A Virtual Laboratory for the study of Mechatronics

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Abstract—**In this paper we describe the design and implementation of a remote virtual laboratory for cooperative learning of Mechatronics over the Internet. The proposed architecture provides several advantages to institutions offering eLearning and distance education courses in industrial automation. It facilitates the learning process over the Internet by providing a Web based user interface that allows remote users to access and control several physical models of technological processes and also verify created control programs via a virtual model without damaging the system equipment. The architecture presented in the paper is not dependent on a specific SLC hardware or software configuration and offers a great potential for industry by providing means of remote controlling and verifying control programs in manufacturing systems located at different locations.**

I. Introduction

The rapid changes in society and technology have also generated a demand for more flexible engineers having many more qualifications than just a high level of technical or scientific specialization. Therefore it is important to provide the students with a real world experience. Today this problem is getting more and more attention, because the real experiment gives the students a sense of practical testing and they can also see the influence of the second/higher order effect, real time effects, etc. Building a virtual laboratory is a way how to combine information and communication technologies with real practical experience in the educational process. It allows students to perform experiments safely, without guidance and without any limitations imposed by official working hours in the laboratory.

However, to build an experiment is expensive and it is impossible for an educational institution to have the complete scale of experiments. For this reason the Department of Electrical Engineering and Mechtronics of FEI TU in Košice, in cooperation with the Department of Automation and Control of the FEI in Bratislava prepared a project (KEGA 006-005TUKE-4/2010) for building a joint virtual laboratory dedicated to technological process control via small logic controllers.

The Web-based system control architecture presented in this paper allows remote access to a SLC-controlled physical model of the technological process over the Internet. The architecture provides both on-site and distance students with the same learning environment, and minimises the difference between the qualities of learning of both student bodies. Controlling the "real" technological process via the Internet presents a fundamental difference between this approach and other similar approaches, which rely only on computer simulation.

II. Virtual Laboratory and Remote Laboratory

A stage that had to cover in this investigation was the elaboration of a taxonomy that allows to categorize the Virtual Laboratories of the Laboratories of Remote Access. We understand for Virtual Laboratories those ones where you can make simulations of physical devices using software [1]. In some cases, a well designed virtual laboratory can substitute a real laboratory, mainly when this incorporates elements of animation (graphics, sound, virtual reality). The virtual laboratories that are accessible through Internet/Intranet are highly attractive to reduce the costs of acquisition of equipments; using a browser like interface for a virtual laboratory has the following advantages [2]:

- It is independent of the platform.
- It has a great and easy way of use.
- The need of additional software is minimum in the client's side.

On the other hand, the Laboratories of Remote Access allow that real experiments of laboratory are controlled far through a connection Internet or via Web. Associated to these types of laboratories they are the aspects of Virtual Factory and Remote Factory (or Telemanufacture). The Remote Factory uses services offered through Servers to execute production operations in real time; this way the telemanufacture activities are present from the conception until the creation of the product. On the other hand, the Virtual Factory is a synthetic factory atmosphere where they are integrated objects, activities and real processes with objects, activities and feigned processes [3].

III. Significance of Building a Virtual Laboratory

Small logic controllers nowadays present the main tools used at basic level of automation of mechatronic systems and technological processes. Almost each operational and service engineer needs to master them regardless of whether he is in the position of a user or a designer of the systems with programmable logic controllers (PLC).

In the existing laboratories the teaching of subjects related to automation and control in practice is conducted within the range of 42 hours altogether – this is to learn about the automation tool (PLC) proper, its programming, details of the specific technology and verification of the design. Students fight with enormous demands - each piece of information is new to them and this means that

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they manage to grasp the elaboration of a formal solution of an automation problem during the semester, but due to lack of time its correctness cannot be verified. In order to increase the quality of learning and to acquire a real ability to design control systems in practice, it is necessary to enable the students to make the most of practical experiences in the field of control of systems with PLCs. With the given timetable structure and number of students, this can be realized by more effective utilization of the laboratory and its physical tools. The students should have the possibility to prepare their tasks in the OFF LINE mode and then verify them on the real physical model in the ON LINE mode continuously over 24 hours a day, i.e. also in the time outside the standard teaching time.

The main aim of building a virtual laboratory is to involve a design aspect in educational process of mechatronic systems because a virtual laboratory presents a new e-learning tool in which the experiments should not be only analysis oriented (to measure and see the results) but also synthesis oriented [4].

IV. Virtual Laboratory Design and Development

The general structural layout of the virtual laboratory is shown in Fig. 1. The virtual laboratory includes 9 workplaces with PCs, 6 of which are interconnected with inputs and outputs of programmable logic controllers, and they serve for work in ON LINE mode as well as for formal preparation of tasks in OFF LINE mode. Due to the fact that in the teaching process the formal preparation of tasks takes up significantly more time than the proper functional adjustment of the (relatively simple, school) algorithms, there are 4 workplaces in the laboratory used only in the OFF LINE mode, or for simulation/modelling purposes. Simulation or modelling has several advantages when used as a part of a virtual laboratory. It provides an effective learning environment for students to become acquainted with a concept and/or a specific application related to a physical device and its control parameters at both planning and operational levels without interacting with the physical equipment. Students can experiment and learn at their own pace without the risk of hurting themselves or damaging the equipment. In addition, the same set of software tools can be used for both ON LINE and OFF LINE students.

In virtual laboratory all workplaces are connected via the local network to the laboratory server through which a "remote desktop" access to each workplace or use of common services of the laboratory by all workplaces is possible. The laboratory server enables the control of the particular workplaces through remote computers connected to internet and administration of their use by the students.

The laboratory as a whole has been built from the lower (technological) level towards the upper virtual user level. As we have mentioned in the laboratory of the department there have been built up five physical models of technological processes. Their analogue and binary inputs/outputs are interconnected with the PLC. The programming and visualization software has been installed on independent PCs. Five PCs are connected with the PLC through a serial line and they serve for the work with the concrete model of a technological process in the ON LINE mode. Four PCs serve for preparation of control and visualization programs in the OFF LINE mode and in case of need as backup PCs. The students in the laboratory can work with the physical model and its PLC but in case when students work in ON LINE mode via the internet the real physical models of technological processes are replaced by virtual models. Further, in the laboratory there has been installed a laboratory server equipped by software that is suitable for administration of more users with remote access to laboratory PCs. The PCs are connected via the university intranet to existing internet server. In case when the workplace is free, the laboratory server enables virtual transfer of the screen, mouse, keyboard and other standard tools from laboratory PC to any arbitrary PC connected to internet and thus to work virtually with the concrete PLC and its virtual model.

Physical models of technological processes and control automats of virtual laboratory are divided into two parts and are located physically in two laboratories – laboratory at Faculty of Electrical Engineering and Informatics of Technical University in Košice (FEI TU Košice) and laboratory at Faculty of Electrical Engineering and Information Technology of Slovak University of Technology in Bratislava (FEI STU Bratislava). As each of the departments is provided with physical models of different technological processes, the joining of both departments in the virtual laboratory will make it possible for students of the two universities to use all the tools from both workplaces and thus gain practice in a wide variety of automation tasks. Without the involvement of both departments they would be limited to the physical possibilities of a single local laboratory.

Physical models of technological processes will serve only for the work in laboratory. Students will be able to verify the correctness of control algorithm through the virtual model of technological process which will be connected with real inputs and outputs of PLC. After verifying control program students will be prepared to work with real physical model of technological process in the laboratory.

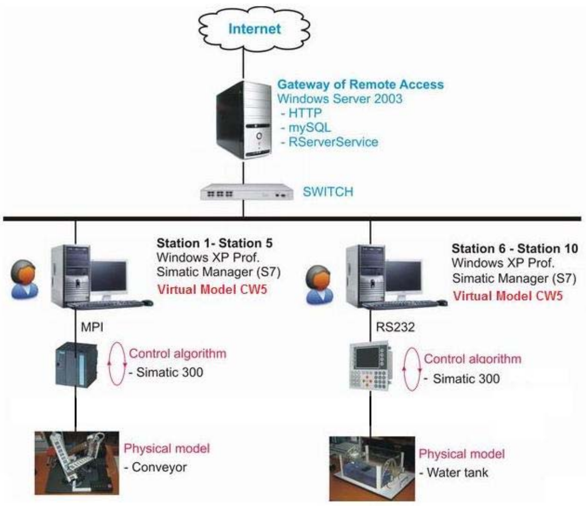

Figure 1. The structure of the virtual laboratory.

Requirements for students who want to work in Web-based PLC laboratory:

Basic knowledge of:

- combinational circuit,
- sequential circuit,
- logic control,
- programming in STEP 7 language,
- ladder diagram programming,
- PLC structure and PLC components,
- PLC instructions.

V. Virtual Laboratory Features and Benefits

With virtual laboratory students participate from a classroom, the office or from home through their own PCs. This system provides students with a complete learning environment where they can view course material, as well as description of the physical models, the instructions how to set the HW configuration of PLC, the description of the control task for individual physical model, etc. The interface of the virtual laboratory you can see in Fig.2.

The main assets of developing the virtual laboratory is:

- VL serves for teaching subjects related to automation, control and visualization of technological processes and that it enables the implementation of new forms of study (distance e-learning forms), which will promote the innovation of the educational process at the Department of Electrical Engineering and Mechatronic of FEI TU in Košice and the Department of Automation and Control of the FEI in Bratislava.
- If effectively scheduled, students can share the same equipment over the Internet regardless of their geographical location.
- Universities can share facilities, instead of individually investing on laboratory equipment, and improve the quality of learning.

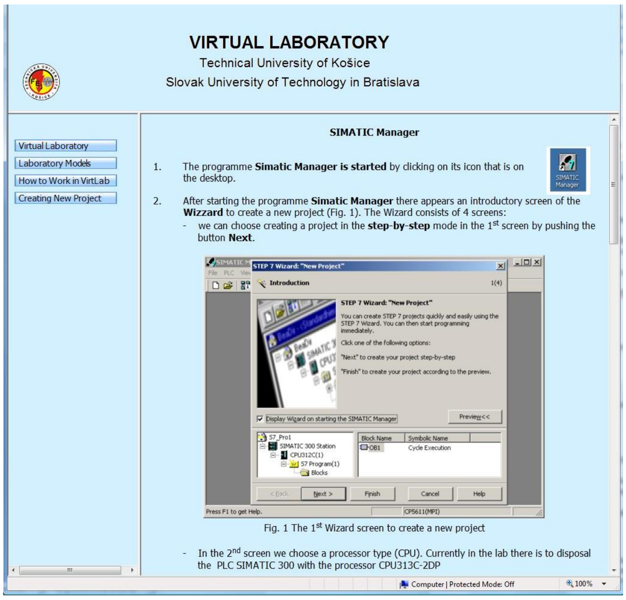

Figure 2. The example of the interface of the virtual laboratory

- Virtual model is a very powerful tool to verify control programs. Executing programs on actual equipment without testing them via virtual model may lead to collisions and damage to the system [5]. Virtual model helps verify programs, thus preventing damage to the equipment. The laboratory model of tanks of liquid and its virtual model are shown in Fig.3.

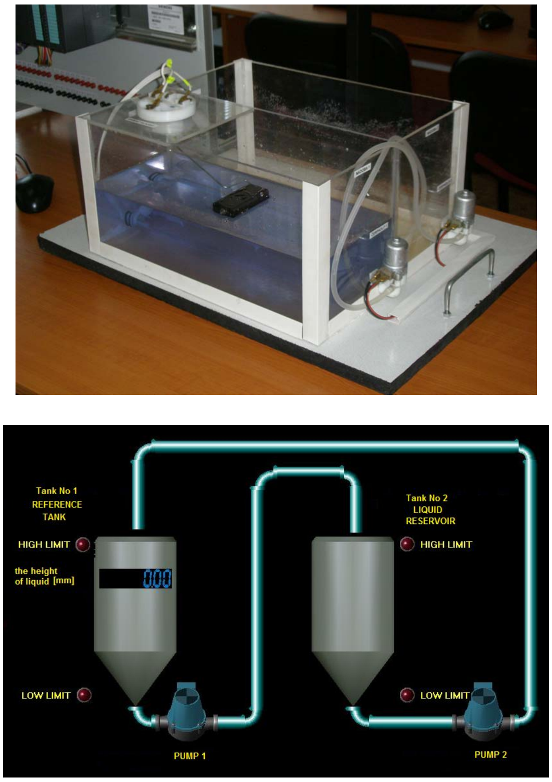

Figure 3. The laboratory model and the virtual model of liquid tanks

- The open concept of the virtual laboratory will in the future enable its simple enhancement by connecting more workplaces, also from abroad

The benefits for students at bachelor, master and PhD study level will be in:

- The higher quality of teaching.
- Higher attractiveness of study.
- Possibility of unlimited access to solution of automation tasks in terms of time.
- Increase in practical knowledge and experience with the design and implementation of technological process control systems based on logic controllers.

Building up the virtual laboratory will enable students to get practical experience in:

- design and debugging of control programs for PLCs, concrete students will be able:
  - to create new project,
  - to define the HW structure of SLC according the project of control system,
  - to configure industrial networks (PROFIBUS, TCP/IP),
  - to define outputs and inputs (type, name),
  - to define required variables,

    - to design control program in the form of ladder diagram or programming language STEP7,
    - to verify designed control program in simulation mode,
    - download control program to SLC,
    - debugging control program in monitor mode,
    - to switch modes in PLC,
    - to run control program in PLC,
- application and verification of standard control structures of real systems,
- remote control from arbitrary location through internet,
- OFF LINE work on the design and programming of control algorithms for drives,
- ON LINE work with real drives and their standardised actuating structures.

VI. CONCLUSION

In this paper, the architecture of Web-based virtual laboratory for the study of technological process automation is presented. The system architecture allows remote users to access and control SLC-based physical models of technological processes via the Internet. The concept utilises a SLC-controlled water tanks system, intelligent gate system, conveyors system, air ball system and wheel pendulum system. If effectively scheduled, students can share the same physical model of the technological process over the Internet regardless of their geographical location. As each of the universities (TU Kosice and STU Bratislava) is provided with physical models of different technological processes, the joining of both universities in the virtual laboratory project make it possible for students to use all the tools from both workplaces and thus gain practice in a wide variety of automation tasks. Without the involvement of both universities they would be limited to the physical possibilities of a single local laboratory. As the virtual laboratory is accessible via internet, it can be exploited also for the training of people who are at most disadvantage in the labour market, including disabled people. The internet controlled distance experimental measurements and virtual laboratories create equal opportunities regardless of gender, race, geographical location or time [7]. The project contributes to improvement of the skills and competencies of people through education and training in the field of the technological process automation and thus can facilitate their integration and reintegration into the labour market.

Remote experimentation using Web-based SLC systems is not limited to education. In manufacturing industry, remote access to distant facilities provides unique opportunities by providing a means of remote monitoring, controlling, and diagnosing manufacturing systems located at different locations [8]. In presented system architecture only one "active" user can interact with the physical model and execute his SLC program, which runs the physical model and also runs the virtual model. Thus, there is no difference between the "real" and the "simulated" terms from the standpoint of SLC programming. The architecture presented in this paper is not dependent on specific SLC hardware or software. It represents generic Web-based system architecture for the study of industrial automation.

A virtual laboratory introduces new forms of e-learning at a larger scale [9]. Using e-learning methods combined with real measurements makes studying more attractive and it represents new trends in learning how to create and verify programs for small logic controllers without damaging the system to be controlled.

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REFERENCES

[1] F. Torres, S. Puente, F. Calderas, F. and J. Pomares, "Virtual Laboratory for Robotics and Automation", in: *Proceedings IFAC Workshop on Internet Based Control Education* (IBCE'01), December 2001, pp. 189-194.

[2] F. P. Brooks, "What's Real About Virtual Reality?", *IEEE Computer Graphics and Applications*, vol. 19/6, 1999, pp. 16–20.

[3] A. J. Alvarez, L. J. Romariz, "Telerobotics: Methodology for the Development of a Through the Internet Robot Teleoperated System", *Journal of the Brazilian Society of Mechanical Sciences*, vol. XXIV, 2002, pp. 122-126.

[4] G. Copinga, M. Verhagen, and M. Van de Ven, "Toward a Web based study support environment for teaching automatic control", *IEEE Control Syst Mag*, vol. 20/4, 2000, pp. 8–19.

[5] J. Abaci, D. Thalmann, "Planning with Smart Objects", in: Proc of Int. Conf. in Central Europe on Computer Graphics, *Visualization and Computer Vision*, Wscg'05, Czech Republic, 2005

[6] B. Aktan, C. Bohus, L. Crowl and M. Shor, "Distance learning applied to control engineering laboratories", *IEEE Trans. Educ.*, vol. 39/3, 1996, pp. 320–326.

[7] G. P. Burdea, P. Coffet, "*Virtual Reality Technology*", Wiley-IEEE Press, Second Edition, 2003.

[8] C. Saygin, A. F. Kahraman, "A Web-based programmable logic controller laboratory for manufacturing engineering education", *Int 0J Adv Manuf Technol*, 24, 2004, pp. 590–598.

[9] L. Benetazzo et al., "A Web-based distributed virtual educational laboratory", *IEEE Trans Instrum Meas*, 49(2), 2000, pp. 349–356.