REMOTE CONTROL OF REAL AND VIRTUAL WELDING ROBOTS FOR LEARNING

Wilhelm Bruns°, Kai Schäfer°°

°Bremen University, Germany
Research Center for Work, Environment and Technology (artec)
bruns@artec.uni-bremen.de
°° Bendit Innovative Interfaces GmbH, Germany
kai.Schaefer@bendit-interfaces.com
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Abstract: An application of a Mixed Reality concept to Internet-Based Robotics will be presented. It will be argued how a coupling of real and virtual, local and remote robot systems may support a cost oriented training and education in context related robotics. This application is related to *Hyper-Bonds*, our unified concept to describe complex effort/flow driven automation systems distributed over real and virtual worlds. It allows selected materialization of parts of the system in reality and is functionally connected to a simulation model.

Keywords: mechatronics, internet-based robotics, simulation, mixed reality

1. INTRODUCTION

Blending real and virtual realities in a mixed reality environment (Ohta & Tamura, 1999) is becoming more and more popular. The extension of this blending towards internet-based distributed environments may offer some interesting possibilities for low cost automation, but also rises several problems. Remote control of robots using augmented reality is a well established field of control theory and practice (Milgram et al, 1995). However a systematic concept to integrate these components of automation into a broader context and its use for situated learning is still missing. We argue for a certain theoretical framework and demonstrate an application of using a remote melting robot for teaching robotics in a process oriented way.

In some previous work, the concept of complex objects was introduced (Bruns, 1999) being objects with a real concrete part coupled to various virtual representations (simulation, animation, symbolic) by means of grasp- or image-recognition. This coupling introduces the possibility to build and change real systems and synchronously generate their functional representatives. Simulation may be carried out with the virtual model and compared with the desired behavior of the real system, Figures 1 and 2.

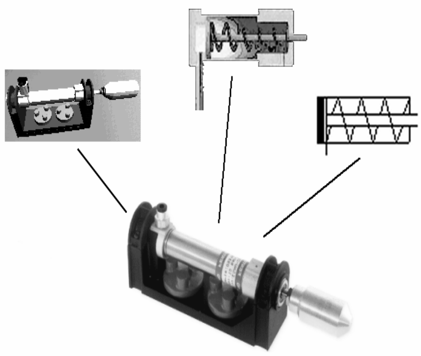

Fig. 1: Complex Pneumatic Object

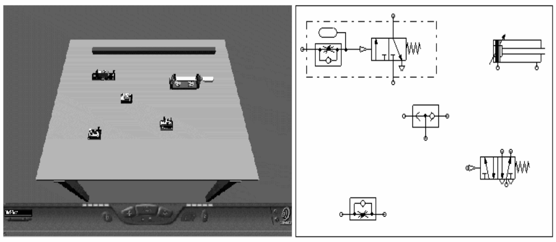

Fig. 2: Two virtual Representations

As long as one stays in physical modeling, it is only the (not trivial) problem to merge continuous and discrete behavior representations. Several simulators support this type of hybrid modeling (for more details see Mostermann, 1997). Two powerful theories approaching each other from different edges are Petri-Nets for discrete behaviors and Bond-Graphs (Paynter, 1961; Karnopp, 1995; van Amerongen, 2001) for continuous flows. Both concepts have in common that they are graph-oriented and therefore may open up a broad area of possibilities to apply methods of theoretical informatics, namely graph-transformation and -replacement methods. Secondly, they support unified views on physical phenomena, a feature more and more important in times of emerging mechatronic systems. Thirdly, they support a certain intuitive engineering point of view (Cellier et al, 1995).
As soon as we come to a mixture of physical and virtual worlds however, be it locally or distributed, we have to face not only hybrid physical connections but also the transfer between energy, signal flow phenomena and information processing. No general concept can be seen yet. However some steps in this direction can be presented.
In a prototype, it could be demonstrated how, by using complex objects of type *conveyor belt*, *container* and *tool-machine*, a system configuration could be built with real concrete models synchronously generating the topology of a virtual representation. Furthermore the desired behavior of the automation system could be demonstrated by concrete hand-movements and signs. From this demonstration, Petri-Net fragments were generated to serve as building blocks for the control algorithm driving a Programmable Logic Controller (PLC) responsible for the control of a real automation system by means of sensors and actuators (Figure 3) (Bruns, 1999).

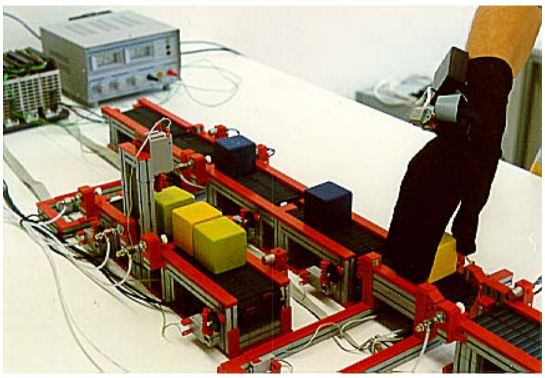

Fig. 3: Specifying Behavior by Demonstration

This concept has been further extended by bi-directional links between the virtual and the real model, being able to sense and generate various relevant physical continuous effort and flow phenomena via universal connections: **Hyper-Bonds** (Bruns, 2003). The reason, to call this connection Hyper-Bond is because it aims, similar to Bond-Graphs to a unified interface concept for various physical flow phenomena. However, there is no direct translation of bond-graphs into hyper-bonds. Bond-Graphs describe energy flows, whereas hyper-bonds provide the interface between energy, signal and information flows. Mostermann (1997) describes well difficulties related to cutting a bond-graph into two parts. Therefore the following description is more a conceptual than a detailed implementation view.

An interesting application problem is the remote control of a robot system, which is part of an automation system that is remotely designed, implemented, tested, controled and serviced. Several authors report about remotely controlled mixed reality robots (Milgram et al, 1995, Milgram & Ballantyne, 1997) and related design problems (Milgram & Colquhoun, 1999). Their focus is on a general taxonomy of mixed reality and for the resulting man-machine interface, strongly emphasising the visual representation of tremote reality.
Our vision is, to have an interface concept to be able to design a system and successively construct it locally in virtuality and reality and materialise it at a remote place, not only grasping through the Internet but transfer all physical phenomena through the network.

2. SYSTEMS AND BOUNDARIES

A system behaviour may be studied by cutting it at well defined boundaries and replacing the external influences by some observable and measurable relevant variables, reducing the investigation to the internal dynamics of the rest (figure 4). In work oriented systems design we may use this principle to cut a system into two parts, one non-relevant for man-machine interaction or ergonomics, and the other one important and relevant (safety, performance, human-skills). Certain well known aspects of a system can be represented in a formal way by algorithms in the computer, others to be investigated in more human related way are represented in reality, but coupled to a dynamic surrounding. This would allow completely new forms of easy experimental systems design.

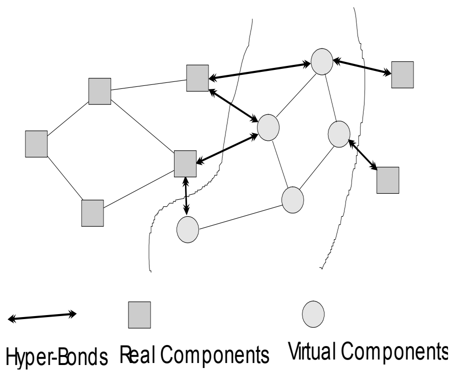

Fig. 4. Boundaries cutting a system

In order to provide arbitrary boundary conditions, we must have a mechanism to generate and sense phenomena (Fig. 5). We implemented a coarse prototype for electrics (voltage and current) and pneumatics (pressure and volume-flow) and demonstrated its successful integration into a virtual construction- and simulation-environment, Fig. 6 (Bruns, 2003). We used pressure valves connected to a pressure source to generate air flow and sensors to measure the pressure for a pneumatic-hyper-bond, and electrical switches connected to a voltage source to generate electric-current flow and sensors to recognize a high or low voltage level at the interface for an electrical-hyper-bond. Connections between real and simulation parts of a system are well known from hardware in the loop tests, however it is new, to provide this possibility in a flexible user-centred way.

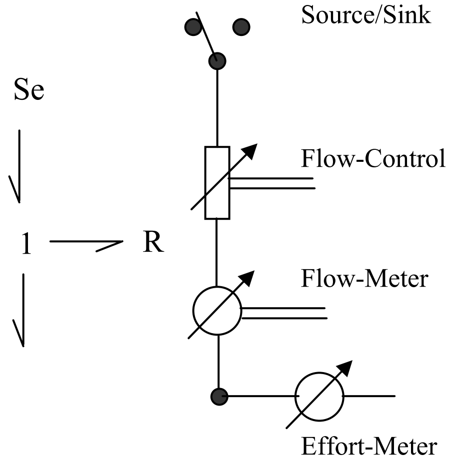

Fig. 5. Abstract mechanism to sense and generate effort and flow (Hyper-Bond)

3. APPLICATIONS

Our concept of Hyper-Bonds is being applied in a learning environment for electro-pneumatics, where students can work on complex systems, freely switching between virtuality and reality[1]. At present, it is not yet possible to cut a real complex system (Fig. 7) at **arbitrary** boundaries and project one part into virtuality and keep the rest in reality, both being connected by a general interface. Or take the other direction: cut a virtual model of the production system in Fig. 7 and materialize it stepwise into a real production. However, in principle it could be demonstrated. Fig. 6 shows a virtual model of the distribution station (a mover driven by pneumatic pressure and electrical signals Fig. 8) as part of a larger modular production system (MPS), Fig. 7. Electrical signals and pressure for the virtual model are generated from the real modeling desk, transferred into virtuality by a pressure hyper-bond (left connector row) and electric hyper-bond (right connector row). As this automation process (sequence of distribution-station with mover, test - station and manufacturing-station with round table, drilling and testing) is a slow discrete event driven process, there are only minor real-time synchronization problems. This changes however for continuous robot control.

Especially if one is interested in a work-process-oriented focus, it is of high value to use authentic situations, see and feel the complex context, be able to select certain interesting aspects of a system, put them as real components on a laboratory desk, but still have them connected to and integrated into the overall system. As the virtual model can be distributed over different locations (however with some restrictions in time behavior), one has the possibility to have one complex virtual system materialized in parts at one location and in parts at other locations. This opens up completely new perspectives for distributed task oriented experiences and co-operation within groups.

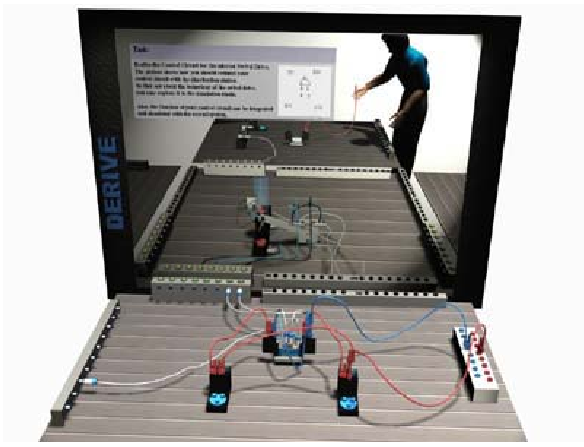

Fig. 6. Virtual and real Part of a System connected by Hyper-Bonds

For systems development our concept may support an incremental implementation and testing of complex devices. For service and maintenance it would support the stepwise investigation and repair of disintegrated parts.

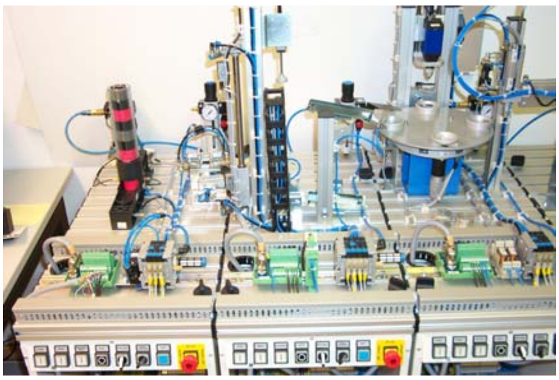

Fig. 7. Modular Production System in Reality

[1] EU-IST Project DERIVE (Distributed Real and Virtual Learning Environment for Mechatronics and Tele-Service

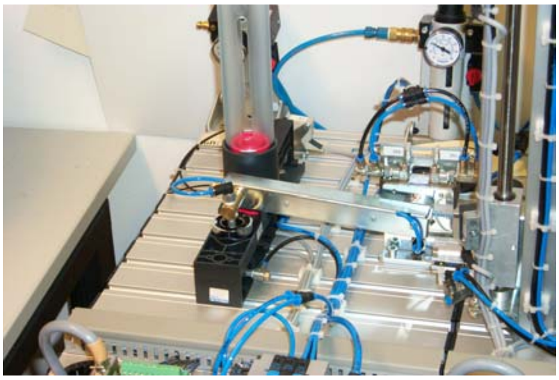

Fig. 8. Distribution Station as real Part of an MPS

One further aim is to combine this concept with real continuous robot processes like welding in a remote way. In a cooperation between several industrial and academic partners[2] we demonstrated the non-critical interactive control and visual observation of a welding robot via internet and its combination with a universal robot simulator COSIMIR (Freund et al, 2002), Fig. 9-10. Entering the Internet Webpage via Internet Explorer, the user has the possibility to program, simulate, control the real robot and observe the resulting process by video image capture.

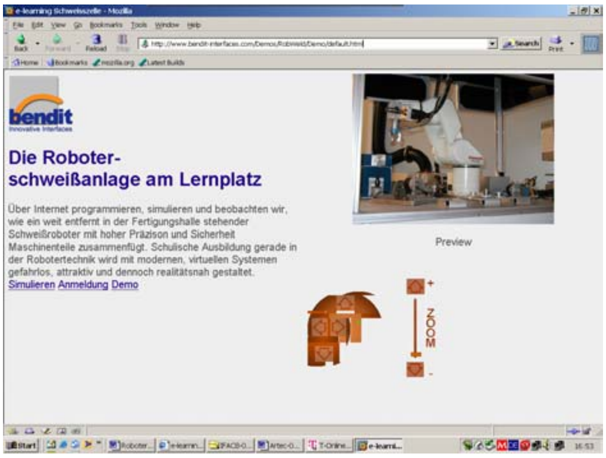

Fig. 9: Internet Access to Remote Welding

http://www.bendit-interfaces.com/Demos/RobWeld/Demo/default.html

This is a possibility for vocational schools not having direct access to the real process or a production line. However it still has to be verified, what the benefits of a remote real but not graspable system may be over pure simulation.

One reason for real systems, even if they are not graspable but situated at a remote side, is the possibility to validate and adjust the virtual dynamic model (bond-graph) of the physical components by and with their real counterpart. Having the possibility to selectively switch between real and virtual components would be of some benefit.

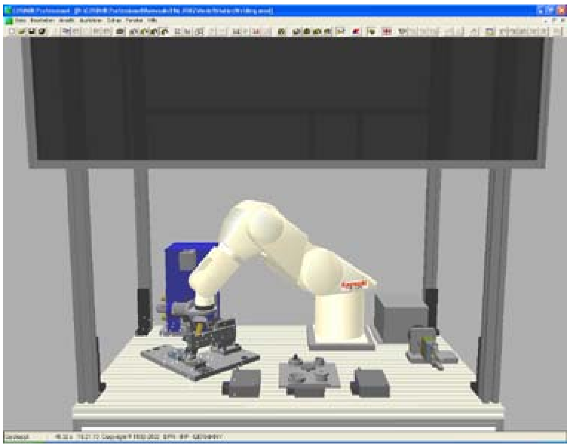

Fig. 10: Simulation of melding Robot

Fig. 11: Video of real process

Another reason supporting our approach is the necessary communication and cooperation between real persons at the process location and remote experts or learning students. This important mode of collaboration can be experienced with the system. The demonstration may be used as an entrance to distributed collaboration in virtual and real environments not only relevant for mechatronic systems design but also for maintenance and control of complex automation systems. A third reason having robots remotely controlled for learning applications, is the desire to configure remote laboratories of the above type (Fig. 5) without 24-hours onside human help.

However, to reach a state where the theoretical unified concept of bond-graphs, its implementation in a universal mixed reality analog/digital interface and the necessary network quality of service is available, much work still has to be done (Hirche & Buss 2003; Melchiorri 2003). Some low-cost steps in this direction will be presented at the conference (Yoo & Bruns 2004), Fig. 12-13.

[2] Festo, K-ROBOTIX, Inst. Robotics Research, ARTEC, Bendit

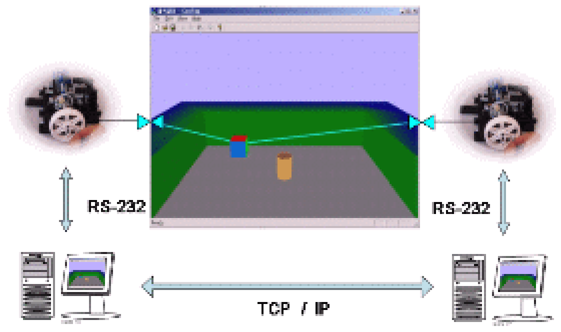

Fig. 12. Distributed Mixed Reality model

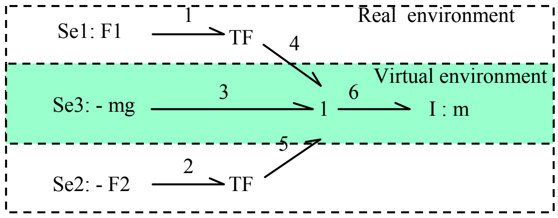

Fig. 13. Bond-graph model of mass transportation with force-feedback

REFERENCES

Amerongen, J. van (2001): Modelling, Simulation and Controller Design for Mechatronic Systems with 20-sim. Proc. 1st IFAC conference on Mechatronic Systems, pp. 831-836, Darmstadt, Germany

Brave, S., H. Ishii, A. Dahley (1998). Tangible Interfaces for remote Collaboration and Communication. Proc. of CSCW '98, Nov. 14-18

Bruns, F. W. (1999). Complex Construction Kits for coupled real and virtual engineering Workplaces. In: N. A. Streitz et al (Ed): Cooperative Buildings. Lecture Notes in Computer Science 1670. Springer, Berlin, pp 55-68

Bruns, F. W. (2003): Hyper-Bonds. Human Skills Oriented Systems Design with Mixed Reality. Proc. of 6th IFAC Symp. on Automated Systems based on Human Skill and Knowledge. Göteborg

Cellier, E. F., H. Elmqvist, M. Otter, (1995). Modeling from Physical Principle. In: The Control Handbook, (W. S. Levine (Ed)), CRC Press, Boca Raton, pp 99-108

Freund, E., Hypki,A., Pensky, D.H. (2002). Multimedia Robotics Teachware based on 3D Workcell Simulation System COSIMIR® Proc. 1st IEEE International Conference on Information Technology & Applications (ICITA2002), Bathurst, Australia

Hirche, S., Buss, M. (2003). Study of Teleoperation Using Realtime Communication Network Emulation. Proc. IEEE/ASME Int Conf. Advanced Intelligent Mechatronics, Kobe, Japan

Ishii, H., B. Ullmer (1997). Tangible Bits: Toward Seamless Interfaces between People, Bits and Atoms. CHI´97, Atlanta, Georgia

Karnopp, D. C., D.L. Margolis, R.C. Rosenberg (1990). System Dynamics – A unified Approach. John Wiley, New York

Melchiorri, C. (2003). Robotic Telemanipulation Systems: An Overview on Control Aspects. 7th IFAC Symposium on Robot Control, Wroclaw, Poland

Milgram, P., Rastogi, A., Grodski, J. J. (1995): Telerobotic control using augmented reality, Proc. IEEE Int'l Workshop on Robot-Human Communication (RO-MAN'95), pp.21-29

Milgram, P., Ballantyne, J. Real world teleoperation via virtual environment modeling. Proc. 7th Int. Conf. On Artificial Reality and Tele-Existence (ICAT'97), pp.1-9, 1997

Milgram, P., Colquhoun, H. (1999). A Taxonomy of Real and Virtual World Display Integration. In Ohta, Y., H. Tamura (Ed). Mixed Reality – Merging Real and Virtual Worlds. Tokyo, pp. 5-30

Mostermann, P. J. (1997). Hybrid dynamic systems: A hybrid Bond Graph Modeling Paradigm and its Application in Diagnosis. Dissertation, Vanderbilt University, Nashiville, Tennessee

Ohta, Y., H. Tamura (1999). Mixed Reality – Merging Real and Virtual Worlds. Tokyo

Paynter, H. M. (1961). Analysis and Design of Engineering Systems, MIT Press, Cambridge, MA

Yoo, Y.-H.; Bruns, W. (2004). Realtime collaborative mixed Reality Environment with Force Feedback. 7th IFAC Symposium on Cost Oriented Automation, 2004, Ottawa

http://www.derive.uni-bremen.de/
http://lab.artec.uni-bremen.de/
http://www.labfuture.net/
http://www.bendit-interfaces.de/