MOTOR SKILL LEARNING WITH FORCE FEEDBACK IN MIXED REALITY

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Abstract: An experimental study of interactions in real and mixed reality learning and control environments will be described. The experiments aim at more insight into the difference between three interaction modes in handling automation systems: interaction with real components, mixed real-virtual handling with visual feedback only and with visual and force feedback. A simple, low cost, and internet based force feedback device will be presented, being a further implementation of the **Hyper-Bonds concept**, a unified concept to describe complex *effort/flow* driven automation systems distributed over real and virtual worlds. This work is a step towards a modular mixed reality construction kit allowing design and implementation of automation systems based on an arbitrary distribution of real and virtual components.

Keywords: multi-modal interactions, mixed reality, mechatronics, force-feedback

1. INTRODUCTION

Most human-computer interactions have been developed for visual and auditory feedback. However it is a general assumption, that for many applications, human learning and handling related to complex systems may be improved by haptic interactions, and several investigations in human factors research have confirmed it (2-3 citations). A person riding a bike for the first time is an every day example for the importance of feeling a force balance for the development of riding skills. But force feedback may also be important in an epistemic sense, to develop adequate cognitive mental models of a complex system (Kirsh & Maglio, 1994).
To investigate the effect of force feedback in various application domains, a flexible interface technology with an easy possibility to shift between modalities and contexts is needed. A low cost force feedback device integrated in a concept of *Hyper-Bonds* will be presented and used to elucidate the process of learning and handling in three experimental modes to lift a mass connected to a magnetic field: a real lifter model (RLM), a virtual reality lifter model with visual feedback (VRLM), a mixed reality lifter model with both visual and force feedback (MRLM). Experimenters in these environments will have the same task to lift an object.

To implement the experiments, a low cost momentum handle (LoMo) was developed. It can be used in various virtual-real applications, is simple, cost efficient and internet based. It is a further implementation of our Hyper-Bond concept (Bruns, 2003), based on Bond-Graph Theory (Paynter, 1961) extended towards force and momentum phenomena. Hyper-bonds provide bi-directional links between the virtual and real world, being able to sense and generate various relevant physical continuous *effort* and *flow* phenomena via universal connections. Details of the force feedback algorithm will be described in this paper. Its reliability is demonstrated through these experiments.

Further applications may use this simple force feedback device in internet based training scenarios:

in virtual-real physics laboratories, mechatronic systems including robotics and games.

2. EXPERIMENT

Hypotheses

- Force feedback improves handling of dynamic systems
- Force feedback improves motor skill learning

According to the first hypothesis we expect a better performance of a user if force-feedback is added to visual feedback. The second hypothesis should result in a faster reaching of the individual performance maximum.

Real Lifter Model

Using a magnetic lifter, as shown in Fig. 1, a user can lift or lower an object of a certain mass (33 g) from a source position to a destination. Once the magnetic lifter mass (11g) is attached to the target object, the user should carefully turn the wheel-handle to lift the object and not loose the object (max force = 48 g * 9.8 m/sec).

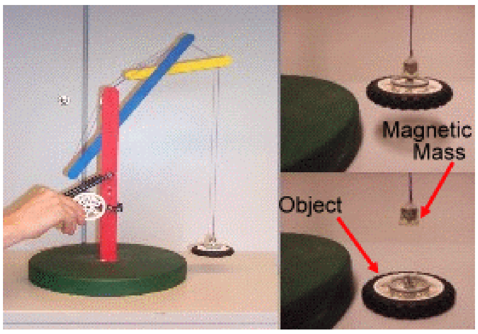

Fig. 1. Real Lifter Model

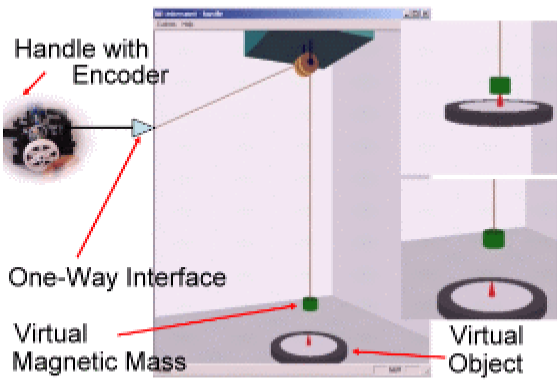

Fig. 2. Mixed Reality Lifter Model with Visual Feedback

Virtual Reality Lifter Model with Visual Feedback

In a virtual reality environment the real magnetic lifter mass and the real object have been replaced by virtual representations, only the lifter wheel still being real. To display virtual mass and object, a 3D virtual environment, which can simulate the law of gravity is provided. The environment has been implemented using OpenGL and C++. The real handle without any force feedback is "virtually" connected to the environment via encoder, attached to the handle, sending out the position data of the handle to the local computer (running the virtual environment). While the subject rotates the handle, the 3D virtual magnetic mass is proportionally lifted or lowered by the position data. If the handle is accelerated faster than the allowable acceleration force of the object, the virtual object will fall on the ground. The task for the user is, to lift the mass as fast as possible only with visual feedback.

Mixed Reality Lifter Model with both Visual and Force Feedback

A virtual magnate and a virtual object are displayed in a 3D virtual environment as in the former experiment, however the interface is based on a bi-directional force feedback Hyper-Bond, Fig. 3.

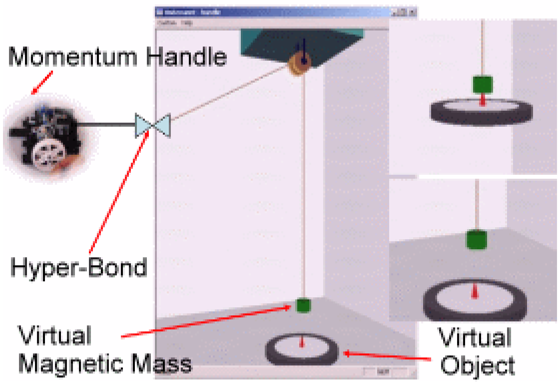

Fig. 3. Mixed Reality Lifter Model with both Visual and Force Feedback

To realize the model, a low cost momentum handle, as shown in Fig. 4, has been developed with Lego-bricks. From this handle, the user can feel the artificial force feed back from a DC motor and pressure sensor (Fig. 5). If the handle is rotated, it generates via pressure sensor and *wheatstone bridge* a signal which is forwarded to the micro processor through an A/D converter. The voltage of the *wheatstone bridge* is directly proportional to the torque applied by the user. The DC motor is driven by PWM (Puls Width Modulation) calculated and generated by a PLC-Programmable Logic Controler based on Infineon's C164CI 20 MHz micro processor and a Dual Full-Bridge Driver L298. The implemented algorithm is shown in Fig. 6. With an AMD Athlon 600 processor and 256 MB RAM, Windows 2000 (no realtime!), a cycle time between sensor measurement and motor control (generating force-feedback) was 1 ms if the mass-force calculation was done within the PLC and 9 ms if done in the PC. From a point of view of hyper-bond implementation, the calculation of effort/flow superposition and results should be carried out in the virtual world, however for this implementation we used the faster solution to stay near a desirable 1000Hz reaction frequency (Basdogan et al., 2000).

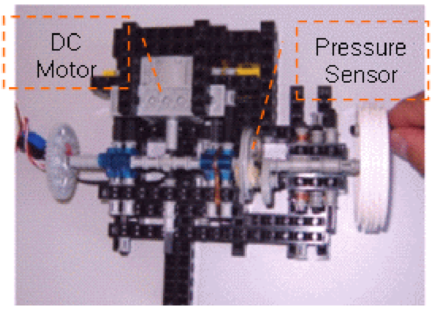

Fig. 4. Low Cost Momentum Handle (LoMo)

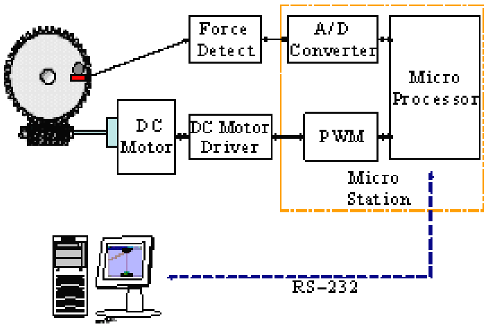

Fig. 5. Implementation of LoMo

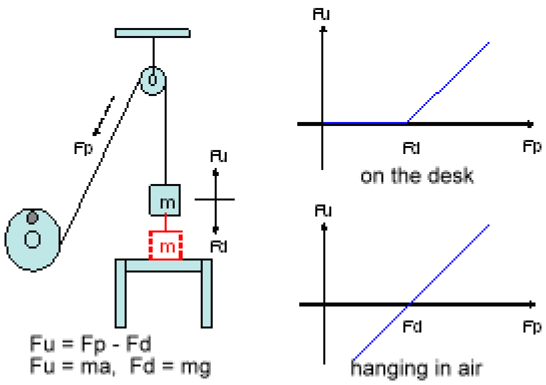

Fig. 6. Implemented algorithm

As the resistor of the pressure sensor is inverse proportional to the force, F_p, imposed on the sensor, the voltage detected from the *wheatstone bridge*, V, can be written as follows:

$$V \propto F_p, \quad \tau_p = r \cdot F_p \qquad (1.1)$$

$$F_u = F_p - F_d = kV - mg \qquad (1.2)$$

In the above equation, r is the distance from the rotational axis of the handle to the sensor, as indicated in Fig. 5; τ_p the torque; k a constant; g the acceleration of gravity; m the total mass of the magnetic mass and the object. The worm gear connects the rotational axis of the motor and the axis of the handle. The motor should be rotated in the direction of the force given by the subject, by the amount of the net force F_u. Therefore, the torque of the motor, τ_m, results in $r \cdot F_u$. As the generated τ_m of the motor is proportional to its current, i_m, it is generated by PWM as follows,

$$i_m \propto r \cdot (kV - mg). \qquad (1.3)$$

Since physical values obtained from the real environment are transferred to the 3D virtual environment and virtual values generate physical phenomena, this can be considered in a general way as an effort/flow control, as it is done in Hyper-Bonds (Bruns, 2003). Applying the Hyper-Bond concept, the *effort* is set as τ_p of eq. (1.1) and the *flow* as ω_p, the angular velocity of the handle. The angular acceleration of the handle is related to the acceleration of the object, a, according to

$$a = \frac{kV - mg}{m} \qquad (1.4)$$

In practice however, we have a motor and also a worm gear with friction, inertia and even damping, which requires a more detailed view. This can be supported by bond-graphs (Amerongen van, 2001) and is not covered here in more detail (Fig. 7).

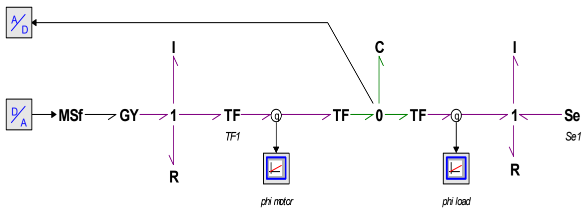

Fig. 7. Bondgraph for motor, gear, 2-wheel system

It turns out, that in practice eq. 1.4 holds for a quasi-static consideration, but for dynamics we only have a resulting velocity proportional to the applied current. As it could be observed from test-persons, this is also the preferred mode of control for a real mass lifting.

Task-Scenario

Users were asked to perform the following task: try to lift an object 5 times successfully without loosing it. This is done for all three settings: in reality, in virtuality (without force-feedback) and in mixed reality (with force-feedback). As a pre-test 10 persons were chosen. This not yet representative sample indicated some significant difference between the performance in virtuality, with only visual feed-back and the two force feedback solutions (real and mixed reality). Further results will be presented. Our investigation will result in the maximum reachable performance for every task and the individual learning curves for all three tasks.

3. PERSPECTIVES

This investigation only serves to demonstrate, how a low cost mixed reality solutions can be used to investigate the influence of force-feedback on motor skills. However it also opens up further possibilities to explore the development not only of motor skills but also the understanding of systems characterised by effort/flow phenomena, like electric voltage and current, air pressure and flow, force and velocity, temperature and heat-flow used in automated systems (Fig. 8). It also may show how generalised concepts like Bond-Graphs can be applied more efficiently if they are linked to concrete experience. It further paves the road to more general cooperation problems in shared virtual environments coupled to real human actions and physical phenomena (Ruddle et al, 2002).

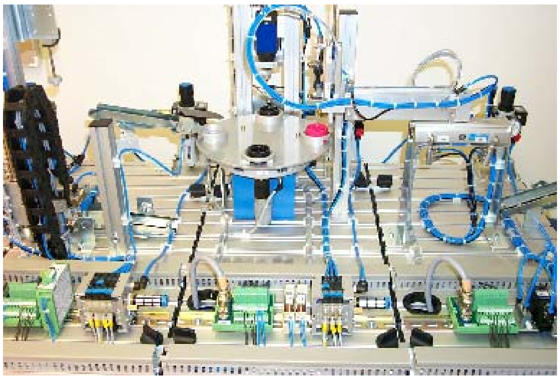

Fig. 8. Modular Production System with electrical, pneumatic and mechanical effort/flow

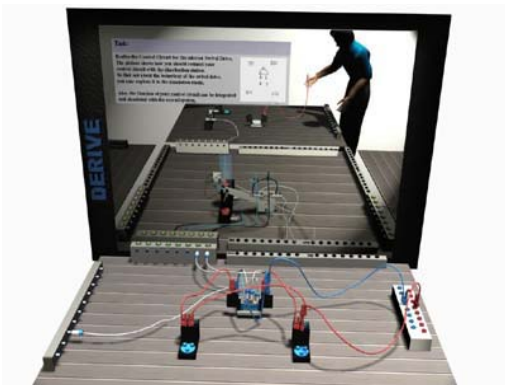

Fig. 9. DERIVE Learning Environment

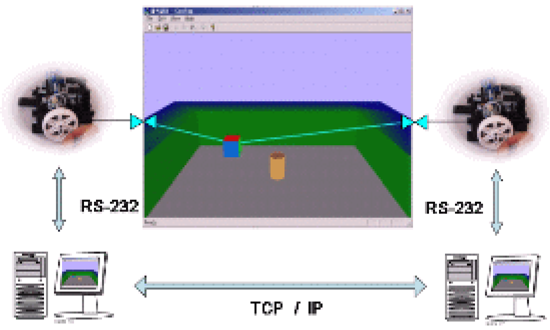

Fig. 10. Distributed Mixed Reality model

In European-projects DERIVE (Distributed Real and Virtual Learning Environment, Fig. 9) and Lab@Future, we are developing technical solutions for mixed realities based on hyper-bonds. Discrete air-pressure and electric-voltage as driving efforts have been implemented so far. An integration of analogue force and momentum, as presented here and in a distributed way (Yoo & Bruns, 2004, Fig.10) will improve our operation of complex mixed systems.

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