HYPER-BONDS
- HUMAN SKILLS ORIENTED SYSTEMS DESIGN WITH MIXED REALITY -

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Abstract: A Mixed Reality concept will be introduced to ease the design of automation systems which are human skills oriented. *Hyper-Bonds*, a unified concept to describe complex effort/flow driven automation systems distributed over real and virtual worlds, allow a selected materialization of parts of the system in reality and have it functional connected to a simulation model. This generalized concept to blend physical systems with their virtual counterparts, being their computer-internal representation or a functional continuation will be presented. The theory is laid down and a first application in learning and working is shown. Consequences for a human skill oriented design are shown.

Keywords: mechatronics, systems design, participation, simulation, mixed reality

1. INTRODUCTION

Mixed realities (Ohta & Tamura, 1999) are becoming more and more popular and offer some interesting possibilities for human-centered systems design. They represent a kind of coupling of real world phenomena to various information, represented in a computer. This might take place in the sense that information is displayed and overlaid to real phenomena (see Augmented Reality research: Weiser, 1993; Wellner, 1993), in the sense that real phenomena are used as handles to manipulate information (see Graspable User Interface research: Fitzmaurice, et al., 1995) or in the sense that both worlds are bi-directional tight together (Ishii & Ullmer, 1997; Brave, et al., 1998; Brauer, 1996). The focus of this paper is the later approach.

In some previous work, the concept of complex objects was introduced (Bruns, 2000) being objects with a real concrete part coupled to various virtual representations 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 behavior of the real system. It is then possible, to download the controlling algorithm, driving the virtual model, also to a Programmable Logic Controller (PLC) and drive the physical system by means of sensors and actuators. This concept has been extended by a bi-directional link between the virtual and the real model, being able to sense and generate various relevant physical effort and flow phenomena via universal connections: **Hyper-Bonds**. A first prototype was realized for pneumatics (Bruns and Gathmann, 1999).

A unifying concept allowing this approach is the Theory of Bond-Graphs (Paynter, 1961; Karnopp, 1995). This concept was implemented via PLC-technology. At first, a short recall of bond graphs is given and their usefulness for this approach shown. A short motivation for Hyper-Bonds from a system dynamics point of view follows. In section 3 the detailed concept of Hyper-Bonds is introduced. Some applications and perspectives finish our contribution.

2. USEFULLNESS OF BOND-GRAPHS

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 and power-flow continuity. Effort (e) is the driving force for flow 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. Bond graphs are networks with edges of (e,f)-connection and nodes with constant e (0-node) or f (1-node). Bond graphs can be used to describe dynamic behaviors of different physical domains with one formalism (figures 1 and 2), similar the way we use differential equations for all kinds of physical phenomena. In fact, for calculation means, bond graphs are transferred to systems of differential equations and then integrated (symbolic or numerical). For engineering purposes bond graphs have several advantages as they are vivid and preserve important constraints (Cellier et al., 1995). One important feature of bond graphs is the input-output relation of effort and flow, seen from a physical component perspective. Components are always connected by bonds having the value pair e and f where one of them can be seen as input the other as output from a cause-reaction point of view. However, it can only be determined from an overall systems view by causal reasoning which one is input and which one output. Knowing e and f at one connection, resulting from calculation or measurement, allows a cutting of the system in two parts and two separate investigations.

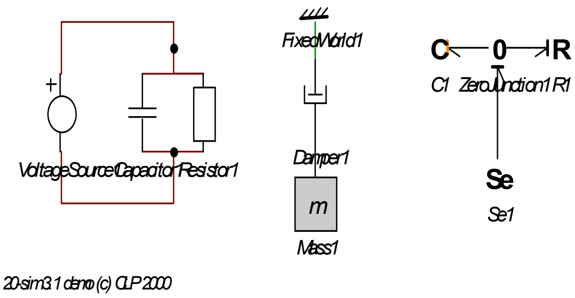

Fig. 1. Bond-graph for equivalent mechanical and electrical systems

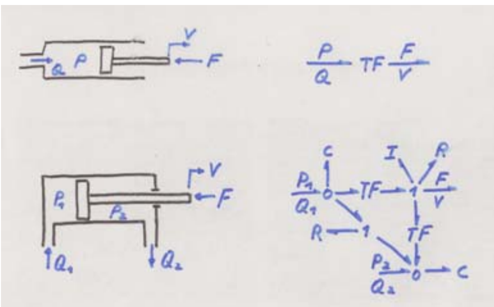

Fig. 2. Bond-graph for pneumatic cylinders (different levels of abstraction: lower graph includes resistance R, capacity C, induction I of piston and air

Bond-graphs are especially useful for the description of mechatronic systems, where power-flow is transformed and exchanged between different forms of energy.

The feature of effort and flow, determining a systems behavior can be used fruitfully, to implement arbitrary cuts in an overall system, realizing one part in reality, the other one in virtuality and provide a mechanism to sense and generate arbitrary efforts and flows. This will be demonstrated.

3. 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 3). In work oriented systems design we may use this principle to cut a system in 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.

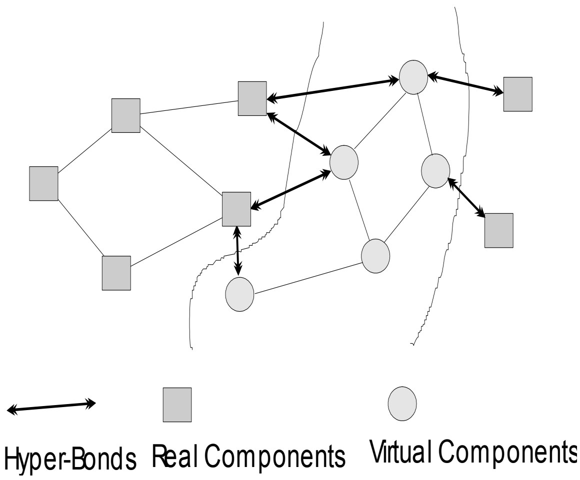

Fig. 3. Boundaries cutting a system

There is a long tradition of favoring real concrete models compared to abstract representations (Breretron and McGarry, 2000) in systems design. It is well known that architects of cathedrals (like the St. Peters Dom in Rome) and engineers of automotive factories (like Chrysler and Ford) and even today, there is a tendency to communicate new concepts by graspable models (Scheel et al., 1994). A technology of hyper-bonds may combine both worlds: the world of graspable concrete objects and the world of simulation models.

4. HYPER-BONDS: A SENSING AND GENERATING MECHANISM

In order to provide arbitrary boundary conditions, we must have a mechanism to switch between source

and sink and to generate one phenomenon and sense the other. The implementation for electrics (voltage and current) and pneumatics (pressure and volume-flow) is given in figure 4, together with its abstract bond graph representation. A simplified version of a prototype is shown in figure 5.
The successful integration into a virtual construction and simulation environment has been demonstrated for learning applications, figure 6.

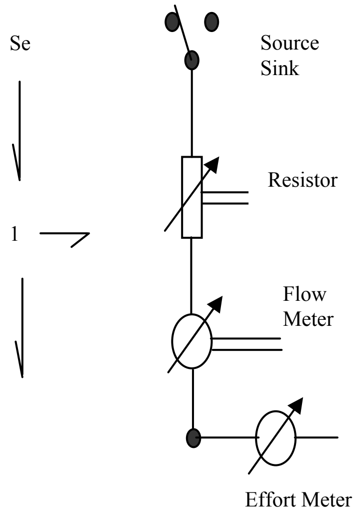

Fig. 4. Hyper-Bond for Voltage/Chargeflow and Pressure/Volumeflow

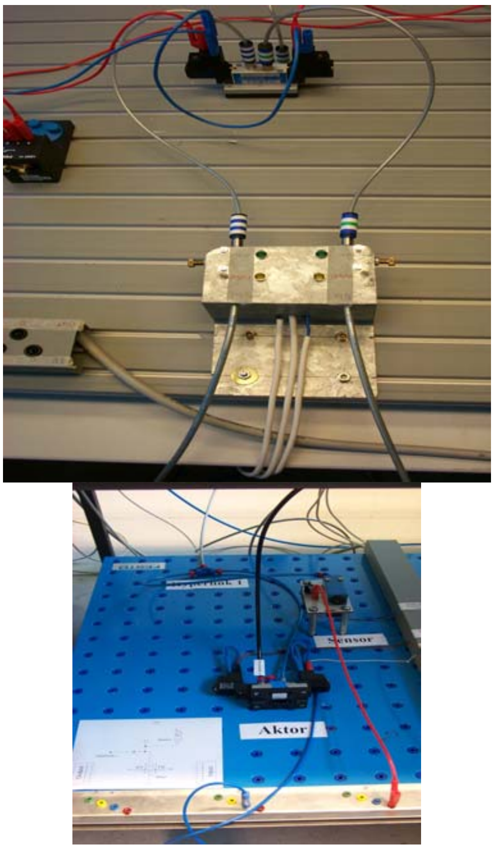

Fig. 5: Implementation of a Pneumatic Hyper-Bond (lower picture shows implementation, upper picture application side)

5. APPLICATIONS AND PERSPECTIVES

The new 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], figure 6. Especially if one is interested in a work-process-oriented focus, it is of high value to use authentic situations, see 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 easily be distributed over different locations (only 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 completely new perspectives for distributed task oriented experiences and co-operation within groups.

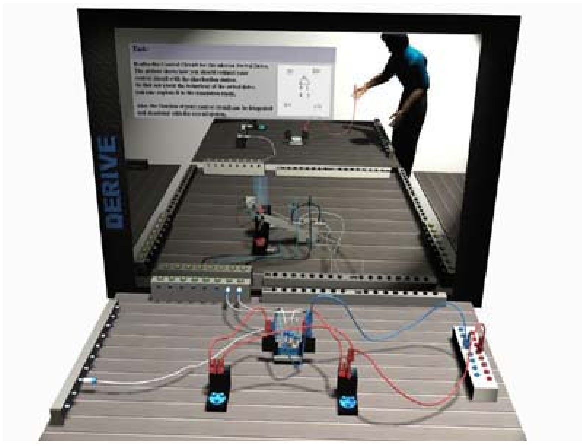

Fig. 6. DERIVE Learning Environment

For systems development our concept may support an incremental implementation and testing of complex devices, figure 7. For service and maintenance it would support the stepwise investigation and repair of disintegrated parts.

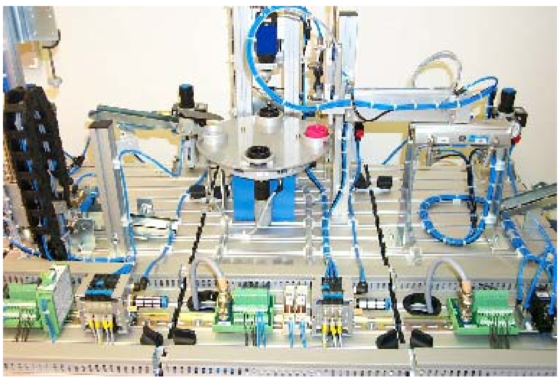

Fig. 7. Modular Production System in Reality

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

So far, the implementation of *Hyper-Bonds* in the domains of electrics and pneumatics have been shown, the implementation for hydraulics, thermodynamics and mechanics will follow.

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