VIRTUAL CONTROLLERS IMPROVE INTERNET-BASED EXPERIMENTS ON SEMI INDUSTRIAL PILOT PLANTS

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Abstract: TCP/IP-based access to pilot plants for research and educational purposes in the field of distributed process control was presented. Five especially chosen pilot plants, having permanent importance in process biotechnology and heat transfer have been developed. First distributed control system (especially useful for remote experiments via Internet) has been presented. A new idea of application of TCP/IP-connected virtual controllers, which improves such experiments, is presented, discussed and demonstrated in the paper. *Copyright © 2005 IFAC*

Keywords: Virtual controllers, Distributed process control; Ethernet-based networks; Internet-based control; pilot plants; real-world experiments; remote-access laboratory.

1. INTRODUCTION

Nowadays automation systems designed for industrial plants are complex, distributed and include a lot of different components such as control equipment, control software and communication nets. A growing need of appropriate research and education techniques for such complex control systems results in more and more sophisticated methods and tools. Although simulation-based experiments are not expensive, the simulation experiments include only this part of real world, which was modelled. Hence, such a method of investigations is suitable for initial tests. And therefore only testing control software and hardware on real-world processes give results that take into consideration all possible problems occurring in industrial reality. Unfortunately, experiments on real-world industrial processes are not only very expensive, but are also limited by possibility of production disturbance and financial losses.

A concept to use specialised pilot plants – especially designed for control systems investigations can be considered as some kind of compromising solution. This method of experiments is less expensive than those carried out on industrial processes during normal production and, on the other hand, ensures almost the same possibilities that experimentation on real full-scale industrial processes. Several major assumptions define application of pilot plants as real-world control plants for research on control in general and especially for process control education. The most important are the following.

- Although process equipment (tanks, pipes, heaters, heat exchangers, aerators, settlers etc.) can be designed and constructed in appropriate scale, all control and measurement instrumentation (valves, actuators, pumps, sensors, transmitters, controllers etc.) should be industrial instruments existing on the market.
- If a process device designed for industry production is suitable for a given pilot plant, it should be preferred rather than similar, especially made for a laboratory.
- For examination of distributed control systems, a number of pilot plants should be really distributed in space – for example the pilot plants can be built over several different laboratory rooms.

Several pilot plants exist in most of control laboratories (see e.g. Lee et al., 2000). An idea and realisation of a set of pilot plants for testing distributed control systems is presented here.
Although the experiments on pilot plants are less expensive than in the industry, nevertheless the costs of such experiments are very significant for universities. Hence, it can be very interesting to expand the number of participants (typically the biggest number of experimenters taking part personally in the laboratory room can be about ten). Therefore appeared a growing importance of remote access to investigations on real-world plants via Internet/Intranet (see for example Bequette and Ogunnaike, 2001; Gatzke et al., 2000; Metzger, 2001b; Overstreet and Tzes, 1999; Parkin et al., 2002; Saanchez et al., 2002; Srinivasagupta and Joseph, 2003).

A shortened description of five especially chosen pilot plants, which can be treated as control plants, has been presented in the paper. All these plants deal with two major technical areas, having permanent importance – namely: process biotechnology and heat transfer. All presented plants were designed and carried out in the Control Systems and Control Instrumentation (CSCI) Group at the Institute of Automatic Control (IAC) over last years. Recently a distributed control system (especially useful for remote experiments via Internet) has been designed and developed – and it is presented in the paper, as well. Finally, a new idea of application of TCP/IP-connected virtual controllers, which improves such experiments, is presented, discussed and demonstrated in the paper

2. PILOT PLANTS

2.1. Heat distribution network

The industrial scale heat distribution pilot plant was developed and worked out at the laboratory of the CSCI group (Metzger et al., 1997). This pilot plant has a structure of a real heating system with flexible connections of the heat receivers. This structure itself was developed on the basis of the real industrial heat distribution plant and it consists of three heat exchangers of different type, the mixing tank, the electric water heater and the several water circuits. The most important part of this installation, which also ensures heating and cooling of jacketed reactor is presented below.

2.2. Hybrid exothermic reactor.

Continuous and batch exothermic reactors considered as the control plants are ones of the most challenging control plants. A concept (Metzger, 2001a) of a pilot plant (see Fig. 1) is based on the following.

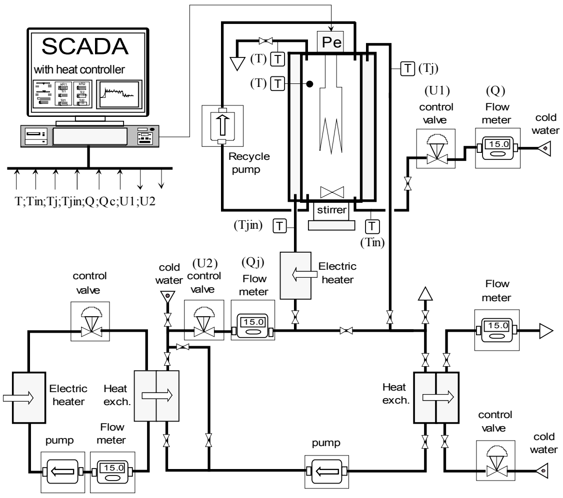

Fig. 1. Simplified scheme of the pilot exothermic reactor embedded in heat distribution network.

In the real world plants the equipment for measurement of the substrates and products concentrations are very expensive and in the majority of cases it is impossible to obtain the continuous or discrete measurement data of these parameters. Therefore only the inlet and outlet temperature can be considered as the controlled variables since the temperature can be easily measured on-line. When only temperature measurement data is accessible and the temperature inside the reactor is the controlled variable, the process of the cooling of the exothermic chemical reactor with the application of the cooling jacket can be considered as the heat exchange process. Therefore it is possible to carry out the process only with the water inside the reactor tank. The heat, produced in the reactor due to the exothermic chemical reaction that should take place inside the reactor, can be simulated by means of the computer-controlled electric heater (see Fig. 1). This approach allows us to ensure the low costs of the experiments and to avoid the problem of the security standards due to the operating of the chemical reaction. Easy programmable controller for such hybrid exothermic reactor has been proposed by Metzger (2003b).

2.3. Neutralisation pilot plant

The modern neutralisation pilot plant has been designed (Metzger and Choinski, 1999) and worked out at the laboratory of the CSCI group. The installation itself is a scaled model of a real industrial neutralisation plant with two neutralisation reactors (stirred mixers) and with flexible connections of the injection pipes. There is also a possibility to carry out the in-line neutralisation process with the application of the in-line injection. The design features allow this installation to be considered as a first stage of the complete neutralisation and biological wastewater treatment plant that is developed at our laboratory. The simplified scheme of the neutralisation pilot plant is presented in Fig. 2.

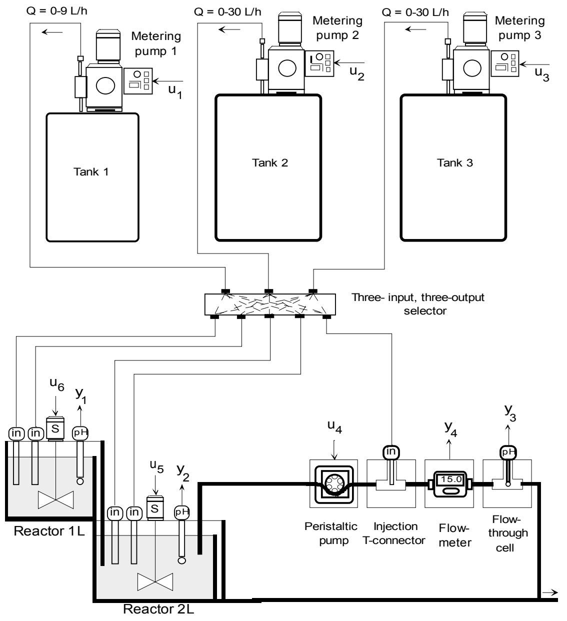

Fig. 2. Neutralisation pilot plant with control and measurement instrumentation.

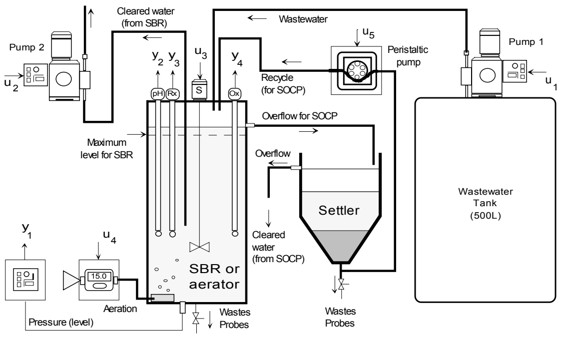

Fig. 3. SBR and SOCP processes for biological wastewater treatment.

2.4. *Sequentially operated biological wastewater treatment plant*

The classical continuous activated sludge process must contain at least two (aerobic and anoxic) reactors for both carbon and nitrogen removal.

Although such classical processes are widely used, sequentially operated continuous processes (SOCP) and sequencing batch reactors (SBR) are an attractive alternative. In these processes, carbon and nitrogen removal can be accomplished in only one bioreactor in which the aerobic and anoxic phases are periodically sequenced. In comparison to classical continuous biological process when the process can be carried out without any control system, the sequences of the periodically operated process must be controlled and thus the development of the SBR (or SOCP) as a real-world pilot plant can be very interesting for the real-world experiments.

A concept (Metzger, 2003a) of a pilot plant is based on the structure presented in Fig. 3. A special 30-liter SBR with appropriate fitting system as well as the pH, Redox and dissolved oxygen continuous measurements is the main part of the plant (Choinski, 2003). It can be noticed that with very little financial costs the SBR reactor can be augmented with secondary clarifier and in that way we can obtain the SOCP process in witch the same reactor used as SBR can be applied as continuous aerator for sequentially operated continuous process.

2.5. *Batch sedimentation pilot plant*

An experimental batch sedimentation pilot-plant has been designed (Metzger and Nocon, 2003) and developed in the CSCI Group. This pilot-plant is schematically shown in Fig. 4. The sedimentation process takes place in the settler where the level of liquid is measured by a pressure transducer. The cleared water is removed from the settler by a peristaltic pump and the suction nozzle is mounted on the float. A turbidity sensor is mounted on the same float and is used to indicate the presence of solids in the water being removed from the settler.

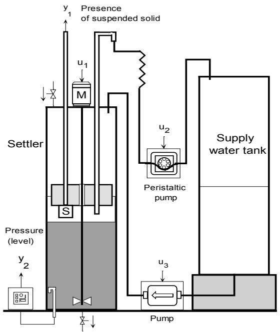

Fig. 4. Batch sedimentation pilot plant.

2.6. *Realisation*

All of the five pilot plants were constructed and made at the CSCI over last years. Overview of the one of these plants is shown in Fig.5 (just for to demonstrate almost industrial scale of the plants).

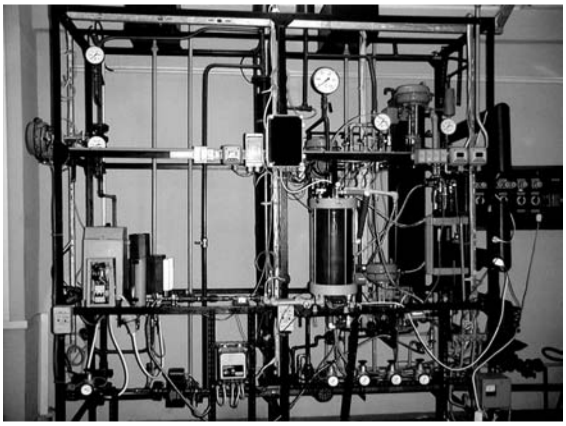

Fig. 5. Overview of the heating network with embedded exothermic reactor.

3. DISTRIBUTED CONTROL SYSTEM

Two real-world distributed control systems are being developed in the CSCI Group at this time. Both are designed for control of our pilot plants. The first system (see Fig.6) is based on National Instruments (NI) hardware and software and has already been used over the last years. This system uses only one standard of data transmission based on the Ethernet. The SS2 Switch 3300/100Mhz equipment allows switched communication using TCP/IP and UDP protocols. Three FieldPoint type controllers (all of them are the newest FP-20XX RT series with real-time operating system and the www capabilities) allow distributed control and monitoring. The FP-1000 distributed I/O with the FP-2010 RT controller can be treated as an illustrative example of distributed modular controller.

The system can be programmed using NI LabVIEW platform, and that is why it will be very convenient for research and teaching. The supervisory control and information system, presented in Fig. 6, will also be an experimental plant for comparative investigations of data transmission capabilities. Control and monitoring executable applications can be run on a PC computers (in the soft real-time mode) and on the FP-RT type controllers (in the hard real-time mode). It should be also noticed that NI FP-20XX RT series controller is an industrial PC running under hard real-time operating system.

Although the industry standard signals are connected to appropriate controllers, the control and monitoring applications can be distributed over the local Ethernet-based control network and over the Intranet/Internet. Five remotely controlled web-cams augment the capabilities of the control and monitoring system based on distributed FP-RT. Those capabilities can be very useful especially for educational purposes.

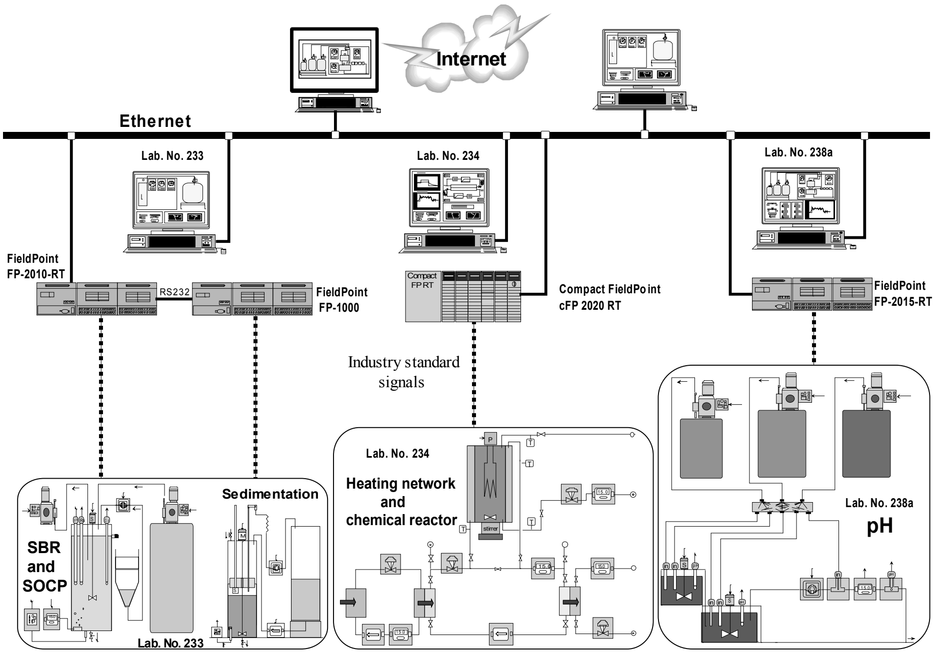

Fig. 6. Distributed control system based on the FieldPoint equipment.

4. VIRTUAL CONTROLLERS AND INTERNET-BASED EXPERIMENTS

The traditional controller proposed by most of the producers existing on the market is a self-containing instrument with a limited number of changing structure capabilities and with fixed user interface features (such as sliders, pushbuttons, gauges and indicators). All of these capabilities and features are designed and fixed by the producer. Programmable modular controllers have similar features, in which the producer fixes programming capabilities. The user-defined PC-based controller, while also equipped with appropriate professional features, can be a very interesting, low-cost alternative to controllers from commercial producers. We can refer to this kind of controllers as the virtual controllers (Metzger, 1999). The NI FieldPoint system presented above is especially suitable for application of such virtual controllers running both on the PC computers and on the NI FieldPoint modules. Although the physical signals are connected to the system by the industry standard the virtual applications can also change data using TCP/IP connection.

At the CSCI group several virtual controllers have been developed in recent years for educational and research purposes such as for example single PI, PID controllers as well as advanced PFC, GMC and self-tuning PID controllers. All of them are equipped with standard professional features such as antireset windup and bumpless M/A switching. Finally virtual versions of professional programmable multifunction controllers such as for example well-known Sipart DR 24 from Siemens are also developed. All of these virtual controllers can be used for control in DCS presented in Fig. 6.

An original conceptual contribution of this paper deals with a new concept of easy performed control experiments on pilot plants with an application of virtual controllers.

The architecture of basic system for each of the processes (a pilot plant) is presented in Fig. 7. The system containing several components connected by TCP/IP localhost data transmission runs on one PC or on one FieldPoint, which also ensures industry standard process connections. The central component – a SCADA system ensures process communication, monitoring and visualisation as well as can work as TCP/IP server for chosen signals. The control algorithms can be embedded in the SCADA system but it is more useful to connect different virtual controllers (only one in time) by localhost. In such a way the virtual controllers are applications separately developed and compiled. Although formally the TCP/IP connection is not time determined the localhost transmission do not change the control properties.

The architecture of the control system with a possibility of remote performed experiments is shown in Fig. 8. The SCADA system and the virtual controller actually connected should be equipped with remote operating panels as http pages accessible by operator-defined ports and for operator-defined IP remote workstations. The control is locally performed, whereas monitoring, visualisation and setting can be carried out from other computers in the Intranet or by the Internet. The experimenter can additionally observe some results of the control by web-cams (for example water level or LED lights on controllers) as well as can store the control responses on HD for presentations. In principle such kind of experiments is reserved for staff only.

The architecture of the system dedicated for students or other distant experimenters is presented in Fig. 9. A professional main SCADA system has been developed by the staff. This SCADA system offers all controls and indicators in local mode as well as the web-based operating panel remotely for staff. This system has the possibility of staff-defined signals (input/output) to be offered on the TCP/IP server using the staff-defined TCP/IP port. Only authorised students know the right sequence of signal transmission, the staff-defined number of the port, and staff-defined password. Students should design and develop their own remote SCADA applications (as clients for main SCADA) for appropriate experiments. At the moment three typical remote SCADA systems can be distinguished: a SCADA system with manual controls, a SCADA system with embedded controllers and a SCADA system with the TCP/IP server for controllers programmed as separate executables (see Fig. 9). These controllers can be connected to the remote SCADA systems using also the "localhost" connection. The programming of such student's applications can be included in the teaching procedure. In the final phase, students perform remote experiments on the real-world pilot plants and observe and store some results of the control.

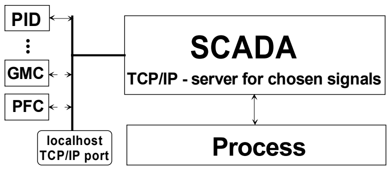

Fig. 7. Basic control system without remote possibilities.

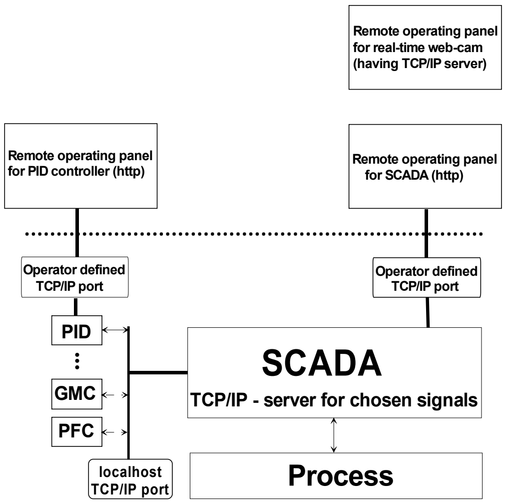

Fig. 8. Architecture of the control system with remote capabilities

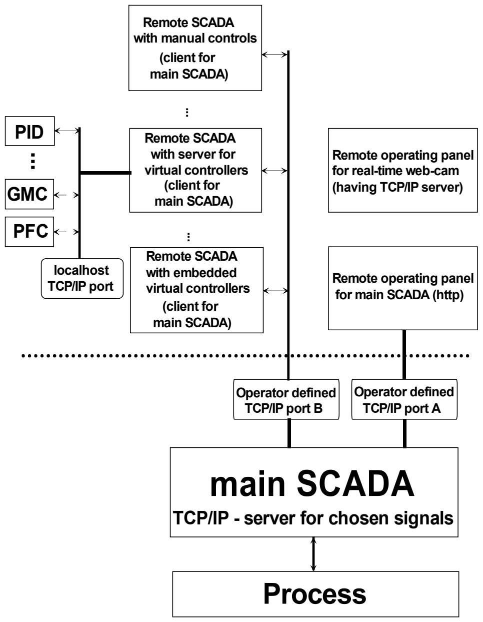

Fig. 9. Architecture of the system with remote experimenter-programmed components.

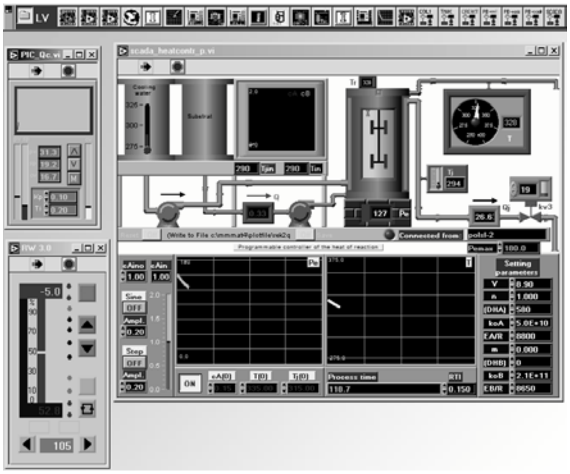

Fig. 10. Typical screen containing the SCADA HMI and two virtual controllers.

Although formally TCP/IP connection is not time determined as well as the control is performed remotely the control responses performed via the Intranet are the same as performed locally (the Internet change control behaviour but not dramatically for short horizon responses). The experimental investigations of influence of TCP/IP connections to control responses have been presented in (Metzger and Plesowicz, 2004). Fig. 10 shows a typical screen with three windows: the main SCADA window and two virtual controllers – the single virtual PI and programmable virtual RW3 (similar to commercial Sipart DR24).

5. CONCLUDING REMARKS

The continuously expanding laboratory of real-world pilot plants has been developed over the last years. The first distributed control system based on the National Instruments FieldPoint standard (especially useful for remote experiments via Internet) has been designed and developed. A new concept of easy performed control experiments on pilot plants with an application of virtual controllers evidently improves research and teaching capabilities and therefore becomes attractive and convenient. The remote data monitoring is possible for all interested in, as well as the view from five remotely controlled web-cams, whereas only authorised users can exert the control.

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REFERENCES

Bequette, B.W. and B.A. Ogunnaike (2001). Chemical Process Control Education and Practice. *IEEE Con. Syst. Mag.*, April, pp. 10-17.

Choinski, D. (2003). Design of SBR for a pilot plant. Internal Rapport.

Gatzke, E.P., E.S. Meadows, C. Wang and F.J. Doyle III (2000) Model based control of a four-tank system. *Computers & Chemical Engineering*, Vol. **24**, pp. 1503-1509.

Lee, P.L., R.M. Allen, G.R. Cole and S.S Shastri (2000). A modular laboratory for process control and process engineering. *Journal of Process Control*. vol. **13**, pp. 283-289.

Metzger, M., P. Laszczyk and K. Pasek (1997). Industrial-scale heat distribution pilot plant. In: *IAC – Internal Activity Report 1995-1996*. Edition I&D Gebka, Gliwice, pp. 32-36.

Metzger, M.(1999). Application and experience with virtual controllers. In Simulation in Industry ESS99, SCS Publishing House, pp. 325-328.

Metzger, M. and D. Choinski (1999). Neutralisation pilot plant. In*: IAC – Internal Activity Report 1997-1998*. Edition I&D Gebka, Gliwice, pp. 56-58.

Metzger, M. (2001a). Pilot exothermic batch and continuous reactor. In: *IAC – Internal Activity Report 1999-2000*. Edition I&D Gebka, Gliwice, pp. 73-75.

Metzger, M (2001b) TCP/IP-based virtual control systems – a low cost alternative for realistic simulation of control systems. Proc. of the 13th SCS European Simulation Symposium on Simulation in Industry, Marseille, pp. 140-143.

Metzger, M. (2003a). Pilot switcheable SBR and SOCP processes for biological wastewater treatment. In*: IAC – Internal Activity Report 2001-2002*. SUT Editions, Gliwice, pp. 80-82.

Metzger, M. (2003b). Easy programmable controller for hybrid exothermic reactor. Proceedings of the IFAC Workshop on Programmable Devices and Systems (PDS 2003), Ostrava, pp. 69-74.

Metzger, M. and W. Nocon (2003). Batch sedimentation pilot-plant. In*: IAC – Internal Activity Report 2001-2002*. SUT Editions, Gliwice, pp. 85-86.

Metzger, M. and P. Plesowicz (2004). Experimental evaluation of TCP/IP-based control systems. Proc. of the 10th IEEE International Conf. on Methods and Models in Automation and Robotics, Miedzyzdroje, pp. 1165-1170.

Overstreet, J.W. and A. Tzes (1999). An Internet-based real-time control engineering laboratory. *IEEE Control Systems Magazine*, October 1999, pp. 19-34.

Parkin, R.M., C.A. Czarnecki, R. Safaric and D.W. Calkin (2002). A PID servo control system experiment conducted remotely via Internet. *Mechatronics*, Vol. **12**, pp. 833-843.

Sanchez, J., F. Morilla, S. Dormido, J. Aranda and P. Ruiperez (2002). Virtual and remote control labs using Java: a qualitative approach. *IEEE Cont. Syst. Mag,* pp. 8-20.

Srinivasagupta, D. and B. Joseph (2003). An Internet-mediated process control laboratory. *IEEE Cont. Syst. Mag.*, Febr. 2003, pp. 11-18.