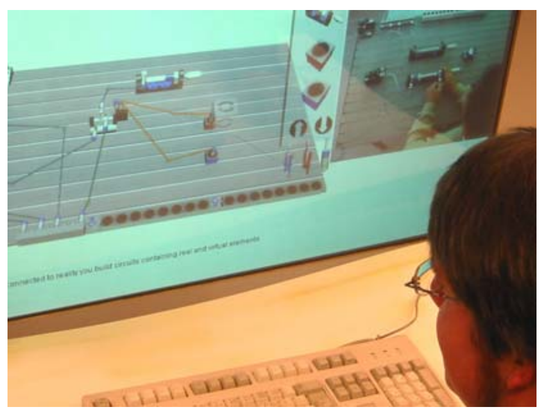

Fig. 2.

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 a Hyperbond, (Bruns, 2005), Figure 3.

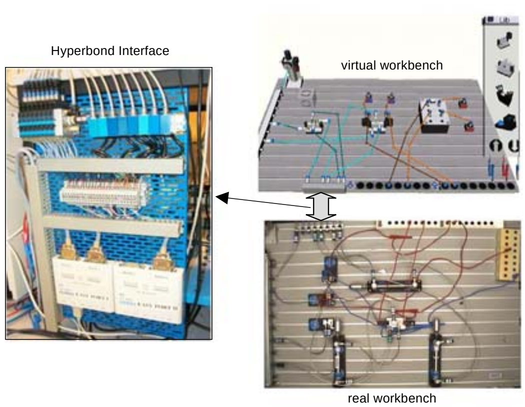

Fig. 3.

The learning environment has been further developed including Programmable Logic Controllers at workbenches (Fig. 4), using low cost and common off-the-shelf equipment, standard Internet tools, and, far as possible, low budget software to provide a distributed virtual and real environment for PLC training. The system is designed to integrate all necessary components either as a remote learning lab in faculty, or as an affordable standalone solution (Faust & Müller, 2006).
Also Schaf & Pereira (2006) extended the pneumatic workbench with Programmable Logic Controllers. There intention is to introduce the remote learning concept to train the workforce in distributed vocational learning institution as well as in enterprises for further education. All components used are standard components in industry.

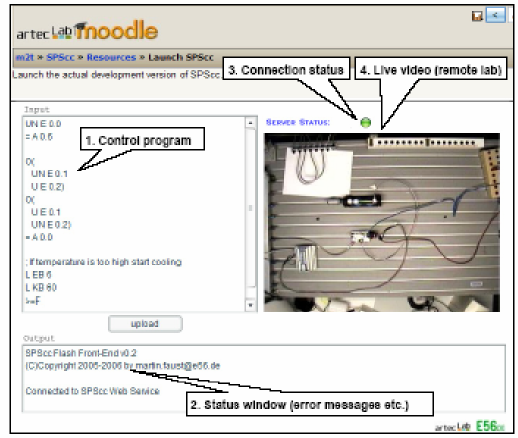

Fig. 4.

2.2. Pedagogical aspects

Teaching and learning with remote labs, as a blend of real and virtual reality, offers the chance to motivate both sides to repeat sequences and modify parameters to get more insight into the subject to be learned. But that could induce a behavior to find solutions by trial and error. The learning tasks have to be structured to force the learners to use textbooks to understand the theoretical background. This should lead to:

- thinking in abstract structure-behavior-function categories, searching for alternative concrete instantiations (e.g. various structures for a given function, or various functions of a given structure)
- thinking in information-control-work process categories and their realization
- searching for unified views of systems dynamics (e.g. Petri nets and bond graphs) for analogous physical phenomena (electricity, pneumatics, force-momentum mechanics …)
- judging the adequacy or deficiencies of simulation models versus real systems.

A theoretical framework for this approach requires insight into how individual learning styles use individual learning media and paths to develop meaning and concepts from basic experience with natural and technical phenomena. Task- and problem-solving requires cognitive and operational knowledge and practical experience.
Cultural differences and similarities in learning and collaboration styles can be noticed, but have not been sufficiently integrated into curricula, courseware and teaching methods. The above

described learning environment offers collaborative learning over distances, different mother tongues, and cultures. Learners and teachers, with English as a common language, can collaboratively solve tasks at the real workbench in connection with the virtual workbenches, communicating with internet telephony and vision to their respective workplaces. It is assumed that this environment fosters collaboration over distances without face-to-face work.

3. DISTRIBUTED WORKSPACES

Extended and networked enterprises distribute the design of products, planning of the production process, and manufacturing regionally if not globally. Employees are therefore confronted with collaborative work over remote sites. A cost effective collaboration depends highly on the organization maintaining a common understanding for this kind of work and a suitable support with information and communication technology. The usual face to face work is going to be replaced at least partly if not totally by computer mediated collaboration. Creating and maintaining virtual teams is a challenge to work conditions as well as technology. Distributed design of products over remote sites is a strong demand of the automobile industry for saving time and therefore costs. Centers for e-design got established at different universities, just to name Pittsburgh University together with the 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

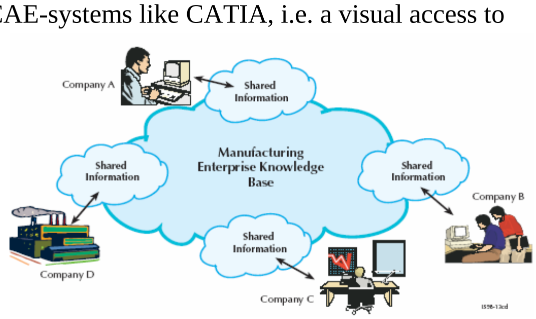

Fig. 5.

the products under the design process. The designers have to negotiate a shared understanding (Fig. 5).

Nof (2006) defines e-work as any collaborative, computer-supported and communication-enabled productive activities in highly distributed organizations of humans and/or robots and autonomous systems. The transformative influence of e-Work can be described by this quote: “As power fields, such as magnetic fields and gravitation, influence bodies to organize and stabilize, so does the sphere of computing and information technologies. It envelops us and influences us to organize our work systems in a different way, and purposefully, to stabilize work while effectively producing the desired outcomes” (Nof, 2003). He states: “e-Work and e-Production/e-Business are strongly related, but the e-Relations are not the same as the traditional relations between them. In general, e-Work enables e-Production/e-Business, and the latter require e-Work” (Nof, 2006).

e-work needs distributed workspaces, co-located or remote. A 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. 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.

As was presented in section 2 the mixed reality and hyperbond concept was used to manipulate discrete event processes with pneumatic cylinders and valves. It is also possible to distribute continuous events in real and virtual parts. Yoo (2006) studied a haptic ball manipulator (Fig. 6), using bond graph description and 20-sim simulation. Rotational input from the user is changed into translational motion of a virtual ball, while power is transferred from a user’s handle to the virtual ball *m*; the user’s handle is provided with haptic feedback from a virtual spring and the ball. If the torque imposed on the user’s handle exceeds the force of the virtual spring, the ball *m* will be moved. If the virtual ball collides with a virtual object M, collision energy is added to the behavior of the haptic ball manipulator.

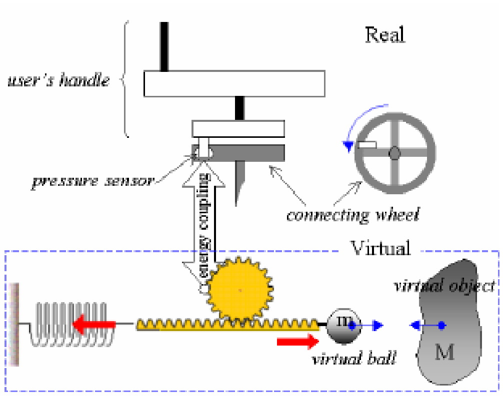

Fig. 6.

The theory in the background is an analog-digital continuation and vice versa described with bondgraphs (Fig. 7). This continuation between reality and virtuality will be generated with a hyperbond.

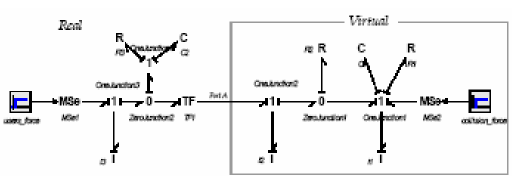

Fig. 7.

Another example for a analog-digital continuation is the design and analysis of a servo-motor. Figures 8 and 9 show an electro-mechanical system described by bond-graph (v. Amerongen, 2002). One part can be modeled in virtuality to experiment with the belt transmission.

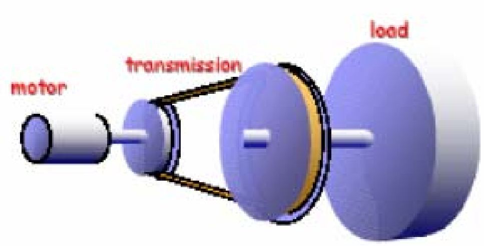

Fig 8.

The servo system may cut off and connected again with a hyperbond generating real and virtual parts (Fig. 10). The hardware implementation is still in development.

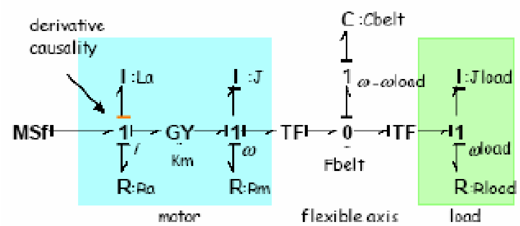

Fig. 9.

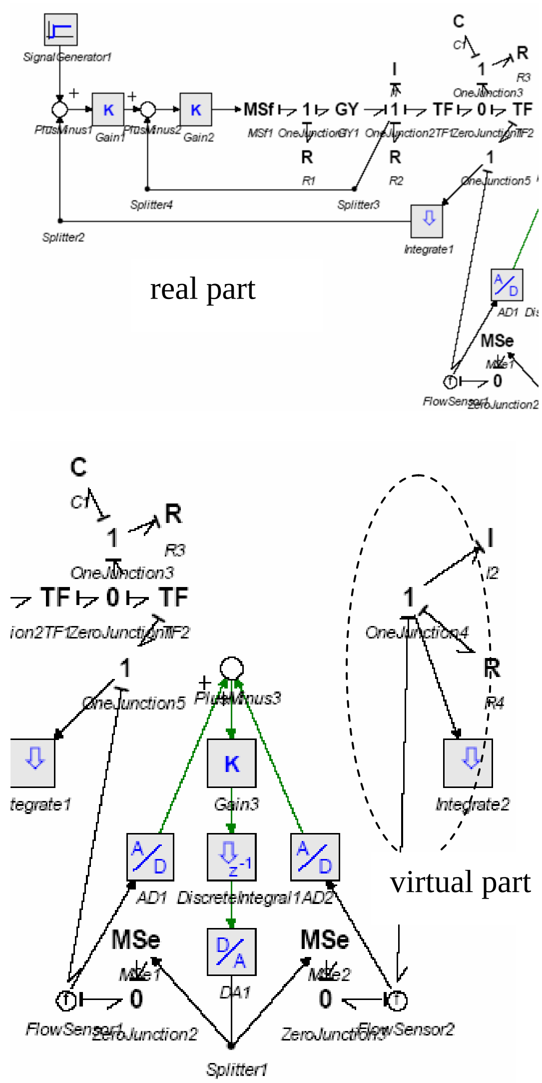

Fig. 10.

4. CONCLUSIONS

Mixed reality concepts support learning environments of remote labs and distributed workspaces. The bidirectional tele-cooperation functionality allows extended enterprises to use the internet for collaborative engineering. Also with new plant equipment being more complex and requiring more complex maintenance, the training requirements for workforce and engineers increases. The presented environment will allow groups of employees at remote locations to take part at the same training using the same equipment (either simulated or real). The employees are able to work in a collaborative way to solve problems and explore problems to be solved. This kind of interaction provides a systematic support for skilled workers and engineers. The environment can be used as an appropriate and cost effective tool to support collaborative engineering.

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REFERENCES

Erbe, H.-H. and F.-W. Bruns (2004). Distributed Real and Virtual Learning Environment for Mechatronics. Amer. Soc. Engineering Education Ann Conf. Salt Lake City

Senge, P. (1990). *The Fifth Discipline.* Doubleday, New York.

Watkins, Karen E., Marsick, Victoria J.(1993). Sculpting the learning organization. San Francisco: Jossey-Bass Publishers

Acosta, C. & Moreno, E. (2005). Distributed Engineering Teams and their organizational Aspects. In: Proc. 16th IFAC World Congress, Elsevier Ltd, Oxford.

Erbe, H.-H. (2005). Learning for an Agile Manufacturing. In: G.Zülch, H.S.Jagdev and P.Stock (Eds.) Integrating Human Aspects in Production Management (pp. 269-279). Springer Verlag, Berlin.

Bruns, F.W. (2005) Annual Review of Control

Faust, M., Müller, D. (2006). Low cost entry into education for ubiquitous automation. In: *Prepints of the 9th IFAc Symposium on Automation based on Human Skill and Knowledge,* Nancy, France

Schaf, F., Pereira, C. (2006). Mixed reality experiment for distributed learning environment in pneumatics systems. In: Preprints of the 12th IFAC Symposium on Information Control Problems in Manufacturing, St. Etienne, France

Nnaji, B. (2004).

Ferreira, J. M., Alves, G. Costa, R., Hine, N. (2002). Cooperative learning in a web-connected workbench. In: Lecture Notes on Computer Science 2438, "Groupware: Design, Implementation and Use", Springer, N.Y

Cooper, M., Donnelly, A., Ferreira, J. M. (2002). Remote controlled experiments for teaching over the Internet: A comparison of approaches developed in the PEARL project. In: Proc. Of the 19th ann. Conf. Of the Austral. Soc. Of Computers in Learning in Tertiary Education, Auckland, New Zealand

Mueller, D., Feirreira, M. M. (2003): MARVEL: A mixed-reality learning environment for vocational training in mechatronics. In: Proc. Of the Technology Enhanced Learning International Conference, Milan, Italy

Bruns, F. W. (1999): Complex Construction Kits for Engineering Workspaces. In: Norbert A. Streitz et al (1999): Cooperative Buildings. Lecture Notes in Computer Science 1670. Springer, Berlin, pp 55-68

Nof, S.Y. (2003). Design of Effective e-Work:´ Review of Models, Tools, and Emerging Challenges, Production Planning and Control, Vol. 15(8), pp. 681-703.

Nof, S.Y. (2006). Robotics, agents, and e-work: The emerging future of production. In: Preprints of the 12th IFAC/IFIP/IFORS/IEEE/IMS Symposium Information Control Problems in Manufacturing, Saint-Etienne, France

Collaboration@Work 2005 Report: http://europa.eu.int/information_society/activities/atwork/hot_news/publications/

Project "Future Workspaces" (2002 – 2003), http://www.avprc.ac.uk/fws/

Yoo, H.Y. , Bruns, F.W. (2006)

Amerongen, J. van (2002). *Modelling, Simulation and Controller Design for Mechatronic Systems with 20-sim*. Proc. IFAC conference on Mechatronic Systems, pp. 831-836, Elsevier Ltd.