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A Remote Laboratory for Learning with Automatic Control Systems and Process Visualization*

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This paper presents two complex systems of automatic control and measurement as an example to demonstrate the effectiveness of remote laboratory. One platform presents control and torque measurement of a stepper motor and the second model illustrates pumping station with two water tanks and pumps. Both remote control systems allow users to access the real-time data, make implementation using PLC/HMI (Programmable Logic Controllers/Human Machine Interface) controllers and build SCADA (Supervisory Control and Data Acquisition) visualization software to monitor and manage the control process. Presented systems are used on the experimental laboratory education on Chair of Computing Engineering at Poznan University of Technology in Poland. The author presents the philosophy and methodology of using approach, including the implementations details and his experience in using it. The objective is to present remote laboratory kits for teaching and learning some aspects of control systems. Additionally, the security policy that provides multiple access is described and the effectiveness of the platforms in educating students is discussed.

Keywords: programmable logic controller (PLC); stepper motor; remote access laboratory; supervisory control and data acquisition (SCADA)

1. Introduction

In recent years, there have been important changes in engineering education, especially in electrical and computer engineering, both in terms of content and delivery. With the advent of computers, learning through computer-based environments has dynamically increased [1–5]. In education, the Internet opens a variety of new avenues and methodologies for enhancing the experience of learning and provides an opportunity for students to access laboratories from outside the campus [6–7]. The Internet is increasingly important medium for distributing information, which is free of time constraints, and able to display information numerically and graphically on any client platform [8–9]. It is very important to present knowledge in interested form especially in the engineering faculties.

The rapid pace of technological developments and the high cost of engineering equipment, pose several challenges to traditional modes of engineering education [10–11]. Remote laboratories are a very cost-effective solution, provided that they allow the students to access real automatics systems from any site connected to the Internet, without their having to buy commercial software to control, measurement and visualization [12–13]. Total cost of software licenses presented in this work is estimated at 3000 Euro. In addition, the equipment cost was 6000 Euro and 5500 Euro to be properly done the pump station platform and the stepper motor control system.

Unitronics Remote Operation is an application programming environment for Unitronics Vision series PLC/HMI controllers. The remote operator utility module enables users real-time HMI panels and screens, and click on-screen objects to operate the PLC. It is possible to display and operate multiple PLCs simultaneously, and easily zoom in-and-out of the system by adjusting screen size [14].

SCADA systems was installed with OPC (OLE for Process Control) server to control, monitor, and manage the process, as well as providing access to all inputs and outputs in real time. The OPC standard specifies the communication of real-time plant data between control devices from different manufacturers [15]. Discussed laboratory kits use the KEPServerEX OPC and Communications Server as a web server to view and setup data via the Internet (it is free for student demo version—only registration is needed).

2. Security policy applied in the remote control systems applications laboratory

The remote management of automation equipment provides a high level of risk. In contrast to the traditional forms of teaching, it is particularly important to ensure the safety of equipment, because human health risks is reduced. The author's aim was to identify the major hardware risks and to explore the security models that can be used to mitigate them.

The solution proposed in this paper is a novel approach to remote hardware management with a high level of security. The PLC/HMI and SCADA application security policy has been integrated with Windows XP system privileges. This allows to

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specify the level of software implementation security and also restrict access for certain students and applications. In one window student can control the process and setup the PLC algorithm and in another one can verify this algorithm using SCADA visualization. This attempt is very flexibility, because allows to share work within group of students.

The proposed software architecture is a solution type Software as a Service (SaaS). The main benefit of SaaS is to reduce the complexity of having to configure and maintain software in-house. The SaaS cloud providers achieve economies of scale by building large software centers and then sharing resources among all of their customers. This identification is a key line of defense for the SaaS and cloud compute offerings. Virtualization provides a practical vehicle to transfer compute environments and share physical compute resources in the cloud. The idea of sharing a compute infrastructure with other students makes good economic sense [13, 16].

Because the solution is a shared environment, the administrator needs to ensure that students are identified properly and that no user has the ability to see or change another user's data. By securing student's own unique credentials, however, each user's files will be separate. No one else will be able to log into another account and delete the data.

A strong security strategy is a necessity, but it should not seriously impact performance. Encryption of data being sent to the server, and decryption of files called back from the server, should happen with little or no impact on the user experience, especially in the automation control systems. Ideally, it should all happen without the user noticing a thing. The model used in this paper offers the SSL (Secure Socket Layer) encryption through the KEPServerEX OPC and Communications Server functionality. Fig. 1 shows the security structure.

The user management system of the server controls what actions a student can take within a server project. The user properties dialog is used to configure the name, password and privileges available for each account. Teachers can select the authentication, launch and access security requirements through the security configuration utility.

Experimental verification of theoretical knowledge responds to need for accelerated acquisition and adoption of best practice techniques and methods and it increases the quality engineering education [2, 17– 19]. The author takes into consideration basic demands for design and education application of experimental laboratory exercises [11, 20]:

- Similarity of physical laboratory model with real industrial devices (plants).
- Miniaturization of dimensions, power input, etc.
- Good dynamical responses of output signals (quick reaction, short time constants).
- Unified input and output electrical signals (U = 0–10 V, I = 4–20 mA).
- Good possibility of connection with miscellaneous computers or alternative numerical unit (Programmable Logic Controller—PLC, Industrial PC—IPC, Industrial microcomputer—IMC)
- Availability of model function parts and their reasonable price
- Cooperation of students on design and production of laboratory stand (on the subjects, for instance Part project, Final project, Diploma thesis).

3. Pumping station platform

First laboratory kit is a model of pumping station built on Unitronics Vision280 controller. The Vision280 is a powerful PLC with a built-in HMI operator panel, comprising a 4.7′ graphic touch screen display and a customizable keyboard. The system has an Ethernet communication module and Modbus TCP/IP protocol implemented [14]. Additionally, SCADA software was integrated with the system to monitor and control the process. The system includes two constant speed pumps and the automatic control philosophy of this pumping station was as follows:

- If the suction level exceeds the ON-level during 5 seconds, the first pump starts.
- The running pump(s) aim for a certain target suction level. If the pump works and the level

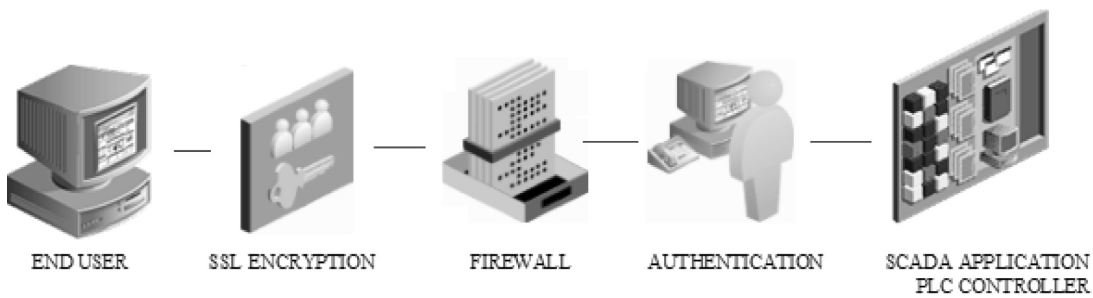

Fig. 1. A view of security structure for automatic control software system.

does not drop to the target level within some preset stabilisation time, the next pump will start.

- If water drops to a certain (minimum) level and more than 1 pumps are in operation, then one pump will switch off.
- If the OFF-level is reached, the last pump will switch off.
- If a certain pump switches off at the OFF-level, then another pump should start first when the ON-level has been exceeded again.

Every moment the dynamics of water inflow and outflow can be set. Additionally there is a possibility of breakdown simulation of any pump (the system is protected against the pump overfall and the lack of water by dedicated swimming magnetic sensors).

The work makes use of the tight construction container which holds 10 liters of water. Water circulation takes place by pumping water within two containers set one into another. The simulation of inflowing water is carried out by the virtual entry or in the case of manual mode by the regulated potentiometer.

The liquid level signaling device makes use of the phenomenon of current flow through water. The probes built in the supervised tank are the steering elements of the signaling device; the same probes are jointed to the relay. Probes are supplied with alternating voltage which prevents from erosion caused by electrolysis. It has two independent channels to which two level probes are jointed.

Sensitivity regulation is common for all channels and takes place step by step with the help of rotary switch. There are eight possible positions of the level of sensitivity. A student is modeling the system having contacts (K1 and K2) from two conductometric probes (S1 probe defines the minimal level while S2 probe defines the maximum level) (Fig. 3). Such function simplifies matches of automation of steering pump (Fig. 4).

To count and illustrate the actual level of liquid within the acceptable scopes defined by probes it is used piezoresistive transducer MPX50500. It is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a PLC controller with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog

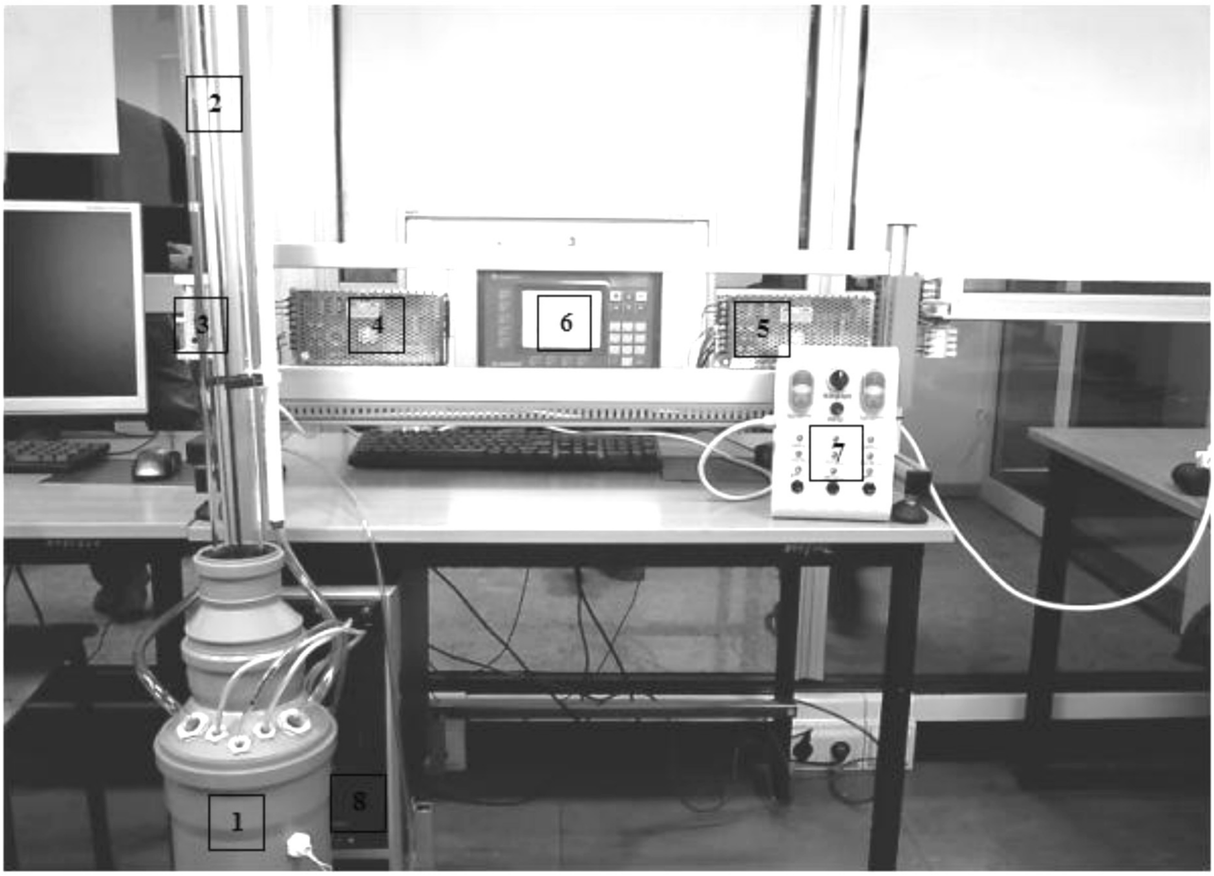

Fig. 2. A view of the pumping station hardware system. Where: 1—tank with two pumps, 2—two conductometric probes, 3—pressure sensor, 4—AC voltage transformer, 5—stabilized power supply, 6—PLC/HMI Unitronics Vision280 controller, 7—control panel with LED visualization, 8—PC computer (application server).

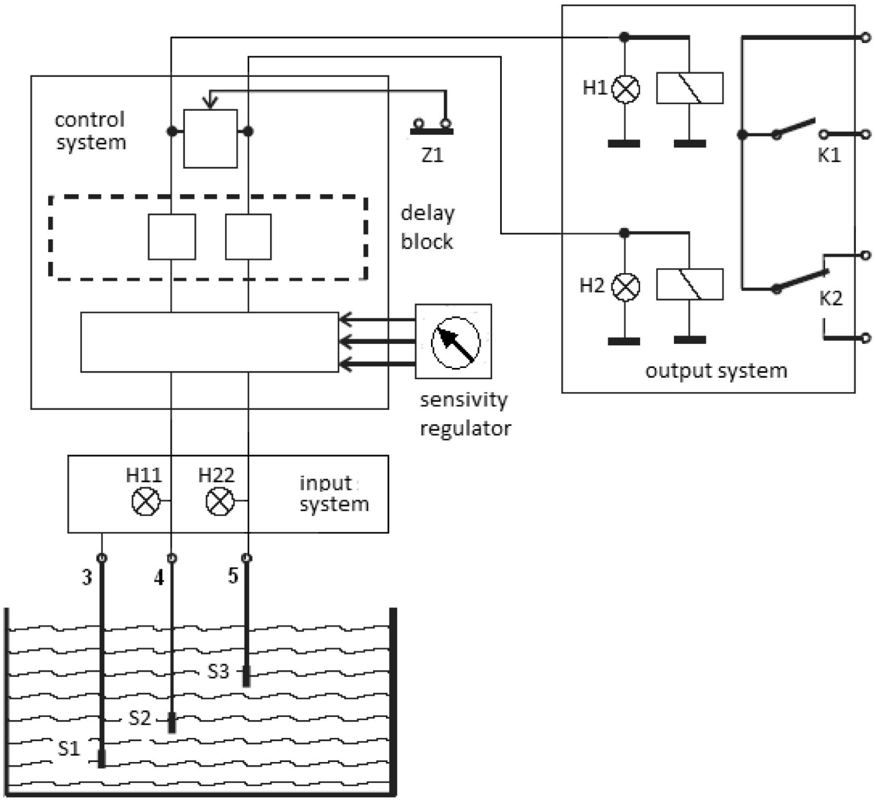

Fig. 3. Flow chart of conductometric liquid level pointer.

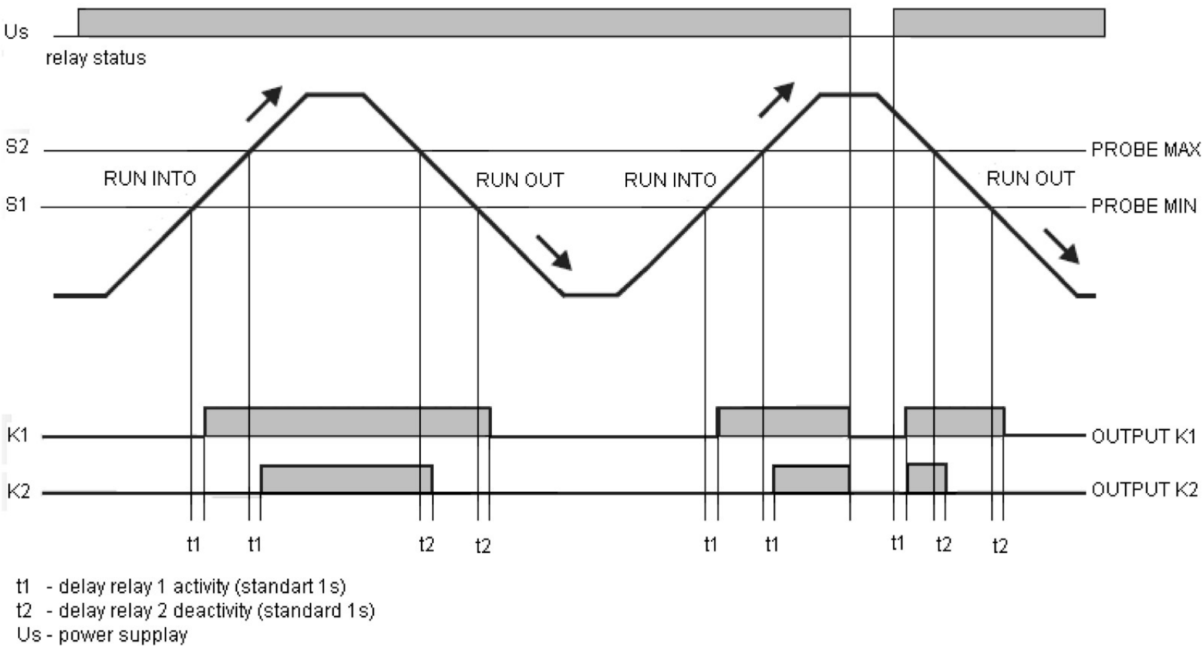

Fig. 4. Working schematic of conductometric liquid level pointer.

output signal that is proportional to the applied pressure. It is ideally fit for presented in this paper PLC pumping station model. The analog output value will saturate outside of the specified pressure range.

4. Supervisory control implementation

This remote laboratory is supported by Proficy HMI/SCADA—Cimplicity developed by GE Intelligent Platforms. It is an open-system software allowing the development of highly interactive HMI for remote control. It can communicate with locally and geographically distributed devices through communication protocols like OLE Process Control (OPC) and Modbus TCP/IP. Cimplicity is a client/server based visualization and control solution that helps visualize PLC operations, perform supervisory automation and deliver reliable information to higher-level analytic applications. This SCADA has state-of-the-art process displays, diagrams, and symbols [6, 14].

The server is an object-oriented software with database, alarm detection, and scaling functions. It can process trend history, which is scalable in time and can display multiple signal trends, provides students the opportunity to experience a SCADA system, and its application to the management, supervision, and control of electrical and mechanical systems [5, 6]. Cimplicity allows students and management team to make more informed decisions with its real-time visibility technology along with actually making the change through its proven and robust control engine.

There is a direct graphical feed-back during remote controller programming and SCADA visualization. Students can manage PLC by attractive interface from any location. User can simultaneously run both PLC programmer and SCADA client application on the same computer and make the simulation. During the experimentation phase, every change in the input variables is immediately shown in the graphical user interface, so user can see instantly how the system is behaving. After completing the experimentation, student can download the experimental data and reveals essential characteristics of a pumping station. The suggested architecture helps improve students' skills on SCADA systems in use in industry.

Students must register to access the virtual laboratory SCADA panel by using a dedicated student password. The client accesses the lab via the web server through a OPC server URL (Uniform Resource Location) address, which activates Unitronics Remote Operation server application and SCADA smart access feature. When the client is logged on to the system, the web server redirects the clients to SCADA. Data exchange occurs according to the request-response method. The HTTP client sends a request to the HTTP server which processes it and returns the response. The client and server establish a connection via the Ethernet interface for data exchange [8–9].

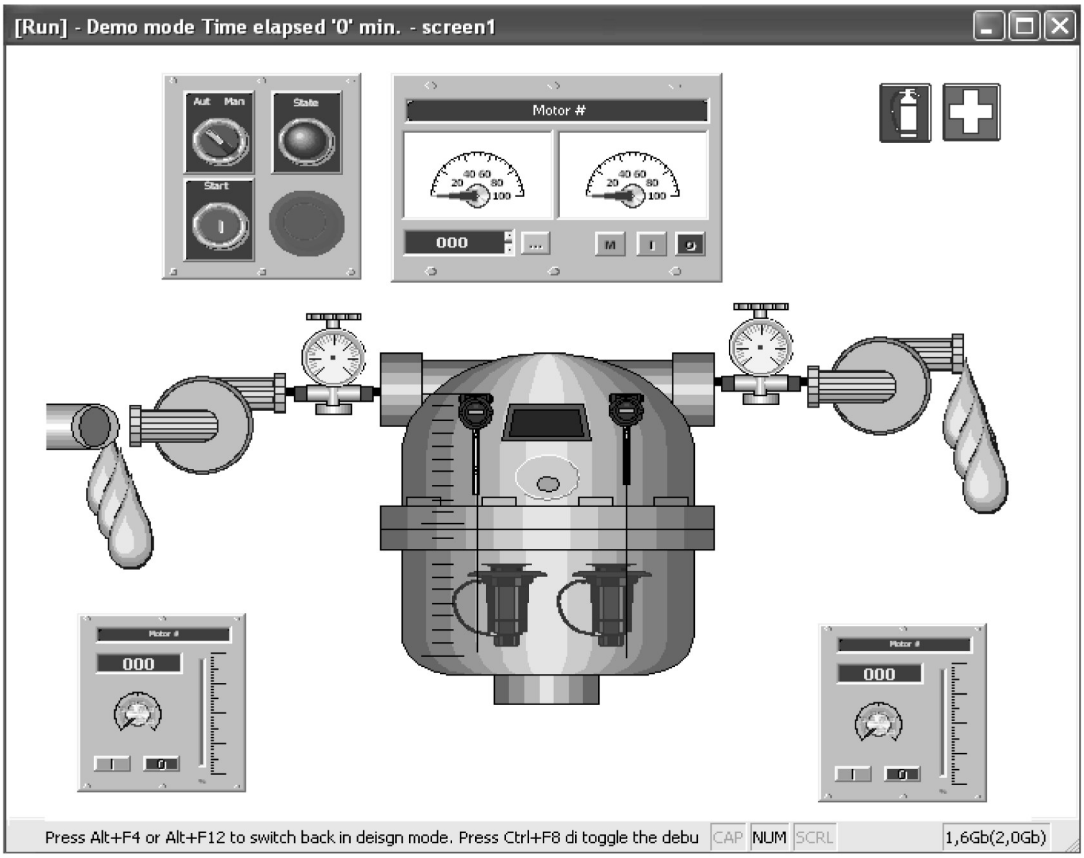

Fig. 5. An example of the SCADA screen used in discussed laboratory kit.

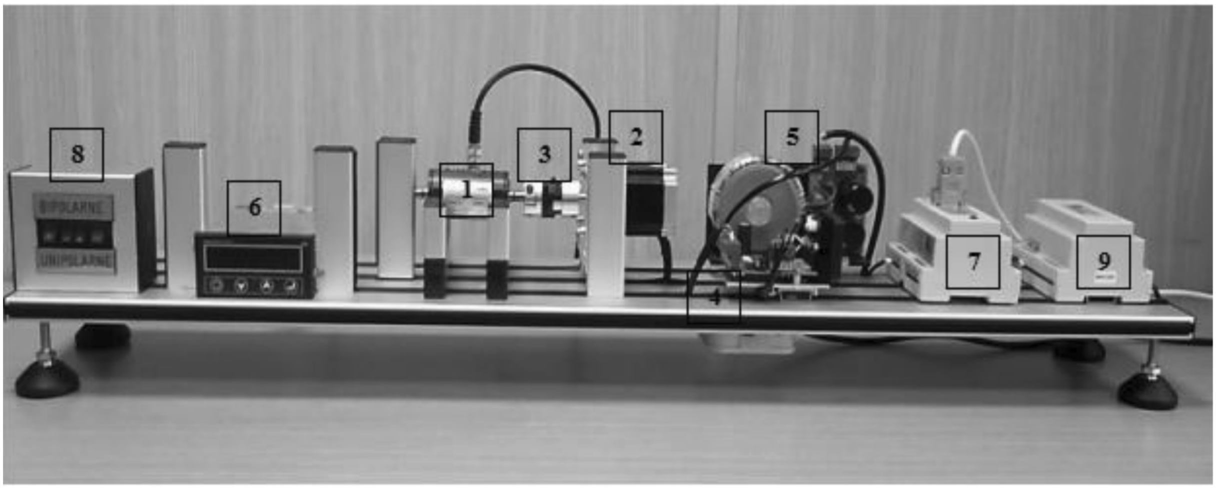

Fig. 6. A view of stepper motor system hardware. Where: 1—torque sensor DFM22, 2—stepper motor type 57BYGH804, 3—mechanical clutch, 4—stepper motor controller SMC-64, 5—AC voltage transformer, 6—torque metter MD100M, 7—digital pulse generator MI 1.8.8, 8—bipolar/unipolar mode switch, 9—stabilized power supply.

5. Stepper motor control system

Stepper motors are widely used in electromechanical micro machines. We actually come across them every day, although we may not realize this. They find application in all kind of electromechanical devices in which high accuracy and precision is required. To those groups many appliances from our everyday life can be numbered along. For instance: computer hardware like printers, scanners, cd-roms, dvd-roms, hard drivers, multimedia devices: video players, positioning of cameras, potable cd players; medical and laboratory equipment; positioning devices; etc. Stepper motors are, as proven, today technology which works basing on transformation of electrical impulses into discrete mechanical movements [21]. It is achieved through electromagnetic field which acts as a link between the electrical and the mechanical side of the devices. As a result of applied sequence of electrical impulses, the shaft of the stepper motor rotates. It makes discrete steps which size and frequency is tightly related to the character of the steering impulses. The more frequent the impulses to the input side of the motor are delivered, the bigger the angular velocity of the shaft becomes. Furthermore, the total value of an angle closely depends on the amount of impulses applied. In the same way the direction of the angular position of the motor is determined by the sequence of electrical pulses from the trajectory generator [20, 22].

The laboratory kit presents stepper motor type 57BYGH804 made by Wobit (Fig. 6). It is a two-phase motor with a step size 1, 8° and torque 1, 2 Nm. The features of the motor are being examined through the measurement of the dynamic torque and its comparison to the reference value, through accuracy of the DFM22 sensor. For the steering purposes the SMC-64 power controller is used. This driver is designed for efficient work with a two-phase motor and gives the possibility not only for operating with the full step mode but also with microstep one in ratio 1/2, 1/4, 1/8, 1/16 and 1/32 [21]. The controller is connected to the industrial electronic (digital) pulse generator MI 1.8.8, which interacts with the user remote control in setting the values and setup the stepping motor driver for controlling the motor. These parameters are following: initial angular velocity, maximal acceptable velocity, acceleration and interchangeably the number of steps or the constant value of an angular velocity without limitations on steps. View of this tool is presented on Fig. 7.

The check-up of execution of the given task is possible thanks to torque sensor DFM-22 rigidly connected to the shaft of the stepper motor. The sensor sends information to the output device which is torque meter MD 100M. The stepper motor is a plant of an open-loop control system. That means there is no feedback needed for the accurate control of the position and velocity. Used in laboratory kit torque sensor was designed to real time torque measure on static and moving axles in both directions. Due to WINMI Environment students can define full stepper motor trajectory in unipolar or bipolar control mode, and observe dynamic torque characteristic in relation with control parameters. Another target of the research is to find out how the motor and its controller behave when it comes to change from the full step working to the microstep one, like 1/2, 1/4, etc. Used controller has protected block implemented by administrator, which detects any abnormal system condition and execute the necessary action to prevent further deterioration

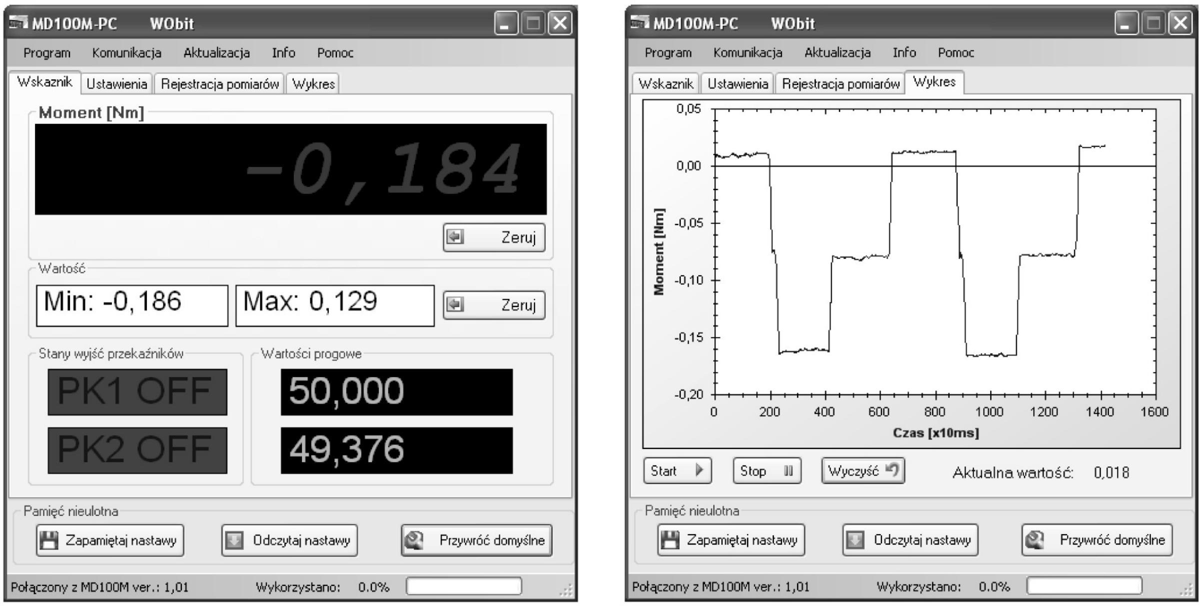

Fig. 7. Measurement and chart windows of torque meter MD 100M application.

of a disturbance or damage to equipment. Some limitations were placed on the WINMI program to protect the motor from overloading and rapidly switching bipolar and unipolar modes.

This laboratory kit shows students that the working of the stepper motor installation is not deprived of mistakes [22]. It is, however, very difficult to state whether the errors are implication in the function of the stepper motor itself or of the control system. If the problem is connected with the motor, it means that it loses the electric impulses. When, however, it is a case of control, it means that the stepping motor driver does not generate the correct number of impulses or it does but in a wrong sequence causing disruption in stepper motor's operation [21, 23].

6. Pedagogical results

Interested form of automatic process visualization maintains a high student motivation during the courses and foster students' ability to cope with new algorithm problems [24]. The same problem could be solved by different way, so students are free to decide on the PLC program structure, SCADA layout configuration and the sensorial system.

Presented laboratory kits are utilized for practical exercises in chair specialization subjects 'SCADA Systems and Industrial Networks' and 'Programming of Industrial Controllers'. In this paper only two kits are presented, but in discussed laboratory there are other kits which present different automatic equipment (data transmission using laser technology, closed-circuit television, 3G intrusion detection system, remote control inverters, etc.) Developed kits have a significant impact on the efficient use of purchased equipment and software. Log in to the virtual laboratory is set according to the weekly schedule of the real occupancy laboratory.

The Remote Control Systems Applications laboratory has been tested with a group of thirty students during the final semester of course 'Programming of Industrial Controllers'. All students were requested to fill in an anonymous questionnaire to evaluate their perception of prior and acquired competencies. The pedagogical goal of these experiences was that of having the students acquire the sets of competencies listed in Fig. 8. The average results are graduated from 1 point (minimum) to 10 points (maximum). This indicates that the proposed tools and methodologies can achieve a good pedagogical result for students with different initial competence levels. Especially visible virtue is self-confidence increase in the face of new automatic control problems.

Additionally, Table 1 presents the objectives and requirements for students pursuing work in the virtual sets described in this paper. In the final examination, just 74% of students obtained better results compared with the previous semester during which the classes were conducted only with the hardware. Students, in general, reported that there was interesting intellectual substance in the activities: 79% of the students stated that they had found the laboratory activities intellectually stimulating, while 74% of the students noted that the laboratory remote activities had helped deepen their understanding. Such results indicate that the students did have a valuable learning experience in the Remote Control Systems Applications laboratory.

Table 1. Virtual Laboratory objectives and requirements

	Pre-laboratory Module	Data collection module	Report submission
Objectives	• review stepper motor fundamentals • SCADA and PLC programming course	• familiarize students with test stand and instrumentation • collect data	• conduct experiment and theoretical analysis of the stepper motor control, PLC and SCADA systems • prepare a laboratory report
Student requirement	• stepper motors fundamentals • difference between bipolar and unipolar control modes • method of measuring torque • ability to create SCADA layouts • PLC programming language experience	• watch laboratory video • collect all relevant data points for all experimental • create PLC control program to control pump station in optimal way • implementation SCADA layouts	• calculate theoretical stepper motor performance parameters using experimental data • OPC server management and define data acquisition module • submit a laboratory report

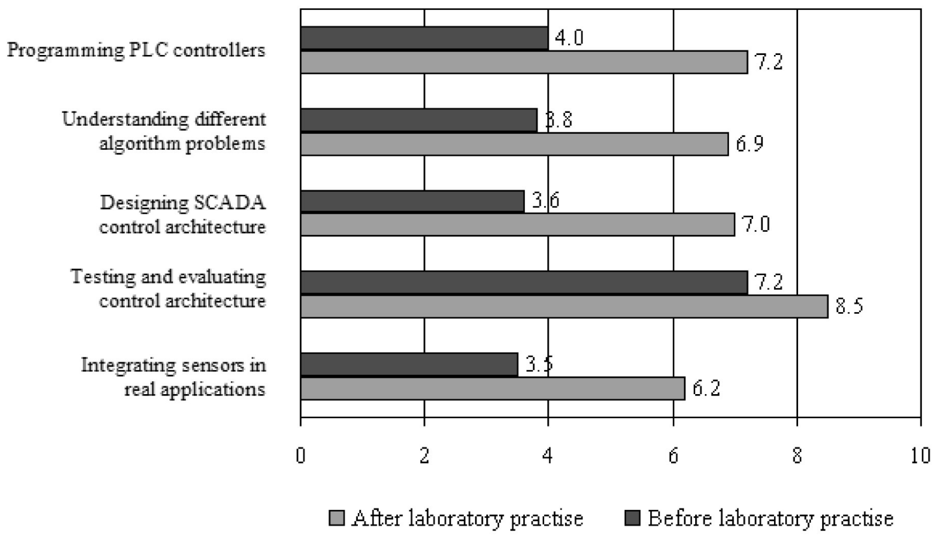

Fig. 8. Students' perception of acquired competencies.

Most students (88%) also reported finding the informal demonstrations after the laboratories to be interesting and motivating. The majority (76%) stated that they were more interested in electrical and computer engineering as a result of their experiences.

At the end of the course, a poll was taken to verify the satisfaction of the students. 93% of the students considered the virtual laboratory to be a good tool to learn the automatic control systems and 7% considered it to be useless. The practical nature of the experience also received explicit positive comments.

7. Conclusions

In the field of automation, communication and data visualization technologies play an important role. The laboratory kits designed and presented here are a combination of the virtual transmission system with real equipment, thus enabling the students to understand the concepts of a remote telemetry and its functionalities.

For all the new benefits that come with the remote learning, there are also a new set of risks. Each of the laboratory systems comes with a unique set of benefits and security challenges. The author presents the security model to ensure sharing of equipment with a high level of safety protection equipment.

The effectiveness of any virtual educational tool depends upon its ability to adequately replicate a real experience. The Control Systems Applications laboratory is used for virtual demonstration of function multilevel control and measurement support PLC/HMI and SCADA on the web environment. Such educative experiences allow a student to better understand the theoretical aspects of the automatic discipline in addition to its integration with practical knowledge. The virtual laboratory can be used with a traditional book as well as with a hypermedia learning system. The combination of the tutorial and the virtual laboratory constitute a bridge between theoretical lessons and laboratory classes.

The research and accumulated experience show that using this tool, undergraduate technical students improve their performance and increase their efficiency in the laboratory. Students were enthusiastic about the remote activities that followed the formal laboratory sessions. At present the virtual laboratory is being used on continuous education courses for electrical engineers with very good results and educators find the system very useful.

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