REALTIME COLLABORATIVE MIXED REALITY ENVIRONMENT WITH FORCE FEEDBACK

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Abstract: A low cost *Mixed Reality* implementation with force feedback as a base for further empirical studies of collaboration in distributed real and virtual environments will be presented. It will be shown, how the system can be used to get more insight in tangible cooperation between humans, avatars or in general real and virtual systems.
This application is related to *Hyper-Bonds*, a 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 into reality and their functional connection to a simulation model. *Copyright © 2004 IFAC*

Keywords: mechatronics, shared virtual environments, force feedback devices, simulation, mixed reality, co-presence, object manipulation

1. INTRODUCTION

A concept of mixed reality, the blending of real and virtual realities (Ohta & Tamura, 1999), from toys at an early school level to tools at a work level is introduced to support experience and understanding of principles of physics, human-computer interaction and automation. Our aim is to use a unified concept of physics and control theory, implement them in low cost hard- and software, to support a continuous expansion of experience and knowledge about automated systems towards a cost oriented experimentation with alternatives (van Amerongen, 2001) .
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 (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 or actual behavior of the real system. This concept has been 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). A unifying concept supporting this approach is the Theory of Bond-Graphs (Paynter, 1961; Karnopp, 1995). Bond-Graph theory considers a continuity of energy (Effort x Flow) flow in abstract networks. Effort can be electric voltage, air pressure, force, momentum, temperature etc. Flow can be electric currency, air volume flow, velocity, heat-flow etc. An implementation of Hyper-Bonds for simple pneumatics and electrical interfaces between computer internal and external system-components has been demonstrated. Its extension towards force and momentum mechanics will be shown. This extension is motivated by a need to have a better feeling for remote process control and for collaboration in virtual environments. The former is a well studied problem known from remote robot control in astronautic or surgery applications. The latter has only recently found consideration with the widespread use of multi-user environments in games, entertainment, learning and tele-work. The co-operation of several dislocated humans in a shared

virtual space, communicating with and sensing each other in a tangible way is a challenging task.

Several authors investigate the role of touch in shared virtual environments (SVE). Basdogan et al., 2000, studied the influence of haptic feedback on task performance and the sense of being together. An interesting vision is their haptic version of the “Turing Test”: one real experimental person has to press a stick against a virtual brick and move it to a position, supported by an imitated or real person . The experimental person is asked to recognize who is currently co-operating. Their actual experiment however was the “Ring on a Wire” scenario: two persons had to move a ring along a curved wire without collision. They developed multithreading techniques for integration of vision and touch and found the graphics and haptic update rates to be of at least around 30Hz and 1000Hz, respectively to have a satisfying experience. Their system enabled haptic interactions of two users on one computer. Because of these severe time restrictions, a collaboration via Internet, even Internet2, with force feedback proved to be unpractical at the moment.

Ruddle et al., 2002 therefore addressed the *piano movers’ problem* (manoeuvre a large object through a restricted virtual space) only with visual feed-back. They systemized this rather uncovered field of human-machine interaction in three levels of cooperation: 1) users can perceive each other, 2) individually change the scene, 3) simultaneously act on and manipulate the same object (independent or co-dependent). The co-dependent simultaneous action has been further distinguished as being symmetric (both actors perform the same role, like wearing and fine manipulation) or asymmetric (one actor is wearing, the other one is fine manipulating).

Haptic communication and cooperation may play an important role in future preparation and training of humans in hybrid production systems. We therefore introduce a low cost solution for the study of force feedback phenomena based on toys, embedded in a concept suitable for extension to real automation problems and distributed applications.

2. BOUNDARIES AND INTERFACES

A virtual system behaviour may be studied and controlled through well defined boundaries, figure 1. If these boundaries are dislocated and connected to the virtual world via Internet, we face severe problems of time delay and synchronisation. This is a limitation for the distribution of hard real time processes. Nevertheless, for slow real-time or state oriented, event driven processes a distribution is possible and offers interesting perspectives.

In order to provide arbitrary boundary conditions, a mechanism is necessary to generate and sense various physical phenomena. An implemented coarse prototype for electrics (voltage and current) and pneumatics (pressure and volume-flow) demonstrated its successful integration into a virtual construction and simulation for learning applications (Bruns, 2003).

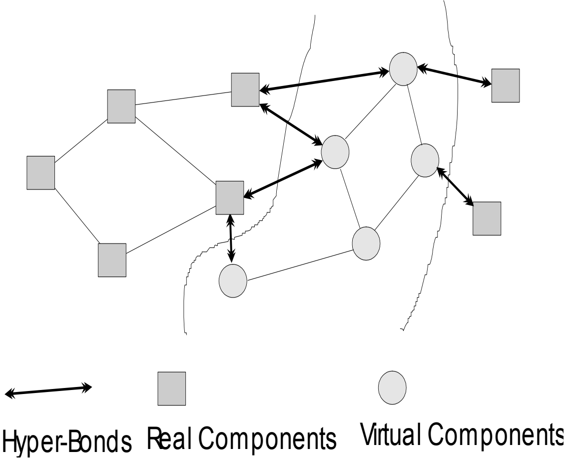

Fig. 1. Boundaries cutting a system

The 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 2. The modeling desk can be used in a distributed way according to Ruddle’s category 2: multi-user may place objects on the virtual table and modify the circuit synchronously but only related to different objects. However, the system is able to support several cooperation tasks close to category 3 in a distributed way. Figure 3 shows a situation where a real pressure valve can be pressed to drive a virtual cylinder and a virtual valve can be pressed at the same time to drive a real cylinder. This cross-circuit may be changed to a safety circuit, allowing to activate a pneumatic-cylinder only if two pressure valves are pressed simultaneously. These two pressure valves may be distributed in a virtual environment and a real place. This concept is now being extended to mechanical phenomena (force, momentum).

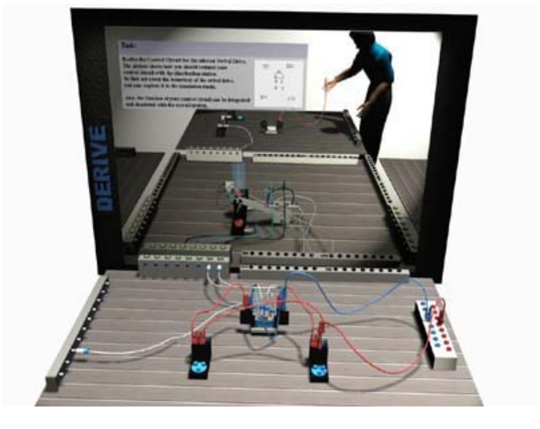

Fig. 2. DERIVE Learning Environment

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

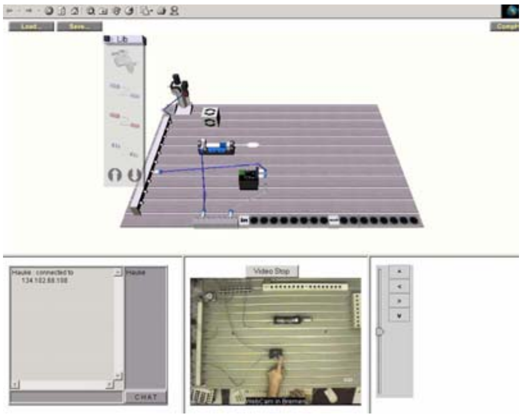

Fig. 3. Distributed Cross-Mixed Reality Circuit

3. FORCE FEEDBACK SOLUTION BASED ON LEGO BRICKS

A Low Cost Momentum Handle (LoMo), based on Lego Bricks, which can be used to feel the artificial force feedback generated from a DC motor and sensed by a pressure sensor, was developed (figures 4-7). The LoMo can be used in various distributed mixed reality applications, implementing a flexible force feedback.

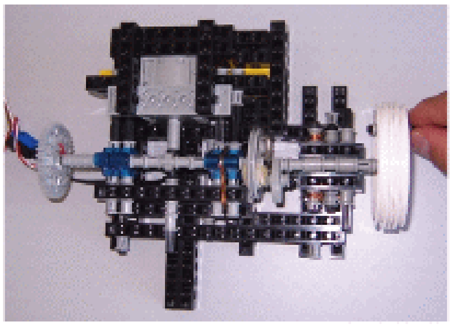

Fig. 4 Low Cost Momentum Handle (LoMo)

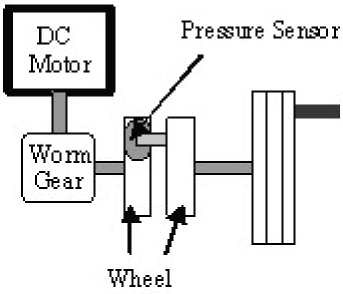

Fig. 5. Upper view of LoMo

If a force is applied to the handle, trying to rotate the wheel, a signal is generated by a wheatstone bridge equipped with the pressure sensor and forwarded to a micro processor through an A/D converter; a PLC based on Infineon's C164CI (20 MHz) microprocessor was used as a micro station. The voltage of the wheatstone bridge is directly proportional to the torque applied by the user. To generate the relevant pulses by PWM (Puls Width Modulation) to drive the DC motor, a Dual Full-Bridge Driver L298 was used.

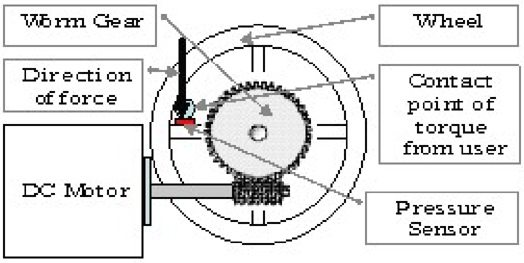

Fig. 6. Side view of LoMo

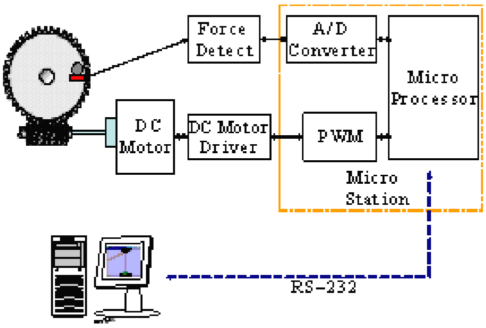

Fig. 7. Hardware implementation of LoMo

The duty ratio of pulses were calculated at the microprocessor level. A worm gear connects the rotational axis of the motor with the axis of the handle in such a way, that no rotation can be directly transmitted from handle to motor but only from motor to handle. The motor only rotates in a software-controlled way in the direction of the force given by the user. As the resistor of the pressure sensor is inverse proportional to the imposed force *F*, the torque τ_s applied to the sensor-wheel is (1.2).

$$V \propto F\ ,\quad F = \frac{r_u}{r}\cdot F_u \tag{1.1}$$

$$\tau_s = r \cdot kV \tag{1.2}$$

with

V , voltage detected from the wheatstone bridge;
k , constant,
F_u , force imposed on the handle by the user,
r_u , distance from the axis to the grip of the user ,
r , distance from the axis to the sensor.

A LoMo is able to communicate with another LoMo via internet using UDP sockets (Fig. 8). When a signal comes from the serial port (RS-232) module, it is processed by Hyper-Bonds Operation module, and then it is forwarded to the GUI (Graphic User Interface) module and TCP/IP module.

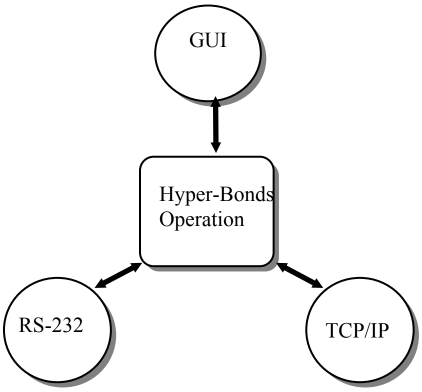

Fig. 8. Software implementation of LoMo in a PC

4. IMPLEMENTATION OF HYPER-BONDS

A distributed mixed reality cooperation model (Fig. 9) is used to investigate the process of Hyper-Bond implementation, its time critical behavior and its ergonomics. Two networked users can carry a mass from one side to the other via internet using handles connected via virtual rope. They can feel the artificial force feedback from the handle and see a virtual mass in the 3D virtual environment. The law of gravity is simulated. Drawing the bond-graph model for a completely real environment (Fig. 10) may give some insight into how to draw physical borders between real parts, virtual parts and the hyper-bond interface and to find key equations (hyper-bond equations). These equations apply to core algorithms of the hyper-bond interface. Assuming that it will be cut and implemented as shown in Fig. 10, *Se1, Se2, TF1, TF2* are real elements, *Se3*, *I* and *node 1* are virtual elements.

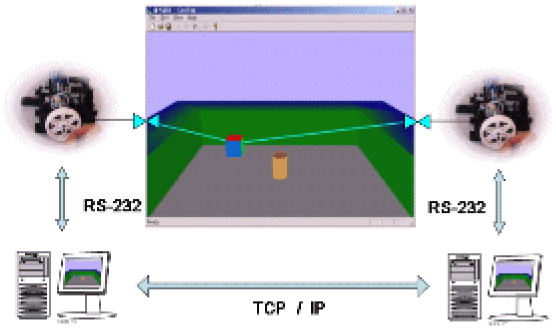

Fig. 9. Distributed Cooperation Mixed Reality model

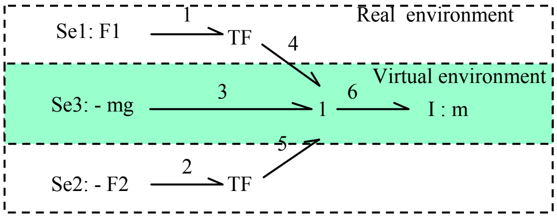

Fig. 10. Bond-graph model of figure 9 (g: acceleration by gravity, m: mass of the object.)

Implementing Hyper-Bonds allows the control of a virtual mass through signals from real parts and vice versa. Both handles are controlled by signals from the virtual part, using (1.3) and (1.4) derived from bond-graph (Fig. 10). The energy source Se3 and storage *I* is translated into effects to both handles and the display by using these equations as core algorithms of a Hyper-Bond Interface System.

$$e_6 = e_4 + e_3 + e_5 \qquad (1.3)$$

$$f_6 = \frac{1}{m}\int e_6 dt \qquad (1.4)$$

$$e_4 = ne_1 = nF_1,\ e_5 = ne_2 = -nF_2,\ e_3 = mg$$

(e : effort, f : flow, n : constant, F : force)

In the GUI (Graphic User Interface) the mass is moved in two dimensions, consequently equations (1.3) and (1.4) have to be calculated as vector sum (Fig. 11). The force feedback value used to rotate the right handle is a scalar sum of *F2* and *p*, the projection of vector sum *F1* and *mg* to the *F2* direction (Fig. 12).

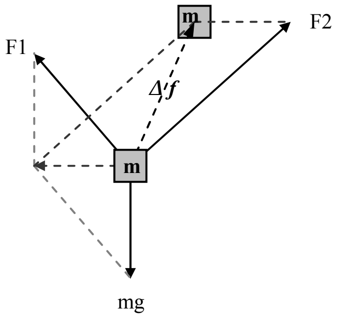

Fig.11. A graphic display algorithm using vector sum of the equation (1.3)

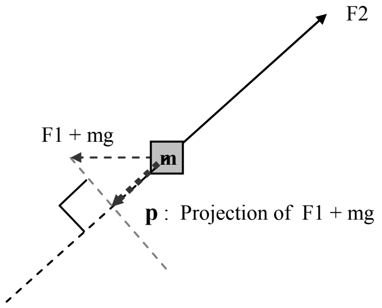

Fig. 12. Algorithm deriving force feedback value

From (1.3) and Fig. 11 the resulting torque of the motor for feedback is

$$\tau_2 = r_2 \cdot (F_2 + p) \qquad (1.4)$$

This torque-value is used to drive the right motor by pulse-width modulation. The left motor is driven accordingly.

5. CONCLUSION

We tested the implementation with the above scenario (Fig. 9) using a 100 MBit dedicated LAN, 2 PCs with AMD Athlon 600 processors and 256 MB RAM, Windows 2000 (no realtime!), 2 Conrad PLC with 20 MHz, resulting in a sensor-PLC-motor-cycle of 1 msec, a PLC-PC-cycle time of 8 msec and a distributed sensor-PLC-PC-LAN-PC-PLC-motor-cycle of 18 msec + LAN-time (order of msec depending on load). Although these 18+ msec for the whole cycle are well below a desirable 1000Hz found by Basdogan et al., 2000, the "feeling" of the weight was already appreciated by several test persons. To compare this distributed solution with a local real-virtual connection, we use a scenario of Fig. 13, which may also be used to teach basic physics in a tangible way. Further evaluation experiments to compare various modes of control (Melchiorri, 2003) and network-influences (Hirche & Buss, 2003) will be undertaken (Yoo & Bruns, 2004).

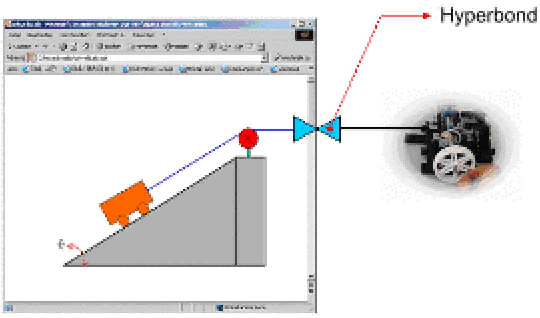

Fig. 13. Local Hyper-Bond Solution

Together with a general interface concept of Hyper-Bonds, this solution is not only a stand-alone experiment, but can be integrated in a general consideration of systems from a point of view of continuity of energy flow. This opens up a broad area of empirical investigations on how physical phenomena and logics can be experienced in a tangible and transferable way, thus contributing to new concepts of distributed real and virtual laboratories[2].

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[2] EU-IST Project Lab@Future (http://www.labfuture.net/)