LOW COST ENTRY INTO EDUCATION FOR UBIQUITOUS AUTOMATION

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Abstract: The widened access to "life" experiments and work assignments offered by remote labs and workshops is in the beginning stages of being established in the field of engineering education. However, remote lab equipment is often very cost intensive and not available for widespread use. In this paper, the application of inexpensive off-the-shelf hardware and software is proposed, with the intent of setting up an integrated learning environment for skill-oriented PLC programming and configuration. PLC programming is regarded as a basic technology for ubiquitous automation. The objective is to provide engineering students ubiquitous access to real control hardware and devices in an uncomplicated and cost-oriented way.

Keywords: Educational aids, control education, remote control

1. INTRODUCTION

The work presented in this paper was developed in connection with MARVEL (Virtual Laboratory in Mechatronics: Access to Remote and Virtual e-Learning), a pilot project under the European LEONARDO DA VINCI programme. MARVEL developed and evaluated concepts for learning communities and inter-site collaboration in which the stakeholders involved (e.g. vocational colleges, training enterprises, universities) can share and use distributed workshop and laboratory facilities via the Internet (Müller and Ferreira, 2004). This includes not only examples of fully remote experimentation and workshop settings in which all devices and equipment are real and available via the Internet, but also examples of mixed-reality environments in which real devices interact with simulation models. The main application areas covered by MARVEL are remote labs and workshops for solar energy, digital electronics, industrial robotics, and control engineering (http://www.marvel.uni-bremen.de).

One important objective of MARVEL was therefore to investigate how to make labs and workshops ubiquitous tools in engineering classes. Remote resources are often not available for widespread use in educational environments (i.e. for economic reasons). What are needed are solutions based on inexpensive hardware and software in place of high cost commercial equipment. In this paper, an example of an easy to use and cost oriented solution is presented, with which students can access a real programmable logic controller (PLC) in local settings or remotely over the Internet. The proposed solution illustrates the benefits and challenges of such an approach.

The next section presents some background of PLCs in control engineering, both in terms of technical and pedagogical aspects. The relevance of PLCs in industry will be also considered. Afterwards, some of the forthcoming trends in the training of PLC engineering are described, followed by pedagogical issues in relation to remote and local PLC experimentation. In the next section, the prototype developed by artecLab within MARVEL is presented. The underlying concepts and related work are then highlighted. A final section presents the conclusions and summarises the development plans that are envisaged for the near future.

2. BACKGROUND

Programmable logic controllers (PLC) are small control systems used for automation of real-world-processes, such as security monitoring, energy management, the control of machines and production lines. A PLC is usually based on a microprocessor with battery backed memory. PLCs are used to read input signals from sensors (e.g. limit switches, temperature indicators or photoelectric sensors,) and to send output signals to control electronic and mechanical devices, such as pneumatic or hydraulic valves or cylinders, magnetic relays or solenoids, and electric motors.

Before PLCs came along, sensors and actuators had to be physically connected using relays and hardwired control panels. As programmable logic controllers were initially adopted by the manufacturing industry, the configuration and programming of PLCs was usually done by skilled control engineers specialised in this application area. Over the years, the technology of PLCs has evolved, and nowadays the functionality of a PLC includes sophisticated motion and process control, distributed control systems and complex networking. More and more important are also PC-based PLCs, called soft-PCLs, where a program runs on an ordinary computer that mimics the operation of a standard PLC. As PLCs become more functional, smaller, and able to work in tough environments, they are becoming fundamental to advancing the field of manufacturing automation. Thus, the world market for programmable logic controllers will still continue to grow steadily (ARC Advisory Group, 2005). There are currently more than 30 manufacturers worldwide. Accordingly, there is a great need for qualified technicians and engineers in this area. Consequently, PLC technology plays a significant role in vocational and undergraduate automation and control related courses.

3. PEDAGOGICAL ISSUES

Experiential learning seems to have been the core methodology in skill oriented engineering education for quite a while (Harrisberger, et al., 1976). The term *experiential learning* covers varying concepts and practises (Fenwick, 2000). What all of these theories have in common is that learning is understood as an iterative process in which knowledge is generated by reflection on concrete experience.

David A. Kolb (1994), one of the main exponents of experiential learning, proposes a four-stage model. According to this model, a learning process begins with a concrete experience, followed by reflective observation. This observation is then assimilated into a theory by abstract conceptualisation. Finally, new (or reformulated) hypotheses are tested in new situations. The model can be characterised as an iterative learning cycle (Fig. 1). In this cycle, the learner tests and modifies new ideas and concepts as a result of reflection and conceptualisation. The use of hands-on experience to test theories in practice, as well as the use of feedback to modify these theories, are significant elements of experiential learning. Concrete experiences in engineering education are typically provided through laboratories, workshops and field trips in relation to practical experiments or work tasks. Hands-on learning in real workspaces provides opportunities for experiential learning, because learners can 'experience' concrete situations, measurement and instrumentation (Bencomo, 2004). Since the practical experiment enables the learner to observe and reflect on the results of tasks and assignments, each experiment or practical work task may therefore be a starting point for understanding the underlying theoretical principles.

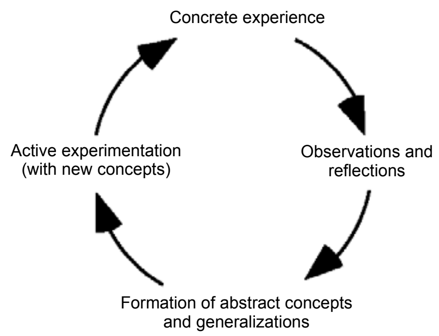

Fig. 1. Experiential learning cycle

In addition to these theoretical findings, experts in the field of engineering education in PLC technology clearly demand learning by doing with real industrial PLCs. In particular, the peripheral hardware devices (sensors, actuators) are essential elements to becoming competent with PLC based systems. Simulation or virtual labs are very useful tools in the learning process, but cannot completely substitute experimentation with a plant or real device (Cooper and Fina, 1999.) This is particularly true regarding the sensations perceived by the learner in the experiment. Practical education is based on errors and irregularities, as occur in real control systems, in contrast to ideal models represented on a computer's screen.

Nevertheless, many educational institutions are not able to provide learners with necessary practical equipment and lab tools. This is because a complete laboratory with a reasonable number of workplaces including industrial PLCs and hardware equipment requires a lot of investment which a small College or University could not always afford. Furthermore, well equipped laboratories or workshops with continuous technician support are not only costly to establish, but also costly to maintain. Lastly, limited access to local laboratories and limited equipment availability are particularly evident in courses, where learning resources are needed simultaneously by a large number of users.

If local access to real laboratory resources is not possible, remote access to real plant equipment via the Internet is an option. The possibility of the control and manipulation of remote objects, just as if they were operated directly, is defined as teleoperation. Teleoperating remote lab equipment requires a sufficient degree of feedback stimuli (e.g. visual, auditory, haptic) to give the user an impression of telepresence (e.g. feeling of being in the lab). Although full telepresence is not realistic there are many control-engineering tasks in practise that are based on concepts of telepresence. Remote repair, diagnostics, and maintenance (RRDM) are catchwords for such tasks in this domain (Biehl, et al., 2004). These concepts are also relevant for learning and training using remote experimentation laboratories. The widened access to equipment and work assignments offered by remote labs and workshops is starting to be established in control-engineering education and training accordingly (Bencomo, 2004). More recently, authors have also discussed the pedagogical potential of remote labs as training platforms for self managed learning and collaborative work in relation to RRDM technologies (Erbe and Bruns, 2004).

Although using remote laboratories, workshops, and plants seems to be an efficient way of accessing resources for practical experimentation purposes, there are many drawbacks that need to be considered. First of all, not every technical system, however experimental it is, is able to be operated remotely. An example is the assembly of a sophisticated system (e.g. pneumatic circuit), where a greater number of elements need to be manipulated and tested – often in a nondeterministic way. One solution is a simulator based virtual lab, which are available in high quality for many application areas. Secondly, remote experimentation environments must meet certain requirements in order to make them available for widespread use. Bencomo (2004) lists about twenty requisites for successful implementation of remote experimentation environments. Among those, there are five basic requisites which seem to be very essential, if the remote environment is to be used under everyday conditions on a university campus. These basic requirements are:

- simple installation and use
- access through the Internet
- no cost
- interactivity and realism
- total availability.

Last but not least, tiny and simple solutions in learning and training technologies, following the "Less is more" (Buxton, 2001) design principle should be more and more propagated. Keeping this principle and the abovementioned requirements in mind, we will now describe our idea of a low cost PLC lab kit in more detail in the following section.

4. SYSTEM DESIGN AND PROTOTYPE DEVELOPMENT

4.1 Overview

The general design idea of the PLC experimentation lab kit (referred to as SPScc) is to use low cost and common off-the-shelf equipment, standard Internet tools, and, far as possible, low budget software to provide a distributed virtual and real environment for PLC training. The system is designed to integrate all necessary components either as a remote learning lab in faculty, or as an affordable standalone solution. Students should be able to take their lab home to learn independently, with minimal required equipment. From a didactical point of view this is a very important aspect, because it is motivating for a student or a group of students to have all components available to build a complete system on the table direct lying front of them. Care must be taken to achieve the necessary complexity while providing a single solution for lab and home use. Otherwise, solutions to tasks are trivial and students are not challenged. Furthermore, all functions should be available to handle high power loads right out of the box.

A major design aspect of SPScc was that it should be able to be integrated into existing virtual learning environments and into other experimental hardware and software. Components at work, school, and home should all be useable with a small amount of effort.

4.2 Basic structure

The proposed system can be divided into three major parts. These consist of the client interface, the communication and collaboration components, and the laboratory equipment. The system consists of a tiered architecture with three different layers, each layer providing its services to the next layer by using the services of the layer below. A description of each component is given in the sections that follow. Figure 2 outlines the different layers with a brief description of their respective functions.

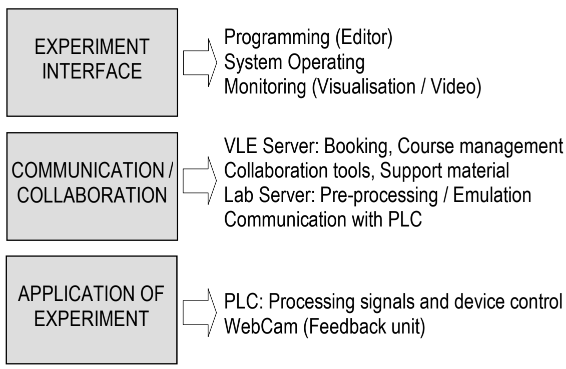

Fig. 2. Architecture of the remote PLC experimentation lab kit

Figure 3 shows this architecture in a graphical way.

1. Interface Layer The interface layer provides a graphical front end for the user. SPScc makes use of a standard web browser (e.g. Firefox) with the Macromedia Flash Plugin installed. A user may access the lab at anytime from anywhere through a computer connected to the Internet (or Intranet.) Through video streaming, the distant laboratory is made visible (Figure 5).

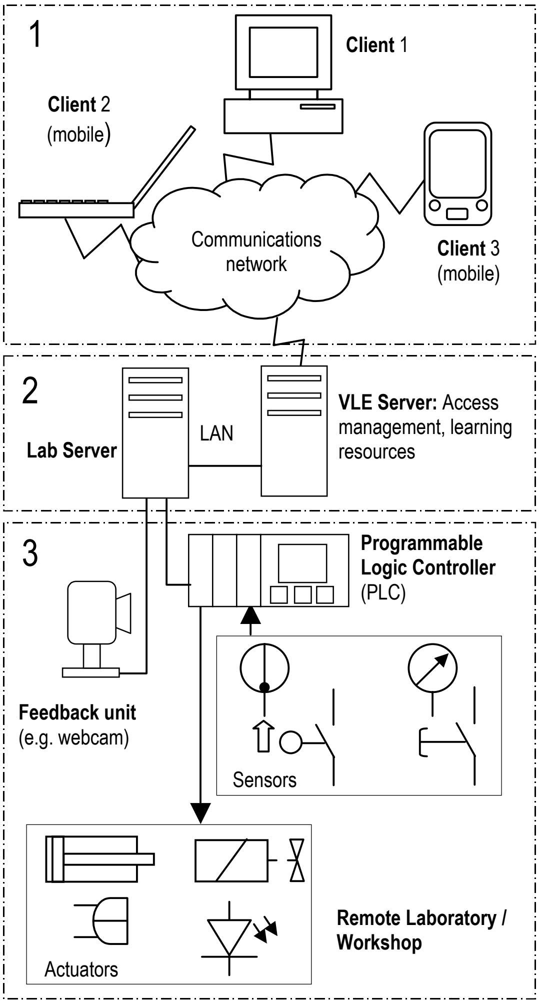

Fig. 3. Schematic presentation of the remote PLC experimentation lab kit

2. Collaboration Layer The communication component builds a layer between the laboratory and the user. It consists of a VLE (Virtual Learning Environment) server (e.g. Moodle[1]) and the lab server where the experiment is running. The lab server provides only the tools for remote experimentation. Placed in the actual learning environment of the faculty, these tools are supplemented by the VLE. The virtual learning environment plays a central role in the concept. It extends the SPScc tools with learning material organized according to the faculty's need. Teachers are providing tasks and background material that are important for the experiment. The VLE is also used for synchronsation with the available hardware (e.g. through a booking system). From a technical point of view, both services could be installed on one computer.

3. Experiment The actual laboratory consists of the automation control unit (PLC), a lab (can be also a complete functional plant) and a feedback unit (e.g. webcam). SPScc uses a Conrad I PLC[2] which costs less than 80 Euros.

4.3 Implementation

SPScc is implemented as a service providing a compiler for PLC languages and an interface to the real components. Currently two languages are implemented, as shown here:

IEC 1131 Instruction List	Step 5
PROGRAM iecTest	O(
VAR	UN E 0.0
F1 AT %I1.0 : BIT	U E 0.1
F2 AT %I1.1 : BIT	)
LED AT %Q1.4 : BIT	O(
END_VAR	U E 0.0
	UN E 0.1
LD(F1	)
ANDN F2	= A 0.0
)	
OR(F2	
ANDN F1	
)	
ST LED	
END_PROGRAM	

Clients access the service through TCP/IP network connections. Figure 4 shows the flow of information between client, server and PLC. After connecting to the server, PLC programs are sent to the server. The server compiles the program and provides feedback on errors or success. Successful programs are then downloaded onto the real PLC and started.

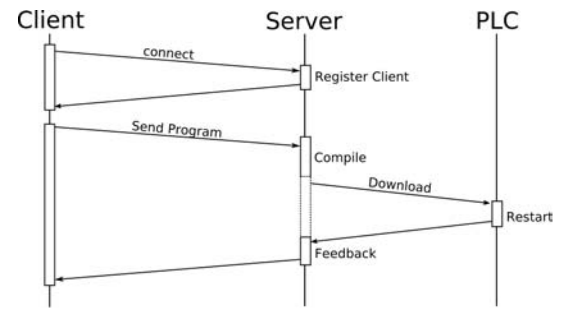

Fig. 4. Flow of information

A challenge was updating the PLC while it was running. Normally, the starting and stopping of a program is done through a switch on the Conrad PLC. But for remote experiments, this method cannot be used. Our solution was to provide an additional framework that listens to the serial connection. When an event on the serial line is received, the running PLC program is interrupted and the internal memory updated. Afterwards, the PLC is soft restarted by calling its setup procedure.

The service is implemented in C# using .NET vers. 2. Coco/R[3] was taken for compiler development. Target of the compilers is the Conrad PLC intermediate language. This makes it possible to upgrade to the second edition without (or with minimal) change to the compiler. Also, a disassembler for the intermediate language is provided.

Following the idea of easy access to the PLC and integration into VLEs, a sample user interface in Flash was developed. In contrast to many other remote experiments, only one standard plugin is needed – and this is in most cases already installed as

[1] www.moodle.org
[2] www.conrad.de, Nr.: 125113 - LN

[3] http://www.ssw.uni-linz.ac.at/Research/Projects/Coco/

Flash is nearly a de facto standard. There is no need to stick to this interface, as one could also write a Java client, for instance.

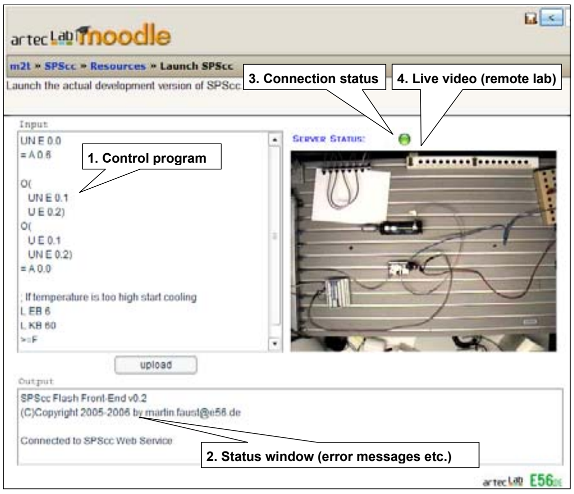

Fig. 5. SPScc launched out of Moodle (Virtual learning environment).

5. UBIQUITOUS AUTOMATION

5.1 Related Work

The presented solution in this paper is strongly inspired by experiences with a PLC controlled solar plant, evaluated for vocational training in the aforementioned MARVEL project. The system consists of several Siemens PLCs in combination with WinCC on a complex industrial base (Hoell and Martens, 2005).

Other examples relevant within the context of this paper come from the Control-Net project, which developed remote lab examples for plant and process control with STEP7 (Meyer, et al., 2004). Langmann introduced a remote PLC lab which provides a programmable authentic assembly station (Langmann, 2004). This lab is designed for control engineering courses based on IEC 61131-3. Hsieh et al. (2003) introduced an online programmable logic controller learning system based on a Soft PLC. Sousa and Carvalho (2005) have implemented an IEC 61131-3 IL (Instruction List) and ST (Structured Text) compiler that is part of an open source PLC project called MatPLC (http://mat.sourceforge.net).

Although some of these approaches propagate low cost or even open source solutions they do not offer the flexibility of SPScc. Utilizing only a set of flexible components, SPScc does not focus on one configuration but gives faculties the possibility to extend and integrate it into their own labs.

In general, there is an interesting discussion in control engineering research about cost oriented solutions, not only for educational, but also for industrial applications. This motivated our work (Bernhard and Erbe, 2001; Wollherr and Buss, 2001). While research in the control engineering field is essential, we also got impulses from software engineering, especially approaches to interconnecting middleware and control devices by Web Services like SOAP (Rasche, et al., 2004). Last but not least, Buxtons' "Less is more" design principle motivated us to reflect more about tiny and simple learning tools in relation to control-engineering education.

5.2 Relevance of proposed concept

Ubiquitous automation differs from ubiquitous computing: there is not only the sensing and processing of information, but also a focus on cybernetics, as a closed loop technology for action and reaction. This requires new engineering thinking, skills and perspectives. An every day world, full of sensors and actors, controlled not only by distributed local devices, but also by central computers, requires the engineers to be thinking in new categories of time, location, and space. Although in computer integrated manufacturing we are used to applying distributed algorithms via fast network connections and protocols like Profibus, the open ended situation of every day surroundings poses a new challenge for adequate and adapted reaction times, suitable not only for deterministic automata and machines but also for human beings and natural objects.

Real-time problems in machine environments are somehow easier to determine but often hard to implement. Real-time problems with humans and natural objects are more difficult to determine, they have a grey zone of possible implementations, because humans and nature are very flexible. This allows the designer to shift the burden more or less on the user. Domains like Ergonomics and Human-Centred-Systems Design have been related to these situations for a long time and contribute to handling this dilemma: how much determinism and freedom of the machine is desirable for how much determinism and freedom of the user? Who is the user in ubiquitous computing and automation? From the consideration of well determined locations and persons (if that were possible,) we have to shift our attention to open, unknown and changing locations. Mobile automation devices will be carried around in the future. Physical and social contexts are changing in an arbitrary way and have to be foreseen in some engineering sense. This requires new forms of abstract design spaces: physical phenomena, changing their relevance from one situation to the next, demand for unified abstract description languages like Bond-Graphs. Physical phenomena could be closely coupled to virtual phenomena to provide some means of distributed handling and control. Hyper-Bonds (Bruns, 2005) are a means to proceed in this direction. Awareness of privacy, safety, and security has to be considered in the design and operating of these systems. All these topics are of course subjects for a good engineering education, but in ubiquitous automation they get a new relevance.

To support an easy integration of these topics into everyday teaching of mechatronics and automation technology, we need more low cost devices for students to use from home and for their own places, from lecture rooms connected to laboratories, or vocational schools connected to students industrial workplaces. Our PLC solution is intended to contribute to this aim.

6. CONCLUSION AND FUTURE WORK

The prototype presented enables ubiquitous access to real control hardware and devices in a very uncomplicated and cost oriented way. Our aim was to show that such a simple system can support active learning within a mixed reality setting. SPScc is designed to be used out of the box. Additional features (e.g. Collaboration) are provided through external applications (e.g. Skype, ICQ, Moodle) .

SPScc challenges students by providing a highly dynamic and reconfigurable setting. Tasks can be developed for different knowledge levels without changing the software. It also integrates into existing hard- and software as well as learning environments. SPScc is completely based on Open Source software and available under the GNU General Public License (http://www.e56.de/SPScc.html). The off-the-shelf PLC hardware used costs less than 80 Euros.

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