MARVEL: A Mixed Reality Learning Environment for Vocational Training in Mechatronics

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Abstract

Mechatronics is an area that merges multidisciplinary knowledge coming from mechanical engineering, electronics and computer technology. Vocational training in mechatronics requires the teaching of 'multi-skills' in various learning contexts, as well as a good blend of learning in the classroom and practical training in work surroundings. This paper presents the contribution of MARVEL to meet these target requirements. The aim of the MARVEL project is to implement and evaluate learning environments for mechatronics in vocational training, allowing students ubiquitous access to physical workshops and laboratory facilities from remote places. The project will cover concepts that merge real and virtual as well as local and remote worlds in real time. We describe a concept of experiential learning which proposes a 'mix' of virtual learning sessions (remote labs, simulations) in combination with learning in real labs or even at the workplace.

Keywords: mechatronics, vocational training, experiential learning, virtual and remote laboratories, distributed learning environments, e-learning, mixed reality

1. Introduction

Mechatronics is the synergistic combination of precision mechanical engineering, electronic control and information technology, with the objective of designing products and manufacturing processes. It relates to the design of systems, devices and products aimed at achieving an optimal balance between basic mechanical structure and its overall control (Bradley et al, 2000). Mechatronic devices are currently of great importance in almost all sectors.

The multidisciplinary concepts that merge into mechatronic engineering require an academic education providing a proper balance between research and development abilities, as well as skilled workers and technicians trained for manufacturing, implementation and service provision in their professional area. Thus in many countries new job profiles and the corresponding vocational training concepts for mechatronics have been created as a mix of mechanical, electrical and ICT knowledge (IVTO 2003). Compared to specialized job-profiles such as mechanics or electricians, vocational training in mechatronics requires the teaching of 'multi-skills' in different learning contexts, as well as a good blend of learning in the classroom and work-related training.

Vocational training colleges together with industry are confronted with the need to develop and integrate theoretical and practical learning sequences that are able to fulfil the demands for multi-skilled technicians and skilled workers. The claim for work-related learning based on the interleaving of theoretical learning and learning by practical work and experimentation is obvious (Attwell et al, 1997). Accordingly there is a growing need for innovative learning concepts, capable of supporting the necessary education and training platforms. E-learning systems and virtual learning sessions (remote labs, simulations) extending to real labs or even to the workplace are able to contribute significantly to a successful outcome of this learning process. The current generation of e-learning environments does not yet provide an integrated solution (comprising pedagogical, technical and organizational aspects) able to meet these requirements in vocational training. Cultural differences and similarities concerning learning and collaboration styles may be devised, but were not yet sufficiently integrated into curricula, courseware and teaching methods.

2. The MARVEL Project

Our European project "Virtual Laboratory in Mechatronics: Access to Remote and Virtual E-Learning" (MARVEL) deals with the above mentioned requirements. The aim of MARVEL is to implement and evaluate learning environments for mechatronics in vocational training, allowing students ubiquitous access to physical workshops and laboratory facilities from distributed and remote locations. The general idea behind MARVEL is to provide a real time environment that merges real and virtual, as well as local and remote learning spaces. Telematics, remote and mixed reality techniques are used cooperatively within a network that includes colleges, industry partners, and national bodies dealing with certification and standardisation issues.

The MARVEL consortium is led by the Research Centre ARTEC at the University of Bremen in Germany and brings together institutions and companies from six European countries. Partners from technical colleges, universities and national bodies are: Higher Technical Institute (Nicosia, Cyprus), Berufsbildende Schulen II Delmenhorst (Germany), Bildungswerk der Niedersächsischen Wirtschaft, (Germany), University of Porto – FEUP (Portugal), Scottish Qualifications Authority (UK) and West Lothian College (Livingson, UK). The industry part of the consortium is related to automation technology, robotics and training technology, and includes Zenon S.A. Robotics and Informatics (Greece) and Festo Didactic GmbH & Co. (Germany). The Haute Ecole Valaisanne from Switzerland is involved in the project as an associated partner.

The MARVEL project is intended to stimulate learning concepts that may help the students in the following ways:

- By providing access to remote lab facilities and workplaces in real time from different locations, bringing more ‘reality’ into the classroom with the perspective of a better integration of learning and working, theory and practice.
- By making available experiment-based bridges to real, tangible media, tools and systems, in addition to theoretical course contents that may continue to be distributed via traditional e-learning platforms.
- Sharing lab resources and workplace facilities from different locations will improve teaching and learning and achieve better usage of resources by sharing distributed and highly expensive equipment.
- Furthermore, the MARVEL project will offer opportunities to facilitate training for persons with disabilities and other people with special needs.

The MARVEL project evaluates and makes available working examples of remotely accessible practical environments, including e-learning and student assessment materials for the following application fields: robotics, modular production systems and process control. The workplan of the project includes the creation of actual demonstration models (learning scenarios and environments) for evaluation purposes.

The main target groups of MARVEL are students in vocational training and employees of companies where learning is integrated into the daily activities. The main teaching subjects are system control, maintenance, process monitoring, automation technology of networked mechatronic plants, and machinery. Learning scenarios on the basis of remote techniques (tele-services) will play a key role in our project.

2.1. Training needs in mechatronics

A major goal in mechatronics training is that students have to acquire theoretical and operational knowledge and practical competencies in terms of *technical core skills*. This type of skills generally relates to the assembly and service of complex machines, plants and systems, in the field of plant construction and mechanical engineering, and in those companies that purchase and operate such mechatronic systems.

Because of their complexity, mechatronic components and systems can often only be installed and operated in combination with support and after-sale services: specialist know-how and – in the case of maintenance or repair work – skilled customer support by the manufacturer’s specialists are required. Accordingly there is a growing need for qualified service personnel in mechatronics, compared to pure mechanics or electronic control technologies, with the following qualifications and skills:

- knowledge about potential and probable causes of malfunctioning in mechatronic systems (cause-effect relationships),
- handling both uncertainty and complexity in sophisticated mechatronics systems,
- knowledge about system-related service procedures and tools.

Mechatronic components can easily be integrated into telematic environments supporting such concepts as remote diagnosis and maintenance (tele-service). In a survey conducted by *VDI-Nachrichten*, one of the most important engineering magazines in Germany, tele-services were considered as the key service of the future (VDI 1999) (Westkämper et al. 2002). Such demands imply further qualification needs for skilled workers, technicians and engineers. The most important aspects to consider are the following:

- installing and using tele-service systems, service software and remote diagnosis systems,
- creating and operating communication access points,
- acquiring data for tele-service purposes,
- providing tele-services in different network and communication structures.

The increasing dissemination of mechatronic systems in combination with (tele-) services also creates the need for new qualifications in non-technical *soft skills* (Maßberg et al, 2000). In contrast to 'traditional' professions, experts in mechatronics are deployed in a relatively broad range of activities that span different sectors of industry. They typically work in locally distributed teams and coordinate their work amongst themselves. This requires not only competent handling of tools and methods for diagnosis, maintenance, monitoring and repair, but above all the ability to communicate effectively with others (e.g. customers, users, installers) with the help of computer-aided means of communication. Skilled service technicians must solve the 'mutual knowledge problem', for example by integrating the know-how of others in order to accomplish their goals using appropriate tools (e.g. electronic conferencing or groupware applications). Special focus must be placed on accessing distributed information from suppliers, customers and manufacturers over the Internet.

Besides normal communication problems, one should not underestimate the role of language barriers that may arise when performing work tasks. Training in foreign languages, especially in English, seems to be very important in vocational training of mechatronics. In addition to adequate foreign language competence, 'intercultural competence' is also an important soft skill, enabling service personnel to be aware of cultural differences between European and other countries, for example in Asia or South America.

Because services are primarily immaterial, the quality assessment made by customers is highly dependent on those employees who perform such services. For this reason, technicians must also be trained in customer orientation – to a greater extent than production workers, for example – with an emphasis on communication training and customer-centred action.

In relation to real work tasks, the training of non-technical skills such as teamwork, the ability to communicate in foreign languages, intercultural competence and customer orientation, will be an important goal in the MARVEL learning scenarios. Working with remote experiments, collaboration in distributed teams and communication in a foreign language with students from a partner college may help to develop and train these skills.

2.2. Learning scenarios

The learning scenarios considered in MARVEL address various mechatronics systems, but will concentrate initially on process control, robotic systems and computer integrated manufacturing. A brief characterisation of these learning scenarios is presented below in table 1.

Learning scenarios			**Settings and course trials**
1	Process control	Process monitoring, control and maintenance of a *full-scale* solar plant	Classroom-only and various types of mixed classroom-workplace learning settings, including remote experiments and teaching sessions with teams from partner colleges in more than one country.
2	Robotics	Configuration and programming of a robot system	
3	Computer integrated manufacturing	Diagnosis and maintenance of a modular production system	

Table 1: MARVEL learning scenarios

Our first learning scenario is illustrated in figure 1 and requires the students to solve different work-based learning tasks, related to process monitoring and control of a full-scale solar plant. The hardware setup of the solar plant consists of four different solar collector panels (installed on the roof of the laboratory building) in combination with two hotwater tanks that are connected in series. The first tank serves as a hotwater buffer. The second tank is only necessary if there is not enough energy from the collector panels, and an extra gas heater is required to warm up the water. The solar heating system is controlled continuously by a programmable logic controller (PLC), connected via a fieldbus to about 40 sensors (for temperature, volume flow, etc.) and numerous actuators (valves, pumps and servomotors).

The PLC has an Ethernet I/O module to provide remote access to the real process via an Internet-based connection. To supervise the behaviour of the overall system, the data acquired is stored continuously on a server and may be monitored remotely. The process interface – enabling students to access the process and read or modify parameters – is realized with the SCADA package WinCC.

characteristics of the two different installations, by exchanging process data and system information between their colleges.

Similar settings are planned for the remaining MARVEL teaching scenarios. All lab assignments and exercises will be supported by web-based learning materials in the form of 'virtual books'. The pedagogical contents are based on existing information sheets, learning task descriptions, and other

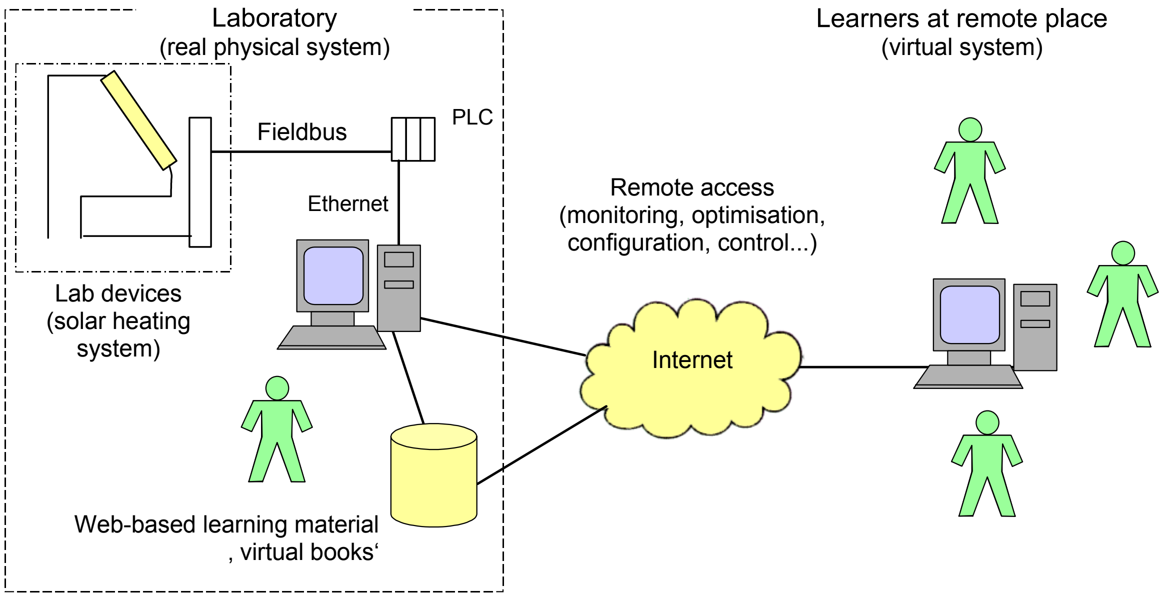

Figure 1: Real and remote virtual system

sources that are already available in digital form. Generally speaking, the learning settings referred above address the following learning objectives:

1. Theoretical knowledge and operational competence to monitor complex processes from remote locations (using IT-tools for process monitoring and control).
2. Theoretical knowledge and operational competence to find out the efficiency of different system configurations (using IT-tools for data acquisition).
3. Competence to maintain complex systems (e. g. finding faults) with IT tools and adequate methods.
4. Ability to collaborate with technicians speaking a different language, and having different cultural and professional backgrounds (e. g. in a company with several branch offices all over Europe).

By studying the effects of teaching and learning through remote techniques and tele-cooperation tools in these different learning scenarios, the following issues are investigated as part of the evaluation:

Various experiments have already been evaluated in a local setting with learning groups from the Technical College in Delmenhorst (Germany) where the solar plant is installed (in this setting the students and the process hardware are in the same building). A distributed learning setting will also be evaluated, where students of the Higher Technical Institute (HTI) in Nicosia (Cyprus) access the same laboratory equipment remotely. A teacher from Delmenhorst, assuming the role of a tele-tutor, will support these learning sessions via the Internet. In a third setting two distributed learning groups (one in Delmenhorst and the other one in Nicosia) will collaborate via the Internet and solve a typical maintenance task, requiring them to program and/or configure the PLC. For safety reasons, their ability to modify parameters remotely is limited, and the learning task will be supervised by a teacher at each site. As a complementary action to this distributed setting, the college in Nicosia will hold a joint teaching session with the Delmenhorst college, using their local pilot solar energy conversion system. Students analyse and filter out typical

1. Will the proposed pedagogical framework meet the MARVEL functionality and usability criteria?
2. To which extent will the needs of students, as well as those of their current and future employers and of vocational colleges, be satisfied, as a result of the higher flexibility to create learning settings?
3. Does the linking of virtual and real systems (i.e. virtual and real learning objects, as well as abstract classroom and concrete workplace settings) improve the pedagogical effectiveness of the learning process?
4. What relevant cultural differences can be observed?
5. Which particular advantages and disadvantages are created by the new learning environment and learning settings, regarding cultural differences between the participating countries?

Data from the evaluation process will be gathered by means of questionnaires and interviews aimed at students, teachers, and industrial experts.

3. Educational concept

The educational concept behind our approach combines experiential and collaborative learning. In line with the constructivist paradigm, students are confronted with learning situations where they can learn from concrete experiences in a situated context. Learning tasks originate from engineering practice and work situations, so the student does not acquire his / her knowledge exclusively from the teacher. Furthermore, students are encouraged to work in distributed groups. Collaborative learning promotes soft skills in team work and remote collaboration. The MARVEL approach emphasizes the combination of virtual learning sessions (remote labs, simulations) and direct “hands-on” experiments in local labs or at the workplace.

Experiential learning seeks to involve the learners in a concrete experience. One of the main exponents of experiential learning is David A. Kolb (Kolb 1984), who proposes a learning theory comprising four main stages, as illustrated in figure 2: concrete experiences, reflective observation, abstract conceptualization, and active experimentation. Based on the work of Piaget, Dewey and Lewin, Kolb explores the interpretation of concrete experiences and the learning styles involved in doing so. In his model the process begins with an experience (1), which is followed by reflection (2). The reflection is then assimilated into a theory (3) and finally these new (or reformulated) hypotheses are tested in new situations (4). The model is a recurring cycle within which the learner tests new concepts and modifies them as a result of reflection and conceptualization activities.

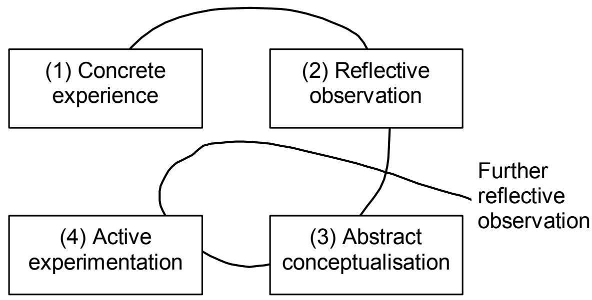

Figure 2. Experiential learning cycle

Action and reflection are the core attributes of learning through experience or experiential learning. This requires a teaching methodology in which students are engaged in doing activities and reflecting on what they did. Our knowledge acquisition techniques are based on virtual and remote labs, simulations, or real life experiences in local labs and work spaces. We try to maximize the learning effectiveness by looking for the right mix of such methods.

Combining lab experiments with virtual learning is fully compatible with the concept of experiential learning, because lab experiments are used as a learning aid, instead of constituting a learning goal by themselves. Lab experiments and practical exercises provide a 'hands-on' approach to learning. They allow a learner to 'experience' data in a more familiar form, since the practical experiment proposed to the students enables them to 'observe and reflect' on what they have just witnessed. Each experiment may therefore be seen as a starting point on the way that will lead them to understand its underlying theoretical principles.

The collaborative approach associated with our learning scenarios is important because the students

- acquire various soft-skills, such as the ability to work in teams and to achieve objectives in cooperation with others;
- learn to communicate with each other using technical expressions that are specific of their professional domain;
- learn to integrate the know-how of others in order to accomplish a given work task;

- acquire remote collaboration skills, when the team work is carried out from several locations simultaneously.

In many cases working in groups is also much closer to real work situations, when compared with isolated learning. As described above this is particularly evident when concerning the provision of various services associated with mechatronic systems.

4. From remote labs to interlinked real and virtual learning spaces

Laboratory exercises play a fundamental role in our learning settings. *Local labs* are normally the best way to get a first hands-on experience with the operation of laboratory devices or constructive exercises. Students working in a local lab can directly perceive and influence reality. The relevance of haptic experience for knowledge construction and skill development has been argued among pedagogical and psychological experts (MacKenzie, Iberall 1994). Accordingly on-the-job-training plays an important role in vocational training. However, learning at the workplace is not always feasible: on-the-job-training is often unplanned, covers only parts of a curriculum and frequently provides no room for conceptual learning and abstraction. Therefore laboratory exercises and experiments are a good compromise. On the other hand the high cost of modern equipment and sophisticated experimental setups is sometimes prohibitive for many institutions that have limited budgets and resources.

Virtual laboratories are computer-based simulations of physical or other real-life systems (e.g. economic systems). Simulations are a very appropriate way to illustrate the complex structure of machines, technical systems and other apparatus (Fishwick 1995). Simulation has proven to be a good technique, especially when the objective is to achieve familiarity and to drill specific behavioural responses to malfunctions or emergency situations. It is particularly important because it eliminates exposure to risk in potentially dangerous activities. In mechatronics there are many good tools available for this purpose, namely for process and robotics simulation. But on the other hand simulations which come close to reality are very expensive and of course we have no tools for systems which can not be described by formal methods or mathematical functions.

A *remote laboratory* provides access to experiments controlled by a computer (the lab server) that is linked up via a local area network to the actual laboratory devices and equipment (Saliah 2000) (Esche 2002). Instead of directly manipulating the devices and equipment in the lab, the students use a global communications network (e.g. the Internet) to interact with the server. Remote laboratories try to combine the advantages of local labs with the flexibility of simulation. They improve the availability of lab facilities and real-life workplaces, since the physical presence of the user is normally not necessary. Schools, research institutions, technological suppliers and companies may share resources and rationalize costs by setting up networks of remote facilities in their areas of activity. Remote lab-based courses offer the opportunity to use facilities from remote sites, without replicating expensive lab equipment at all teaching institutions.

Remote experimentation can also support the development of important engineering skills like remote operation, diagnosis, and maintenance (tele-sevice), as referred earlier in this paper. Remote laboratories are currently being developed and used at many places around the world, as shown by a recent survey that identified 19 projects (Teichmann 2002). There are however some shortcomings associated with remote labs / workbenches via the Internet, with relevance to the loss of haptic experience and concreteness. Students working in a local lab come in contact with concrete artifacts and can directly touch, see, hear and smell the laboratory devices (Tuttas, Wagner 2002). This full sensual experience of being in the lab cannot be provided by remote labs where students interact with remote devices through a computer user interface. Böhle and Milkau (1988) empirically enlightened the problem of diminishing concreteness for a skilful control of machines and the accumulation of experience. This is the reason why remote laboratories are called by Aktan the “Second Best to Being There” (Aktan et al 1996).

In our approach we try to combine simulation training, remote lab experimentation and learning-by-doing on real-life systems, to reduce the problems of transferral between virtual and real systems (Müller 2001). The MARVEL project follows a new and innovative paradigm in training and education, by supporting local and distributed learning based on merging virtual *and* real labs and workshop facilities (Bruns 2001). Mixing tangible objects of real work spaces with the digital representation of information spaces, is an approach that witnessed an increasing interest during the last decade (Milgram, Kishino 1994) (Ohta, Tamura 1999). This concept – also known as *Mixed Reality* – provides a near-perfect match to our requirements concerning tele-service and tele-learning, and as such is used by the consortium to meet the MARVEL learning objectives that were presented in section 2.1. It must be emphasized, however, that most of the actual Mixed Reality research is focused on technical issues (Ohta, Tamura 1999). Our approach in MARVEL focuses more or less on *organisational* models, in terms of learning scenarios and their implementation into work and/or learning processes. Figure 3 illustrates the dimensions of mixed reality learning spaces and shows the range of choices available and the possible interaction among the various technological alternatives.

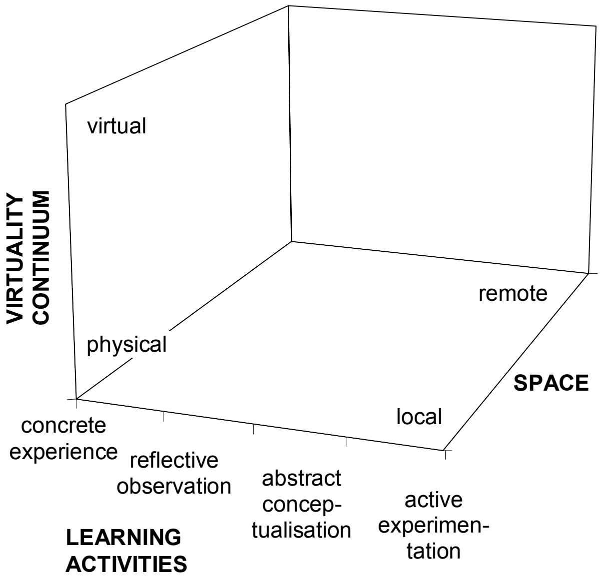

Figure 3: Dimensions of mixed reality learning spaces (Müller 2001)

5. Conclusion

Learning by experience in a real and social context is more and more restricted in computerized virtual environments. In this paper we proposed a mixed-reality e-learning platform for vocational training in mechatronics, by combining virtual learning sessions (remote labs, simulations) with learning in real labs or even at the workplace. Mixed Reality learning environments will be able to find an optimal balance between virtual, remote, and real experimentation systems, with the objective of providing the best platforms to support the acquisition of learning contents and practical skills (Foss 2001).

There are of course limitations to the pedagogical effectiveness of remote and virtual labs. The novelty of remote access to workbenches is a major source of attraction to students and teachers alike, but it is important to consider some of the criticism which occasionally tends to fade away, in the presence of overestimated benefits. The cost of setting up and maintaining remote lab infrastructures, and the insufficiency or incompleteness that are inherent to remote experimentation (higher risk when compared to simulation, inability to convey some manual skills that are acquired when setting up experiments in a real lab), are just two main examples. Some of this criticism may sound excessively pessimistic, but it will help to counterbalance the excessive optimism that is frequently found in many of the current publications in this field. Suffice it to say that remote experimentation is not a universal solution able to guarantee the successful outcome of any technological or scientific learning process. It will however find its own place in the learning chain, not as a replacement to simulation or real experimentation, but rather as a complement that may bring an added value in terms of the pedagogical outcome. There will be situations where an overlapping of simulation, remote experimentation, and real experimentation, will be acceptable, but also other situations where only part of these alternatives will make sense. As the technology supporting virtual and remote experimentation environments progresses, mixed environments will start to become more common, putting together the best tools that are able to support the learning process at any given moment. Failing to benefit from technological innovations with a high pedagogical potential would be even worse than having to reduce the expectations in the case of overestimated benefits.

6. Acknowledgements

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