

MIXED REALITY WITH HYPER-BONDS - A MEANS FOR REMOTE LABS

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Abstract: The paper presents a learning environment where on-site and remote components merge into a cooperative learning process. The envisaged system allows to work 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 to build up real systems as subsystems of complex virtual systems. *Copyright © 2004 IFAC*

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1. INTRODUCTION

Engineering education is confronted with the need to develop theoretical integrated with practical learning sequences to fulfill the demands for multi-skilled engineers and also skilled technicians. Tasks and problem solving in complex technical systems requires cognitive and operational knowledge and practical experience about building systems, diagnosis- and maintenance-techniques. However, a significant challenge is that these tasks are essentially characterized by the use of tele-medial systems. Service staff in the professional field need the ability to achieve their aims in (tele) cooperation with others, and they should be able to cooperate in virtual and distributed forms of organization. Concepts concerning pedagogical, technical and organizational aspects to meet these requirements in education and training are in development. Cultural differences and similarities concerning learning and collaboration styles have also to be considered regarding curricula, courseware and teaching methods.

Computers are now used in the classroom and at the job as multimedia tools to provide alternative sources of learning material, to provide interactive learning situations and to provide simulation of systems that

cannot for reasons of cost, size or safety be used in reality. The use of the Internet is rapidly increasing and is being seen by some people as the greatest source of knowledge available for learning. The use of simulation tools has a number of benefits to education. The learner is not exposed to the hazards of the real world. The learner is able to explore a range of possible solutions easily and quickly. The learner is able to use the tools that will be available in industry. The cost of simulation tools is significantly less than the real world components and allows more participation and interaction than a limited demonstration. An added benefit is that learners today, enjoy using computer based technology and this enthusiasm fosters the learning process. The question is indeed to what extent real experience can be replaced by learning with simulations? The internet makes it possible for e-learners to have access to remote laboratories. They could change control parameters to study the effect on the performance of a plant equipment. Before doing this they can experiment with the virtual equipment in a computer-simulation to save time when remote experimenting with the real equipment.

Remote laboratory applications are not new. With respect to learning support there are however still many open questions:

- How to synchronize multiple remote actions on one lab-object to support collaboration,
- How to handle feedback from the process: visual, sound, haptics or more general: how to sense all interesting physical phenomena
- How to handle action into the process: electrical, mechanical, thermodynamic or more general: how to generate all interesting physical phenomena
- How to represent learning content, scenarios, prerequisites, tools etc. in a standardized Learning Object Module (LOM) to support a modular, open, easy and flexible use
- How to administrate the learning session running on one original critical equipment, supported by an on-line expert?

Goldberg & Chen (2001) and Song & Goldberg (2003) fruitfully address the problem of collaborative control of robotic cameras to observe a remote laboratory and the distribution of video-streams. On their web-page it is also shown how they face the learning object module problem.

Ferreira et al (2002) and Cooper et al (2002) demonstrate 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) report about remote-lab developments in the EU-project MARVEL – a mixed reality learning environment for vocational training in mechatronics.

However, up today, all 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. Going one step further, we suggest a distributed environment where the process-model of energy and information flow can cross the border between reality and virtuality in an arbitrary bi-directional way. Reality may be the continuation of virtuality or vice versa. This bridging or mixing of reality and virtuality opens up some completely new perspectives not only for learning environments but also for evolutionary systems design and service work. To make this possible, Bruns (1999, 2001) developed a concept of *Complex Objects* being a unit of various closely coupled virtual and real representations and *Hyper-Bonds*, a universal interface type. This name has been chosen because of its relation to bond graph representations. Bond-Graphs being itself a very powerful representation-theory for dynamic systems.

2. BOND-GRAPHS AND HYPER-BONDS

Hyper-Bonds combine the unified abstract systems representation of bond graphs with an implementation of “hyper-connections” between physical phenomena of the computer-external environment and the logical structure of computer-internal representations, a blend of physical systems with their virtual counterparts.

Paynter (1961) introduced the theory of bond graphs as a unifying view on physical phenomena from a continuity of power-flow perspective. Power flows through system components and connections by way that the product of effort and flow is continuous, following typical laws of energy conservation. Effort (e) is the driving force for flow (f) and can be a pressure difference, force and torque, electrical potential difference, temperature difference etc. Flow (f) can be a flow of material, momentum, electric current, entropy. The bond graph theory has been further developed by Karnopp et al (1990). Pairs of effort and flow (e,f) are for example in mechanical systems force (F) and velocity (v), in electrical systems voltage (V) and current (i), in pneumatic/hydraulic systems pressure (P) and volume flow rate (dQ/dt). Figure 1 explains the correlation of pressure p, fluid flow q with force F, velocity v and mass/inertia I, compressibility C of the fluid and friction R in a simple pneumatic equipment. In many automation systems, electro-pneumatic circuits are considered as state automata and the elements can be represented as simple off/on switches like the valve and in/out positioning like the cylinder. These state automata do not require a bond-graph representation, but if one is interested in a more detailed dynamic behavior, then this can be described by graphs like the one in figure 1.

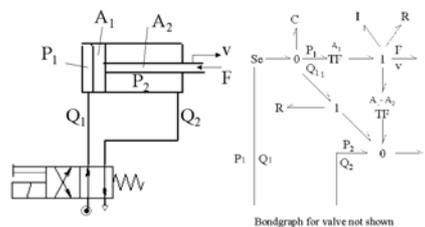


Fig. 1. 4/2 way valve controlling a double-acting cylinder and a bond graph of the cylinder alone

Components (valves, cylinders, etc.) are always connected by bonds having the value pair e and f. Knowing e and f at one connection, resulting from calculation or measurement, allows a cutting of the system in two parts and a separate investigation.

In mechanics one learns the principle of cutting a system 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. In laboratory work this principle is used to construct reproducible experiments, but also mentally it is used to think about systems in hypothesis and mental experiments. Today laboratories, being more and more permeated by computers, a free and easy distribution of a system between reality and virtuality has some advantage. 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 detail are represented in reality, but coupled to a dynamic surrounding. This allows completely new forms of easy experimental work and learning. Here Hyper Bonds comes into play.

In order to provide arbitrary boundary conditions, we must have a mechanism to switch between a source of effort and a sink of effort, and to generate and sense phenomena. Figures 2 and 3 show the cutting boundaries between reality and virtuality and its realization with a special sensor/actuator coupling.

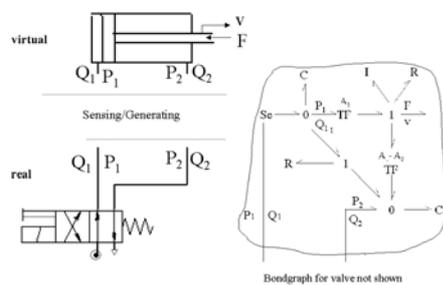


Fig. 2. Cutting of the system of Figure 1 by a sensing/generating mechanism (hyper-bond)

Hyper Bonds are of course also possible for pairs like voltage V and current i , Temperature T and heatflow dQ/dt and mass M and velocity v . Figures 2 and 3 are only simplified examples for use of Hyper-Bonds. The hardware implementation of figure 3 is simple. For every supported physical phenomenon, there must be two sensors (pressure-meter and volume-flow meter for pneumatics) and a controllable source (air-flow and air-pressure). Analog sensor-signals are converted into digital values and then available for the software side of a hyper-bond. The opposite direction requires digital values from the software being converted into analog signals to drive a generating mechanism (force and speed for mechanics).

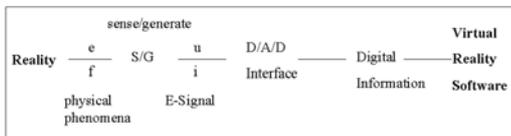


Fig. 3. Hyper-Bond structure

Figure 4 shows a simple connection of a real pneumatic valve, to a pressure source (not seen on the left side) and a hyper-bond below the screen. The valve is under real pressure. If pushed, the tube connecting the valve and the hyper-bond is under pressure and triggers an input signal to generate virtual pressure in the virtual tube-continuation. The simulated cylinder drives out. If the pushbutton is released, the valve opens a pressure release, the real pressure drops and the virtual pressure driven by the back-spring of the cylinder causes an outflow of air through the hyper-bond. This demonstrates the bi-directional character of the hyper-bond.

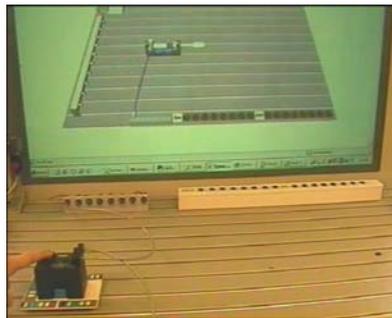


Fig. 4. Pneumatic equipment: single acting cylinder and valve split into reality and virtuality.

Another simple application can be imagined, having two real double acting cylinders crosswise connected via hyper-bonds through a virtual model. Two persons could then play a pushing-game, figure 5. Or in a more practical application, a concrete remote object can be moved with force-feedback and any computer generated support coming from a virtual model, replacing the one-to-one connection between the two hyper-bonds in figure 5.

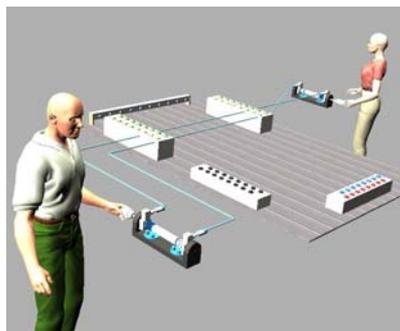


Fig. 5: Two real persons pushing each other by two real cylinders connected via hyper-bonds and virtuality

Hyper-bond is a mechanism based on the translation between physical effort/flow phenomena and digital information like any other analog/digital and digital/analog conversion, however it aims at a unified application oriented solution connecting the physical and its virtual representation and continuation. One of its main feature is, that the modeler does not have to be aware about the direction of energy-flow, hyper-bonds are bi-directional and adapt itself to the environment conditions. Figures 2 and 3 are highly simplified presentations. For a deeper understanding of hybrid bond graphs and how to handle discontinuities, boundary cuts and transfer between power flow, signal flow and logic switches see Mostermann (1997).

3. LEARNING ENVIRONMENTS

The European project "Distributed Real and Virtual Learning Environment for Mechatronics and Tele-service" (DERIVE) used the concept of hyper bonds to describe electro-pneumatics (Bruns et al, 2002) in a unified and didactically expandable way as well as to have a link to several powerful simulation tools supporting bond graph modeling.

DERIVE provides a new learning environment that supports schools for technicians to deliver courses in mechatronics. The support for the learning process will be reflected in a graduation from local real to local virtual to remote virtual to remote real, taking the student from basic knowledge to the full implementation in industry.

The tele-cooperation functionality in the learning environment will allow enterprises to use the training facilities in order to update the knowledge of their employees. With new equipment being more complex and requiring more complex maintenance, the training requirements for workforce and engineers increases. The new environment will allow groups of employees at remote locations to take part at the same training using the same equipment (either simulated or real). This staff will be able to work in a collaborative way to solve problems and explore learning situations. This new kind of interaction will allow the systematic support of skilled workers and engineers. Also, the learning environment is an appropriate tool to realize project orientation in technical training, providing a platform for self-managed and collaborative learning.

A typical learning session could be the following:

Sequence of two Pneumatic Cylinders

Modelling Task:

Build a circuit for a welding operation.

First activate a clamping cylinder with the push of a left button, after this first cylinder has reached its end-position (clamps a work-piece), a second cylinder, the welder is automatically activated. On pressing a right button, the process is terminated and

the clamping and welding cylinders move in, releasing work-piece and welding process.

Solve the task by using virtual and real parts as preferred. Criticise the problem definition and suggest improvements.

You can use in virtuality:

Double Acting Cylinder With Magnetic Proximity Switch

Single Acting Cylinders

3/2-way valves with push button, normally closed

3/2-way solenoid valve, normally closed

5/2-way solenoid valve

Sources of pressure and voltage

Hyper-Bond connectors between virtual and real

Tubes and wires

You can use in reality, observable by video camera:

Hyper-Bond connectors between real and virtual

Single Acting Cylinders

3/2-way solenoid valve, normally closed

Tubes and wires

Session:

Virtual solution with double acting cylinder1 upper half, a 5/2 way solenoid valve, a single acting cylinder2 (left lower side) and a dummy cylinder3 (right lower side)

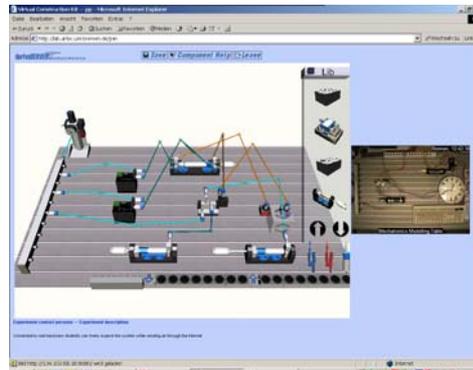


Fig. 6: Pressure supply on -> Dummy cylinder moves out

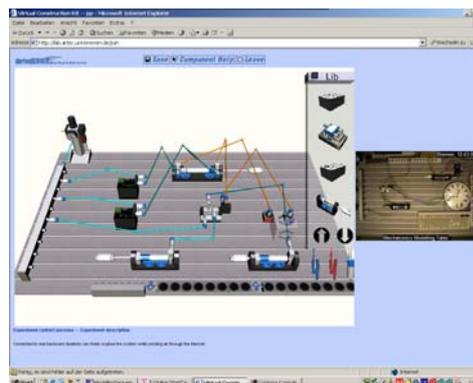


Fig. 7: Virtual circuit in action

In figure 7, if left button is pushed resulting in 1. cylinder out, 2. cylinder out, 3. cylinder in if right button is pushed resulting in 1. cylinder in, 2. cylinder in, 3. cylinder out.

Now export virtual parts into reality!

Connect virtual pressure valve via hyper-bond (first right pneumatic-connector) with a real cylinder seen on video-image upper right, figure 8. Press virtual push-button and see single acting cylinder moving out as long as button is pushed. On release of button, the air flows back from reality into virtuality and cylinder moves in !!! Recognize, that this is a different behaviour than the one in virtuality. Why? In figure 9 most virtual parts are exported. Pushing virtual button, highlighting active connectors in virtuality and moving real cylinders

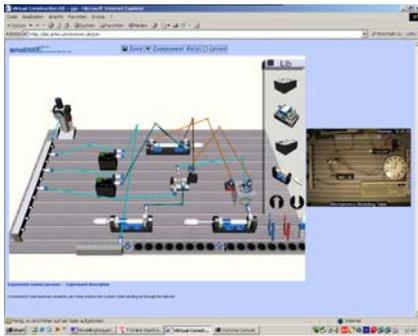


Fig. 8: Exporting pressure

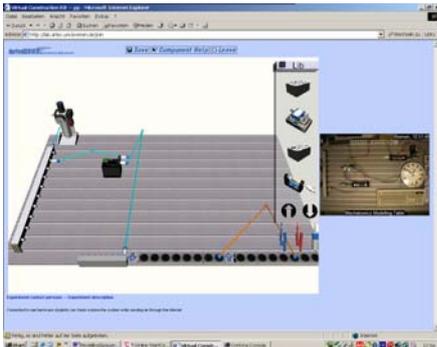


Fig. 9: Most parts exported

4. ADVANTAGES OF MIXED REALITY FOR LEARNING

The project developed a mixed reality human computer interface (Figure 10). To develop adequate technological and pedagogical concepts for e-learning in future technical training, users needs had to be analyzed in depth. The requirements of different user groups (students, teachers, employees) have to be described and consolidated. Acting in an environment, where real world objects and IT-technologies are applied simultaneously, requires

new concepts of supporting cooperating local and distributed learning groups. The scientific challenge is to handle physical as well as virtual presence and

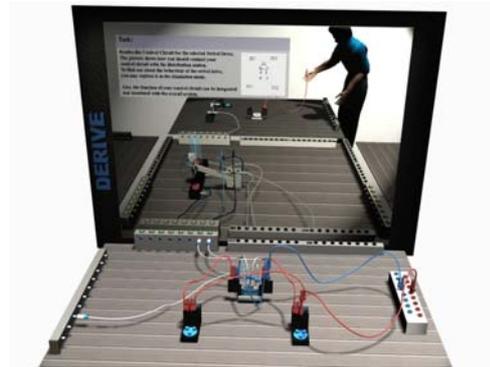


Fig. 10. Real and virtual environment for training in electro-pneumatics to control a Robot-Arm

awareness without confusing side effects for the users. With Hyper-Bonds, a learning environment got realized where on-site and remote components merge into a cooperative learning process. The environment system allows to work together with complex real and virtual systems, consisting of parts which may be distributed remotely. The learning environment includes a supportive web-database with multimedia learning sequences providing theoretical background information, exercises and help to handle training tasks. The learning environment smoothly integrates equipment and supports hardware-in-the-loop functionality, allowing to build up real systems as subsystems of complex virtual systems (Figure 10).

The environment has been evaluated in 3 European vocational schools and colleges and at one industrial site. The results, based on a prototype which was not yet very stable, was already very encouraging for further offering a broad learning-landscape to navigate between concrete and symbolic representations. In a comparative evaluation of

- traditional teaching with blackboard and teacher learner interaction
- support by simulation only (FluidSim-software of FESTO AG, Germany)
- support by real complex system only (Modular Production System/MPS of FESTO AG, Germany)
- support by real and virtual media (DERIVE)

in 20 hours-courses of mechatronics, Grund and Grote (2004) found some hints that students/apprentices being trained with DERIVE showed better performances in symbol based fault finding.

The following main tendencies are considered important:

- thinking in abstract categories of structure-behavior-function searching for alternative concrete instantiations (e.g. various structures for

- one function, or various functions of one structure)
- thinking in categories of information-control-work process and their realization searching for unified system dynamics views (e.g. Petri-Nets and Bond Graphs) for analogous physical phenomena (electricity, pneumatics, force-momentum mechanics ...)
 - judging about the adequateness or failure of simulation models versus real systems

Enterprises recognize that employee expertise is a vital and dynamic living treasure. The demand for employee expertise is meaningless unless an organization (enterprise) can develop it in ways that respond to its business needs. Many enterprises rely on off-the-job training (formal learning) without considering its suitability for the learning tasks at hand. On-the-job training (informal learning) has a substantial advantage: it is more close to the problems to be solved and it can be organized in a cooperative way crossing the border between different professions that are involved in a project to fulfill an order of a customer. But on-the-job training is often unplanned and therefore mostly ineffective. With a structure and using well prepared training material usable at the workplace and facilitating advises from outside for cooperative learning makes on-the-job training a powerful tool (Jacobs and Jones, 1995).

Collecting case studies of solved problems in manufacturing and service could help to solve new tasks. If they are released and are available in electronic format, preferably via internet, it is a powerful instrument for learning at workplaces. Via the internet it is also possible to use training material and remote labs offered by training institutions.

5. CONCLUSIONS

A new interface concept, allowing a flexible and user-friendly modeling in a blended real and virtual environment has been introduced. This concept, suitable for an integration into the theory of bond-graphs, allows some learning and working modalities important for training and systems analysis: the stepwise abstraction and concretization of parts of a complex system still within the context of the whole. This feature supports various individual learning styles, systems diagnosis and repair strategies. Further developments and evaluations are undertaken in an EU-project [Lab@Future](#) where this interface technology is applied in concepts of future remote laboratories.

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