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Collaborative learning and engineering workspaces[☆,☆☆]

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ABSTRACT

Research studies aimed to improve remote collaboration and education are presented and related to practical results for control and automation engineering education. Individual, social and cultural aspects are considered as important requirements in the development of collaborative learning environments. A collaborative learning environment for control and automation education, which includes mixed-reality lab experiments, is presented. The proposed environment hosts remote lab experiments that enable the development of collaborative projects among students working at different sites. Experiences using the proposed learning environment in both university and vocational courses are presented.

1. Introduction

How to effectively use computer technologies to support people in their work, in particular when doing collaborative activities with coordination constraints, is a topic that has been extensively researched for several years (for instance, the term Computer Supported Cooperative Work – CSCW was coined in the 80s). Researchers recognize that this is not only a technological challenge but an organizational and social topic (Boedker, 1991; Grudin, 1988; Kaptelinin, 1996). Moreover, it is not restricted to collocated actors and vision representation (Fjeld et al., 2002). However, only recently a major shift of focus on the difference between cooperation and collaboration occurred. The former being some kind of protocol to avoid conflicts and provide harmonic synchronization of task oriented work (assembly line model), whereas the later being a struggle for new products, tools, work processes and a higher quality of all (creative workgroup model) (Carroll, Neale, Isenhour, Rosson, & McCrickard, 2003). CSCW environments can be classified into the following type (Laso-Ballesteros & Karlsson, 2006): knowledge enabled workers, virtualized collaborative environments, shared workspaces, virtual communities, and responsive environments.

Most of the attempts to develop environments to improve the quality of group-work and group-learning, however, does not handle aspects of real production processes, as well as physical and concrete material issues. The business and desktop metaphor is still dominating the information and learning perspective. Collaboration in and between producing enterprises means learning, working and inventing together from different locations, companies, functions and at different times (Camarinha-Matos & Lima, 2001). Among the benefits of distributed collaboration are: reduced problems of resolution cycle time, increasing productivity and agility, reducing travel to sites, enabling more timely and effective interactions, faster design iterations, improving resource management and facilitate innovation.

Collaborative work over remote sites in so-called virtual teams is therefore a challenge to developers of information- and communication technology, as well as to the involved workforce. Collaboration demands a deep involvement and commitment in a common design, production process or service, i.e., to work jointly with others on a project, on parts or systems of parts (Acosta & Moreno, 2005; Erbe, 2005). Information mediated only via vision and sound might be insufficient for a fruitful collaboration in some production domains. There are several studies indicating that vividness and task performance can be positively influenced by tangible user interfaces or touch feedback with shared tangible objects (Griffin, Provancher, & Cutkosky, 2005). Having the parts in hands in designing and in manufacturing is often desirable and in maintenance is it necessary. To grasp a part at a remote site requires force (haptic)-feedback in addition to vision and sound.

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Engineering education has become a crucial aspect for most countries, since it has been recognized that skilled engineers are one of the main components for the development of innovative products and services, as well as for the optimization of production processes, to ensure high productivity and quality. Considering education on control and automation systems, a key issue is the reduction of the gap between classical theoretical courses and real industrial practice. Hence, it is important to allow students to operate with devices, systems, and techniques that are as close as possible to those of industrial settings. Unfortunately, to reproduce a real industrial plant in an academic environment is not a trivial task. Industrial equipments are, in general, very expensive (in terms of acquisition, installation, operation, and maintenance costs). Furthermore, safety constraints should also be taken into account. Such factors restrict the use of real industrial devices in academic laboratories, which in general are then structured as small-scale experiments with little connection to industrial reality. Within this context, industrial lab facility that are available via Web and therefore accessible at flexible times, to a larger number of individuals, helps to improve the overall cost-effectiveness of such solution. Moreover they offer perspectives of shaping teaching scenarios, which are close to practical engineering team-work. Ma and Nickerson (2006) argue that well constructed group activities used in conjunction with remote labs generate an added value in regard to team skills and remote engineering competences. The development of learning environments for students to train collaborative work over distances where face-to-face work is excluded is of utmost importance.

The Internet growth has brought new paradigms and possibilities in technological education. In particular, it allows the remote use of experimental facilities employed to illustrate concepts handled in classroom and serves as an enabling and powerful technology for distance teaching. However, the availability of remote experiments is not a sufficient condition to ensure success in learning. *Stand-alone* remote experiments without connection to adequate learning material usually lead students to the use of a *trial and error* strategy, which has a lower learning impact than originally expected (Schaf & Pereira, 2007). Moreover, remote facilities are available 24-7 increasing the demand in the number of faculty members and tutors required to provide online guidance.

In order to alleviate these problems, remote experiments can be integrated into virtual learning environments (VLEs) (Michaelides, Eleftheriou, & Müller, 2004) that manage and provide guidance via learning materials before, during and after the experimentation. This paper proposes such an integrated learning environment, on which mixed-reality lab experiments and student guidance tools are combined for control and automation education. Mixed-reality experiments (Bruns & Erbe, 2004), on which simulated components can be combined to real equipment, are used to illustrate different learning situations according to the knowledge level of remote students.

The research described in this paper has been developed within the scope of the RExNet Consortium (Hine et al., 2007), an ALFA[2] II financed project. The consortium had mainly three goals: to share, harmonize and spread current skills on remote experimentation (Hine et al., 2007). The work relies on previous projects on mixed-reality learning environments and remote laboratories for vocational education in mechatronics (Müller & Ferreira, 2005). Recent developments took place in German–Brazilian cooperation.

The remainder of this paper is organized as follows: Section 2 presents the motivation driving this research study; Section 3 describes possibilities for establishing a connection between real and virtual (simulated) environments; in Section 4, the proposed learning environment is described; Section 5 outlines developed case studies developed for validating the proposed environment. Finally, Section 6 draws conclusions and Section 7 indicates future work directions.

2. Why collaborative learning and engineering workspaces?

2.1. Collaborative environments

To achieve higher levels of human–human interactions, which are required to solve complex engineering problems, a strong support of collaboration and multi-perspectivity is required. Concepts of collaboration are closely related to learning. During collaboration, humans interact employing self-critiquing (reflection), inquiring and arguing skills; these skills propel the knowledge building. This is the very essence of the (social) constructivism pedagogy employed nowadays in virtual environments and even in some special dedicated schools.

Even though collaboration and cooperation are closely related, there are differences. According to Carstensen and Schmidt (2002), in cooperation, the task is splitted into independent subtasks, while in collaboration, interwoven problems and subtasks must be handled. In cooperation, coordination is only required when assembling partial results, while collaboration is a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem. For this purpose, collaboration is a required and essential concept to be employed in virtual environments that support human–human interactions.

Collaborative environments are based on distributed technologies to facilitate team-work between geographically dispersed groups. More concretely, the design of a good distributed architecture can be the ground of any kind of distributed application. How to perform interoperability among heterogeneous tools and platforms in distributed systems is the key question addressed to the collaborative community. Interoperability must be carried out in order to provide new services to end users with total integration into the platform.

Computer Supported Collaborative Environments (CSCE) (Ip & Morrison, 2001) can be implemented in a way which is suitable for work as well as for learning applications. The former would allow a shared workspace, the later a shared learnspace, with floating boarders. Thus the same technical function can be applied with more productive or more didactical aims.

2.2. Shared workspaces

Shared workspaces (Ishii, 1990) are employed to achieve collaboration in experimental tasks. Sharing implies collaboration. An ideal CSCE for engineering work would incorporate learning related to real work processes. For educational purposes, the environment should also incorporate support for theoretical and practical content (didactical material and practical experiments) to reflect theory on practice and vice versa. Collaboratories (Kouzes, Myers, & Wulf, 1996) are a well known association of collaborative tools with remote laboratories (experiments). A basic implementation of a collaboratory is the integration of virtual learning environments (VLEs) with remote experiments in a single and unified environment (Schaf & Pereira, 2007).

Virtual environments connected to real world phenomena, can defuse the old dilemma of safe mimetic simulation versus unpredictability of real processes, as they allow a situation dependent verification of the adequateness of the abstraction from reality by simulation. At the same time it allows a harmless replacement of expensive real equipment.

[2] ALFA stands for América Latina - Formacíon Académica and is part of the European Commission External Cooperation Programmes.

3. Real–virtual connection

The connection between real and simulated counterparts brings flexibility to systems that involve complex and configurable components. Mixed-reality techniques support this connection, providing the integration of real and virtual spaces for collaboration. This may broaden the range of CSCEs. It allows a dynamic interchange of simulated and real parts in remote experiments, via the concept of *interchangeable components* (Schaf & Pereira, 2007).

3.1. Hyperbonds

Hyperbonds[3] (Bruns, 2005) are employed to support real–virtual seamless bidirectional connections. A Hyperbond combines the unified, abstract systems view provided by bond graphs with their real-life implementation, by establishing *hyper-connections* between physical phenomena in the computer-external environment and the logical structure of computer-internal schema, i.e., a blend of physical systems with their virtual counterparts. The hyperbond concept is a mechanism based on the *translation* between physical effort/flow phenomena and digital information. This allows remote true feeling of force, vibrations and motion, i.e., haptic (Yoo & Bruns, 2004), bridging the gap between reality and virtuality. Shared workspaces allow a more realistic handling of several instruments and devices if haptic interfaces could be used.

3.2. CAVE as workspace

CAVEs[4] enhance the visual human–machine interface displaying a tridimensional view of multiple users collaboration. CAVEs are subject of research to test the immersion of users into a virtual environment. Directing CAVEs to engineering research areas, this environment can be employed as a common engineering workspace used for solving a joined task, such as collaborative tele-design or tele-maintenance.

The hyperbond connects the two parts: the real and virtual ones. Thus any flow through this kind of object is automatically forwarded to reality or vice versa. Changes in reality are distributed by an updated simulation, but also by a camera observing the real hardware. The virtual part of a running session can be stored on the server and reloaded later to continue the work task. Fig. 1 shows the arrangements used for some test cases and Fig. 2 some more details about the connections. The common virtual workbench and the real workbench (via video projection) are available via Internet and visible at an enlarged screen or are beamed at canvases fixed at the scaffolding.

First experiences gained employing CAVEs illuminated how future engineering workspaces and laboratories could be structured (Erbe & Müller, 2006). Several key features of tomorrow's remote laboratories were identified, including support for freely exploring a phenomenon and its appearance in various applications and contexts, means for a universal mixing of real and virtual objects, and distributed work on tasks in a multi-modal and multi-user way.

3.3. Remote handling with haptics

Remote handling with haptics 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.

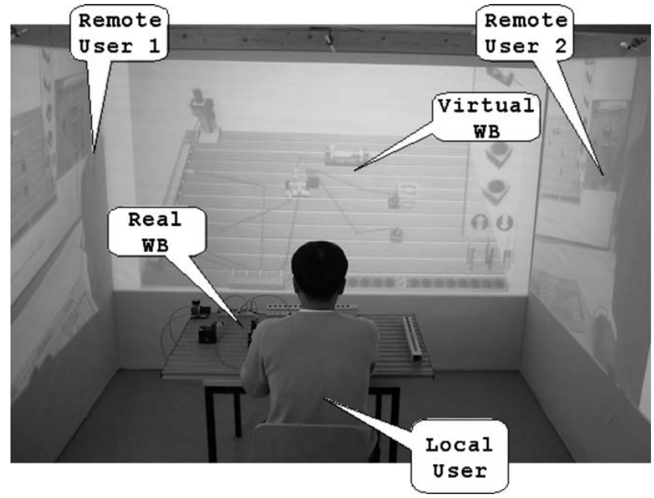

Fig. 1. Mixed-reality CAVE as shared workspace.

The latter has only recently found consideration with the widespread use of multi-user environments in games, entertainment, learning and tele-work. The cooperation of several dislocated humans in a shared virtual space, communicating with and sensing each other in a tangible way is a challenging task.

Haptic communication and cooperation may play an important role in future preparation and training of humans in hybrid production systems. Therefore, Yoo and Bruns (2004) presented a low cost solution for the study of force feedback phenomena using hyperbonds, embedded in a concept suitable extension to real automation problems and distributed applications.

4. Proposed learning environment

4.1. Overall architecture

The proposed learning environment, which has been named GCAR-EAD[5](Schaf & Pereira, 2007), integrates mixed-reality experiments within the Learning Management System (LMS) MOODLE.[6] Educational material was developed in Portuguese and English languages, aiming to combine theoretical concepts with practical examples using remote labs. Mixed reality is made possible with the use of the deriveSERVER[7](Bruns & Erbe, 2004) system, which was expanded and integrated in the MOODLE interface, so that students can learn and interact collaboratively in a common virtual learning environment.

The developed courses contain: (i) learning material describing the electro pneumatic devices involved in the experiments; (ii) a step by step tutorial explaining to the students how to use the remote mixed-reality labs; (iii) experiment guide used to control the sequence of experiments (in the deriveSERVER) that students must perform accordingly to their knowledge level; and (iv) learning material of basic pneumatics commonly used by teachers and technical instructors in SENAI Mechatronics classes.

4.2. Hyperbond enhancements

The hyperbond software (SW) interface was modified to support OPC[8] communication as well as parallel/serial commu-

[3] Also written hyper-bonds.
[4] A CAVE stands for Computer Animated Virtual Environment and is a 3D immersive virtual reality environment where projectors are directed to the walls of a room-sized cube.

[5] GCAR-EAD stands for Distance Education Environment of the Automation, Robotics and Control Systems Group.
[6] MOODLE stands for Modular Object-Oriented Dynamic Learning Environment, is a free open-source LMS.
[7] DeriveSERVER stands for distributed real and virtual learning environment for mechatronics and tele-service.
[8] OPC Foundation (Object-Linking and Embedding for Process Control).

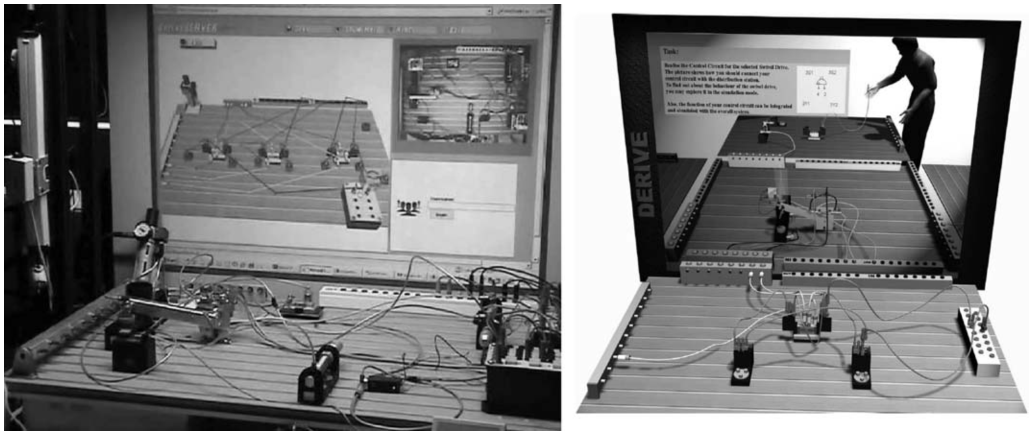

Fig. 2. Local tests mixed-reality installation at University of Bremen.

nication (Schaf et al., 2007). Taking advantage of the deriveSERVER client-server architecture (communication sockets), students/users can handle local hardware attached to simple parallel PC port to interact with the experiment. Fig. 3 illustrates hardware interactivity and the provided communication interfaces, to which OPC interfaces of simulated or real custom devices can be attached. Students can manipulate all the interfaces – both locally or remotely – via a common interface, what significantly eases system use.

4.3. VLE integration with mixed-reality supporting interchangeable components

While the remote access of real laboratory equipment has several advantages, some special aspects related to control and automation applications have to be considered. These are: the number of students and student groups is limited by the number of available physical experiments; long waiting times caused by slow dynamic systems; and interlocking safety systems have to be carefully developed in order to avoid components' damages due to improper actuation by students. As an alternative to overcome these drawbacks the use of simulated components is proposed.

Realistic simulations have some advantages that can be explored in different learning scenarios. One of the advantages of using simulations is their easy replication. Another advantage is that students can speed up slow dynamics systems for quick visualization using simulation models. Other positive aspect on the use of simulation models is that simulation models are not subject to degradation as their physical counterparts. Consequently, safety concerns involving simulation variables limits are not as important as in real experiments.

For this purpose, in Schaf and Pereira (2007) an architecture is proposed based on the integration of: (i) VLEs; (ii) remote experiments with support to interchangeable components; and (iii) a basic tutoring system for experiment evaluation and student guidance. In order to increase the range of possible scenarios of the mixed-reality experiment a strategy is used, the interchangeable components, which enables the execution of distinct learning scenarios. Previous experiences indicate that due to the fact that the learning material was *loosely coupled* with the remote experiment, students were not able to identify which topics to review in case they could not adequately solve the proposed experiments. The GCAR-EAD was proposed in order to overcome those drawbacks. The system is based on a complex architecture (see Fig. 4) that additionally integrates learning material manager, educational

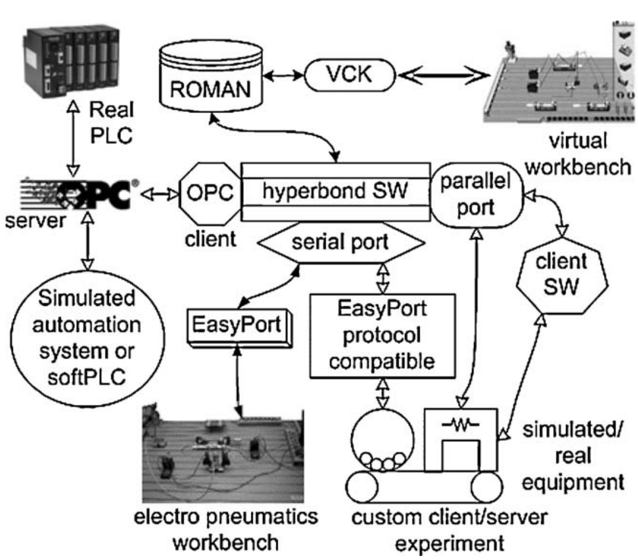

Fig. 3. Extended hyperbond communication interfaces.

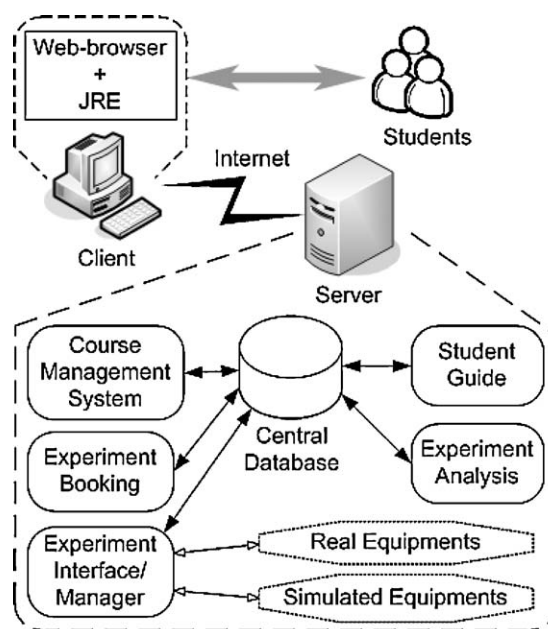

Fig. 4. GCAR-EAD system architecture.

materials, remote experiments with mixed-reality, interchangeable components strategy, experiment analysis/evaluation, and simple student guidance tools. The proposed architecture has five main modules: (i) learning (didactic) material manager; (ii) student guidance system (or student guide); (iii) experiment booking; (iv) experiment analysis (or experiment analyzer); and (v) experiment manager/interface. The interaction with each module is transparent, so that students only interact with the VLE interface. A central database is the main *communication channel* among modules.

5. Case studies

This section describes some real applications using a virtual learning environment integrated with mixed-reality lab experiments, which is described into details in Schaf and Pereira (2007).

5.1. Mechatronics case study

The first case study was developed in Brazil within the scope of an applied research project funded by SENAI, the largest vocational training school in South-America. Experiments built in the remote and in the virtual laboratory are based on a traditional electro pneumatics workbench with cylinders, valves with pushbuttons, solenoid valves, as well as digital controllers (see Fig. 2). The original system version was not designed to handle analog signals, therefore only discrete control is possible with *Boolean* (*on* /*off*) variables. Solenoid valves can be driven by electrical current, making electrical control possible as typically used in electro pneumatics systems. The proposed software and hardware architecture allowed students to control both simulated (from the virtual workbench) as well as real equipments.

The current SENAI installation of the enhanced systems is slightly different from those from the installations of the artecLab (University of Bremen). Several actuators are placed on the real workbench to be controlled and automated via the virtual workbench visualized on a large display. This configuration is aimed to collaborated task solving, where each student is responsible for a different device control.

The stations envisioned in the SENAI project include besides traditional deriveSERVER components, also a mechanical arm controlled by a Programmable Logic Controller (PLC). Making those stations accessible from the Internet has enabled students to create their own competencies in the automation field. This is the idea of the second project in the field of collaborative learning and remote labs.

5.2. Collaborative task solving case studies

Aiming at collaboration, the development of task solving scenarios requiring collaboration and cooperation are of utmost importance. To solve this task collaboratively, work spaces studies within this topic were developed employing mixed-reality with hyperbonds technology.

5.2.1. Common resources task

Bruns (2005) and Müller and Ferreira (2005) developed and tested a collaborative work scenario between remote sites. The task was to develop and test an e-pneumatic control circuit for automatic welding operations. Within this scenario three enterprises at different locations are involved to perform the following tasks: (i) control design – done virtually using a simulated workbench, (ii) validate control in the real workbench, and (iii) manufacturing the device. To solve this task collaboratively workspaces are linked through the Internet.

When a solution to the control tasks is found (using the virtual workbench) the solution can be partly or completely exported via the hyperbond interface to the real workbench. Also, the manufacturer of the welding device is connected to give his comments regarding the feasibility of a solution of the control task.

The connected workbenches are located in CAVE-like constructions. The real and virtual workbenches were implemented as a Web service to take advantage of the Web technology (e.g. easy accessibility, platform independence). A central module is the mixed-reality (MR) server which implements this Web service. The Web service itself processes HTTP requests and also manages the sessions of all remote users. Relevant data belonging to a certain work session is stored on the server, like virtual model data, support material and background information. The WWW front end consists of a HTML page including a Virtual Construction Kit (VCK) and a video stream window.

5.2.2. Connecting distributed resources task

SENAI, together with industrial partners, plan the implementation of a large experiment related to a CIM (Computer Integrated Manufacturing) Lab distributed over three different sites. This experiment represent the interconnection of all systems studied individually in each lab involving: pneumatics, hydraulics, flexible manufacturing systems (FMS), industrial process control units, automatic storage systems and visual inspection workstations. All together connected with a complete drive, command and control system, which uses PLC and Manufacturing Resources Planning (MRP) technology.

5.3. Automation engineering education case study

To achieve practical results from the application of virtual environments in education of control and automation engineers, a simple case study associating VLEs with closed-loop control of remote experiments was developed. This case study was actually implemented and more information is detailed in the section results. So far the experience gained using the system has been very positive. Students have evaluated the GCAR-EAD tool very positively and an improve in the overall students' performance has been observed. In particular, student's motivation has increased. The system is being continuously improved taking into account students and teachers suggestions. For instance, the control systems course that was already taught two semesters using blended learning[9] methodology, students' approval rate has also considerably increased to 90%, 23% more than the previous semester that has traditional classes only.

6. Conclusions

Mixed-reality concepts support learning environments with remote labs and distributed workspaces. The bidirectional telecooperation functionality allows students to use the Internet for collaborative engineering. The presented environment allow groups of students/technicians (or even employees) at remote locations to take part at the same training using the same equipment (either simulated or real). The users are able to work in a collaborative way to solve problems and explore solutions to proposed problems. This kind of interaction provides a systematic support for skilled workers and engineers. The presented research can be used as an appropriate and cost effective tool to support collaborative engineering.

The hyperbond concept allows integration of different remote equipments or simulators providing common environments to remote collaboration of experiments. This is specially important to cost effective remote experimentation, since real hardware must not be duplicated.

[9] Blended learning is the technique where traditional lessons are combined with virtual remotely/e-learning (or distance) lessons.

The GCAR-EAD environment allows an integration of mixed-reality experiments with virtual learning environments and introduces the concept of interchangeable components. It also includes experiment analysis tools and provides student guidance through the learning material. While the GCAR-EAD environment has proven to be very useful for control and automation education, there are still some challenges to be faced. The synchronization in the timing behavior of the virtual and real equipment is heavily dependent on the communication delays of the network infrastructure. In the current implementation, this delay is of around two seconds for the whole communication between client and the end actuators. While this is not meaningful for technical plants with slow dynamics (what is the case in the selected experiments), it has to be improved.

Of course there is a trade-off in having geographically distributed applications and the higher communication times that are required. The GCAR-EAD can also be used for collaborative engineering since experiments can be distributed into several sites and several students (users) can interact using the same environment.

It is widely believed that collaborative experiences are powerful drivers of cognitive processes and can significantly enhance learning efficiency. The benefits of collaborative learning are widely researched and advocated throughout literature. Regardless of the varying theoretical emphasis in different approaches on collaborative learning (e.g. social constructivism), research clearly indicates that in many (not all) cases students learn more effectively through collaborative interaction with others. This motivates to prepare remote labs for collaborative learning (called collaboratories) and to use them in distributed teaching scenarios with simulation tools, hands-on laboratories and practical workshops. As a whole, there is a necessity to improve the usability of collaborative remote laboratory tools, because otherwise learners may quickly get frustrated and stop working with it. There is a strong demand for research that seeks to create such a blended learning, where collaborative remote labs can play a significant role. Emphasis on collaboration adds new technical requirements to the design of remote laboratories.

7. Future work

While software may be designed to achieve closer social ties or specific deliverables, it is hard to support collaboration without also enabling relationships to form, and to support a social interaction without some kind of shared co-authored works. Analogously, the differentiation between social and collaborative software can be compared as that between *play* and *work*. Play ethic (methods) applied to work turn activities that employ computers a more comfortable experience. This is commonly referred to game-like interface. The 3D representation aims to display more realistic (virtual) *worlds* to its users. Commonly this representation is more often in the entertainment field.

Known social *game-like* examples of CSCE's implementations are: Active Worlds – with the more especial designed Educational Universe (AWEDU)(Corbit, 2002) and Second Life (SL).[10] Closely related to this work is the SLOODLE project[11](Kemp & Livingstone, 2007).

SLOODLE offers a possibility to merge the 3D world Second Life with the MOODLE to mirror Web-based classrooms with in-world learning spaces and interactive objects. SL is used like a *metaverse* skin on the MOODLE. This way, lessons and courses are available at the Internet in virtual worlds with traditional LMS advantages.

[10] J. Kirriemuir introduces a series of studies investigating how the Second Life environment is being used in UK Higher and Further Education.

[11] Sloodle project – http://www.sloodle.org.

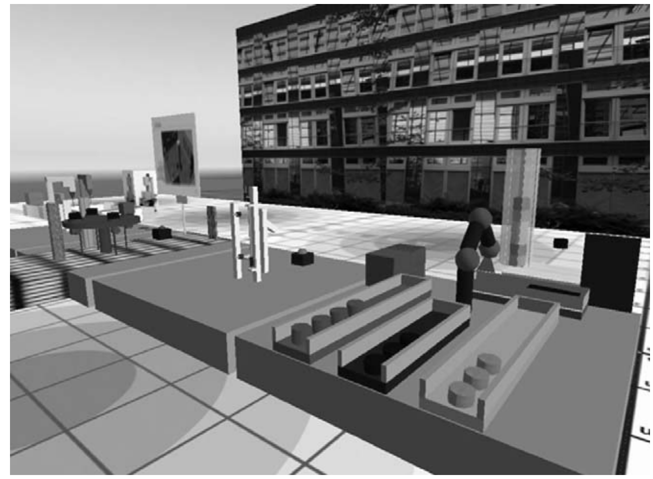

Fig. 5. Simulated MPS inside SL.

Including a social game-like interface together with the 3D world representation gives the environment a *skin* or metaverse (Hendaoui, Limayem, & Thompson, 2008). Compared to other electronic tools for distance communication (Computer Mediated Communication – CMC), the metaverse representation improve the sense of being *there* (in a classroom) (Kemp & Livingstone, 2007), rather than of being a disembodied observer like most of the 2D virtual environments. This representation employs state of art technologies that support collaboration, creativity and sharing over the Web. Simulations of Modular Production Systems (MPS) within social 3D interfaces are being deployed currently in SL metaverse and these works indicate the future trend of CSCEs (see Fig. 5).

Educational tools to enhance system awareness of student's learning status, as proposed by Chastine, Zhu, and Preston (2006), near CSCE's to automatic learning systems capable of autonomous or *automatic* tutoring. Environment's collaboration awareness demonstrates also automatic capabilities associated to CMC. Following this trend, ideas to implement awareness agents developed in Java (JADE – Java Agent Development Environment[12]) that monitor and capture students (avatars) interactions with the MOODLE (Otsuka, 2007; Scutelnicu et al., 2007) can be employed in the CSCE.

Within this context, an extension of the GCAR-EAD with play-like social interactive interface, tridimensional representation and with as much autonomous support possible is under development.

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Unfortunately, the main mentor of this research project, Prof. Heinz Erbe from the Technical University of Berlin, has passed away in the beginning of 2008. His leadership and friendship will always be a inspiration for us and for all that had the pleasure to interact with him.

[12] JADE – http://jade.tilab.com/.

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