

The Development and Implementation of a Thermal Process Trainer for Control and Measurement via the Internet

MILAN MATIJEVIĆ,¹ MILADIN STEFANOVIĆ,² VLADIMIR CVJETKOVIĆ,³ VLADIMIR JOKOVIĆ,¹ NENAD BABAJIĆ,¹ MIROSLAV RAVLIĆ,¹ SNEZANA NESTIĆ²

¹Department for Automatic Control and Applied Mechanics, Faculty of Mechanical Engineering, Kragujevac, Sestre Janjic 6, 34 000 Kragujevac, Serbia

²Department for Production and Industrial Engineering, Faculty of Mechanical Engineering, Kragujevac, Sestre Janjic 6, 34 000 Kragujevac, Serbia

³Faculty of Science, Institute for Physics and Informatics, Kragujevac, Radoja Domanovića 12, 34 000 Kragujevac, Serbia

Received 3 December 2010; accepted 25 March 2011

ABSTRACT: In engineering education, it is very important to provide solid knowledge and practice to students in order to deal with architectures, mechanisms, and algorithms for the control of processes. In this article we will present the concept, detailed technical requirements, description, implementation, and verification of a process (thermal) trainer. In addition three possible educational tasks will be presented with a developed software infrastructure for the remote control of a laboratory set-up via the Internet. © 2011 Wiley Periodicals, Inc. *Comput Appl Eng Educ*; View this article online at wileyonlinelibrary.com/journal/cae; DOI 10.1002/cae.20543

Keywords: process trainer; web laboratory

INTRODUCTION

Education in many different engineering fields demands laboratory work in order to provide practical knowledge and skills to students and to demonstrate different real life processes. It is important to provide solid knowledge and skills to engineering students (especially in the field of industrial engineering, process engineering, and control engineering) to deal with architectures, mechanisms, and algorithms for the control of specific industrial processes. Many laboratories have specific process trainers for training in the field of process and control engineering. Other laboratories use different process trainers enabling

their remote control in order to provide a web-based industrial process control laboratory [1–4]. The Internet provides great potential for the high-level control of process plants, so in many cases the knowledge and experience gained through process trainers (remotely controlled via the Internet) could be easily implemented into real life problems [5].

Due to the need for quality training of engineers there is a need for the construction of a process simulator or laboratory model with different educational roles. Of course there are a number of commercially available process trainers [6,7]. On the one hand, the main goal of this article is to present the design and implementation of a process trainer (temperature process with time delay) with similar performances as commercially amiable models, but cheaper and with some additional specific features. On the other hand, the complete development documentation as well as a developed model (and its

Correspondence to: M. Stefanović (miladin@kg.ac.rs).

implementation in an educational process) provides opportunities for the improvement of teaching and learning for process and control engineering.

In this article we will present the design and implementation of a process trainer which should provide:

- Support for learning and training in the field of process control to technicians [8], process operators, and control engineers.
- Practical training for students at all levels.

The trainer should demonstrate closed and open loop continuous control, two-step control, as well as other features for the demonstration of different control approaches. In this article we will present the concept of the technical system, detailed technical requirements as well as a description and the verification of the system. In order to demonstrate usability of such a system, three possible educational tasks will be presented.

Additionally, it is important to provide the opportunity to control the laboratory training system (process trainer) via the Internet in order to provide the remote control of an experiment and the remote acquisition of results. Providing the opportunity for distant control of this laboratory equipment makes this setup part of a web laboratory environment. Remote web-based laboratories may also allow students, trainees, and even researchers, in different locations, to carry out researches and design work co-operatively and remotely at the same time. Besides, web laboratories with remote control of experiments could be used as a very useful educational tool in classical or blended (mixture of classical and e-learning approaches) learning environments.

DEVELOPMENT AND IMPLEMENTATION OF LABORATORY MODEL PT 400

Concept of the Technical System

The general concept for this technical system is its flexibility and a much lower price compared to referential devices with similar performances. Besides the technical model, a software solution has been developed for supervision and control and it is part of the complete training system. The developed model allows manual and automatic control using PLC (Programmable Logical Controllers), a microcontroller system, and a personal computer with an accompanied A/D and D/A interface. It is possible to perform testing and experiments with different hardware and software platforms as well as testing of different control algorithms. The laboratory model enables the testing of the effects of different sensorial groups at the same moment. It is very important to introduce the practical realization of theoretical models, as well as safe work on real systems to students. This is a way to introduce engineering practice to students showing them the functions of real systems.

In order to describe the right identification of a system, having in mind real systems, it is necessary to develop a model that will present the dynamic characteristic of a real system in a working regime. Using the developed models, different aspects of the systems' behavior could be demonstrated.

For educational purposes laboratory model PT 400 (Fig. 1) has been developed in order to simulate controlled thermodynamical processes.



Figure 1 Laboratory model PT 400.

There are a large number of producers of similar process trainers. The most common are Feedback Instruments Limited with models PT326 and Process Control Trainer 37-100 [7] as well as Quanser Consulting, Inc. with model HFE (Heat Flow Experiment) [6]. A specification of technical requests has been developed according to the performances of similar devices, but with the important addition of some specific requests: the possibility of fast and simple changes of the control unit, and the simultaneous implementation of temperature sensors with different characteristics. According to the above mentioned, the following functional schema has been developed (Fig. 2), and the device has been named PT 400.

Model PT 400 consists of the following four components (Fig. 2):

- Blower, power supply, heater, and thermosensors.
- Air heaters at the tunnel entrance.
- Blowers for air transportation through tunnel.
- Four pairs of thermosensors evenly distributed into two rows inside the tunnel.

The power delivered to the heater is controlled using an analog signal. The blower speed can also be controlled using an analog signal.

Technical Requirements for the PT 400 System

Laboratory model PT 400 is a device that in a technical sense enables:

- (1) Changes of temperature in the limits of the desired range (from 30 to 90°C) in a previously defined way, in the conditions of variable airflow and other external disturbances of airflow.
- (2) The heater and blowers influence on the change of air temperature which flows through PT 400. Actuators (heaters and blowers) are controlled by an input (control) voltage signal in a range of 0–5 V, which could be introduced in different ways: manually using a potentiometer and by using a computer and an appropriate AD/DA interface (such as NI USB 6008 for example), PLC, etc. Their role is to control the change of temperature and the speed of airflow in the tunnel. The control value

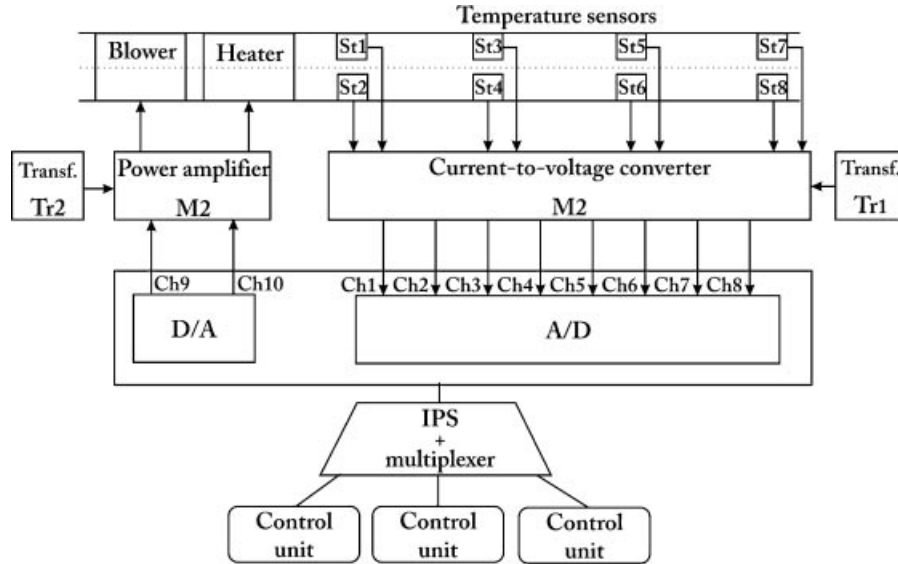


Figure 2 Functional schema of PT 400.

- is an air temperature in the tunnel, and the change of speed of the airflow has the role of disturbance. The selection of the actuator should enable a range of temperature in the tunnel of between 30 and 90°C, with a transient process time of no longer than 24 s, and induced signal in the range of 0–5 V because of the compatibility with the output of standard DA interfaces. The blower has also been excited with a standard electric signal of 0–5 V, and a nominal input of 4 V should ensure a flow of 0.91 m³/min.
- (3) Measurement of the air temperature using sensors with different characteristics placed at different distances from the heater inside the tube of laboratory model PT 400. Sensors have the task to provide information about the air temperature which flows through the tunnel. In the tunnel of laboratory model PT 400, eight thermosensors are placed in pairs, at different distances from the heater. This is a way to demonstrate the static and dynamic characteristics of different types of sensors (or the same, with or without socket, with different heat capacity, etc.) and their impact on the system. Reason for placing sensors at different distances from the heaters is to demonstrate pure time delay on the system. Sensors are selected for the measurement of temperature within a range of 0–100°C, with a transient process time of 4 s with a maximal flow of air in the tube and sensitivity of 0.05 V/°C.
- (4) Precondition of safety usage. It is important to provide general safety requirements of the functioning of laboratory model. Firstly, prevention of electric shock. Secondly, concerning the nature of the process, a thermal process, it is necessary to provide protection from burns and the model itself from overheating and possible fires. In order to provide protection from voltage, the device is grounded, and galvanically separated for network and high voltage, from other elements of the model. The cover of the tunnel also has a protective role to prevent

the touching of the heater and blower. Besides, considering of the possibility of side touching of the blower, protective grid has been placed on the front side. Protection from the overheating of the cover is performed by the placement of a safety thermostat which in the case of overheating disconnects the system from the electric power network.

- (5) Software support for PT 400. For laboratory model PT 400 and accompanied hardware it is necessary to develop software that will enable control of the model via the Internet in order to develop a supervision and control system based on Internet infrastructure.

Description of Model PT 400

Based on the functional scheme depicted in Figure 2, it is defined that M1 is the current-to-voltage converter with function to convert the data gathered from specific sensors into voltage suitable for processing with an A/D converter. The level of these signals is 0–5 V, supplied through a rectifier unit with a Tr1 transformer (5 V) (Fig. 3).

M2 is the power amplifier for the actuators—the blowers and heaters. In order to enable digital control, change of voltage using a D/A device, pulse width modulation (PWM) is used (Fig. 4).

Considering that change of the actuators' polarities is not mandatory (direction of blower rotation), the output amplifier stage is done as a single stage instead of the full N-bridge.

Basic parameters in defining the experimental device were defined. It is set that the dimensions of the working space (tunnel) are 120 mm × 120 mm × 1,500 mm. Based on that volume, it is calculated that:

$$V = 120 \times 10^{-3} \times 120 \times 10^{-3} \times 1,500 \times 10^{-3} \\ V = 0.0216 \text{ m}^3 \quad (1)$$

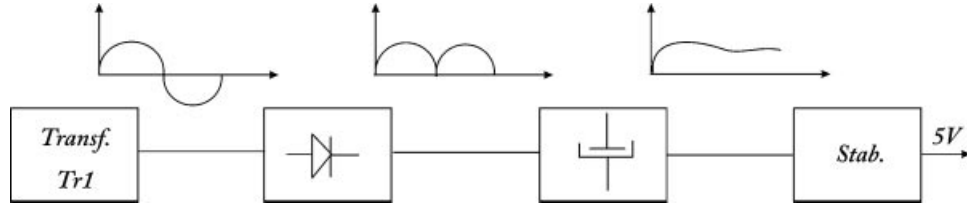


Figure 3 Functional scheme of the supplying of the M1 converter.

On the diagram of the moist air:

$$\Delta h = h_{50/0.1} - h_{20/0.2} = 70.1 - 38.7 = 31.4 \frac{\text{kJ}}{\text{kg}} \quad (2)$$

$$\rho_V = 1.1 \frac{\text{kg}}{\text{m}^3}$$

Which leads to mass:

$$m_V = \rho_V V = 0.02376 \text{ kg} \quad (3)$$

Energy required to change temperature from 20 to 50°C is

$$h_2 = m_V \Delta h = 0.02376 \times 31.4 = 746 \text{ J} \quad (4)$$

Based on the calculated value, the time for reaching the required temperature at t maximum heater power is obtained as:

$$t = \frac{h_2}{P} = \frac{746 \text{ J}}{400 \frac{\text{J}}{\text{s}}} = 1.865 \text{ s} \quad (5)$$

So, with this calculation the heaters' difference in a temperature of 30°C is achieved in approximately 2 s which is quite enough and meets the required demands.

In addition, the blower needs to meet the following airflow:

$$Q = \frac{V}{t} = \frac{0.0216 \text{ m}^3}{1.865 \text{ s}} = 0.011582 \frac{\text{m}^3}{\text{s}} = 0.69492 \frac{\text{m}^3}{\text{min}} \quad (6)$$

$$= 41.7 \frac{\text{m}^3}{\text{h}}$$

The blower is connected to a power supply of 12 V. It is situated at the entrance to the tunnel. The blower power is 3.7 W. The dimensions are 120 mm × 120 mm × 38 mm (built as a finished product (SUNON KD1212PTB1-6A) and features the blower pre-determined as the starting value). The flow that the blower can provide is 2.55 m³/min at maximum voltage, which completely meets the requirements set forth by Equation (6). The blower is excited by the input voltage, which

is in the range of 0–5 V. The threshold of sensitivity that the blower must overcome to run is about 2 V and then it can manage the speed of rotation (and thus can be changed, including the airflow) by reducing or increasing the voltage.

The heater is made of wire with the power of 400 W. The wire diameter is 1.1 mm. The heater is made of wire tied to the vertical columns of the heaters made of pertinax. The connection is made by connecting terminals which are connected to a voltage of 24 V. At the top of the heater, the side from which the blower blows air, there is a safety thermostat which serves as an overheating protection device. The range of effects can be from 50 to 85°C.

On the upper side, in the tunnel, eight stands for sensors are set. Ports are made from a standard 9-pin to DB9 connector, in order to enable the easy and quick change of sensors.

The two types of sensors can be compared. One type of sensor is the LM335. The basic characteristics of LM335 sensors are:

- Directly calibrated in Kelvin degrees.
- Initial accuracy of 1°C.
- Operating range of 400 μA to 5 mA.
- Dynamic impedance of less than 1 Ω.
- Easy calibration.
- Low price.
- Working in a wide temperature range from –55 to 150°C.

However, a drawback is relatively large inertia because of the slightly bigger housing, so it is suitable for the analysis of a slow process.

Thermistor PT 100 is used as a temperature sensor for fast processes. PT 100 belongs to the group of so-called resistance temperature detection (RTD).

Producers give dependence of resistance of temperature and it is necessary to have dependence of voltage of

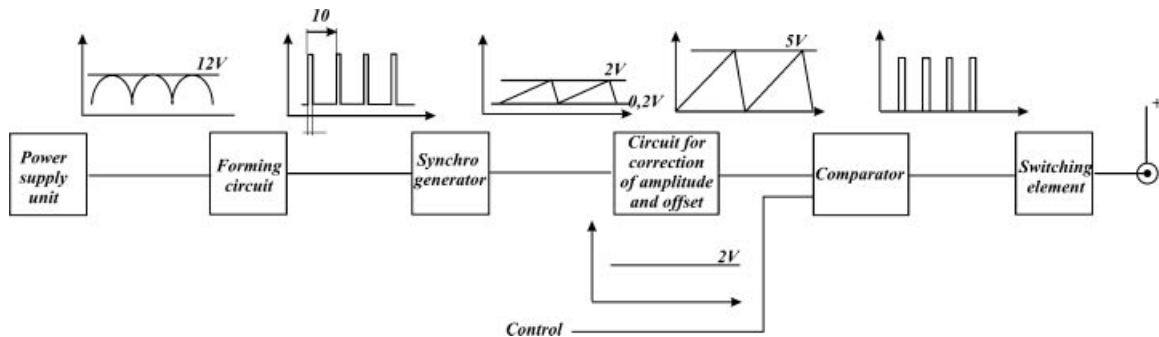


Figure 4 Functional scheme of PWM regulator.

temperature. In this type of sensor resistance is defined with the Callendar–Van Dusen equation for a temperature in the range of 0–800°C:

$$R_t(T) = R(0) [1 + A^*T + B^*T^2] \tag{7}$$

- R_t is the resistance of the sensor on the temperature T ,
- $R(0)$ is the resistance on °C,
- Coefficients A and B are typical for platinum RDT, which has the temperature resistance $\alpha = 0.00385 \text{ } \Omega/\text{ }^\circ\text{C}$, and
 - o $A = 3.9803 \times 10^{-3}, \text{ }^\circ\text{C}^{-1}$
 - o $B = -5.775 \times 10^{-7}, \text{ }^\circ\text{C}^{-1}$

Since coefficients A and B are small, it could be approximated that changes of resistance are practically linear in relation to temperature changes. For the laboratory model it is much more convenient to measure the voltage on sensors than the resistance.

The desired equation can be developed using Ohm’s law, but it is a much better approach to perform calibration, measuring temperature, and voltage. Knowing that the resistance and voltage are linearly dependent from the temperature, it is enough to measure the values approximately with a first range function or linear equation. Using a large number of repeated measurements and after the application of the method of least squares, the following equation describes the performance of the sensors:

$$T = u*(-29.114) + 139.165(\text{ }^\circ\text{C}) \tag{8}$$

The cover tunnel is made of poly(methyl methacrylate) (PMMA). The housing for the electronics is made of a metal sheet with a thickness of 1.2 mm.

The side of the housing contains an opening command panel. It carries a total of 10 connectors of which two are inputs (for heater and blower control) and 8 are outputs (for output signals of sensors). In addition there is an on/off switch and four fuses. In order to prevent overheating inside the device two coolers have been built in.

In order to provide more flexible functioning of the model, a multiplexer with an integrated power amplifier has been developed. Basically for this model only the multiplexer could be used, but during the implementation of the model we decided to develop a universal integrated power amplifier as an independent device or separate component. The results of implemented algorithm on the different devices can be compared relatively quick and easily, and laboratory equipment once assembled could stay in that form for a longer period of time providing different software manipulation for an experiment.

Model IPS 2M4SA/3 is a power transducer and electronic switch that enables a usage of one of three outputs. The power amplifier has the purpose to convert control signals from the control unit in appropriate voltages for the actuators drive. The input from the multiplexer is connected to PT 400, and the outputs are connected to specific control units.

The control units are sub-assemblies through which the implementation of the control algorithm can be performed. This may be a PC with an appropriate interface for the AD and DA conversion (e.g., USB NI6008, NI6229, etc.), a PLC controller, a microcontroller development board, and the like.

As already stated in the project specification, PT 400 has to satisfy rigid safety requirements. To implement protection

against touching voltages, the device is grounded and a galvanic isolation has been made between the networks, high voltage, and the other elements of the model.

The cover of the tunnel is also a measure of protection against accidental contact of the heater and blower. In addition, a safety net from the entrance side has been set preventing the possibility of side touching of the blower.

Protection against overheating of the housing is performed by placing a safety thermostat that disconnects, in case of overheating, the entire device from the electric power network.

The overall technical characteristics of a process trainer are presented in Table 1.

Verification of PT 400’s Characteristics

The responses of the temperature in the tunnel of the laboratory model, an example of the setting of a desired response by tuning to Dahlin’s PID algorithm (Fig. 5).

Dynamics of the response obtained by the prototype is quite comparable to commercial laboratory models [6,7].

POSSIBLE EDUCATIONAL TASK

The possible project task which could be performed with laboratory model PT 400 covers a number of engineering courses such as measurement and control, modeling, and identification. The possible educational tasks that could be set are as follows:

- (1) Testing of static and dynamic characteristics of sensors and actuators.
- (2) Modeling and identification of a process.
- (3) Control algorithm synthesis, verification of the effectiveness of simulation and experiment.

Testing of the Static and Dynamic Characteristics of Sensors and Actuators

The blower is excited with an input signal of (0–5) V. The air-flow in the pipe/tunnel can be measured by an anemometer (available MS6250 Digital Anemometer). The heater is excited with an input signal of (0–5) V, where the airflow in the tunnels/tubes can be set by the input voltage of the blower (three values are sufficient to demonstrate the procedure, for an experiment take 1.5, 3, and 4.5 V). The heater temperature can be measured on an available non-contact infrared thermometer

Table 1 Technical Characteristics of the Laboratory Model PT 400

| Parameter | Value | Units |
|------------------------------------|-------------------|----------------|
| Voltage of power supply of device | 220 | V, AC |
| Max power of heater | 400 | W |
| Max power of blowers | 3.7 | W |
| Max number of rotation of blowers | 3,100 | °/min |
| Number of sensors | 8 | |
| Voltage of sensors’ power supply | 5 | V |
| Calibration of temperature sensors | 100 | K/V |
| A cross-section of the tunnel | 0.0144 | m ² |
| Dimensions of the model | 150 × 275 × 1,500 | mm |

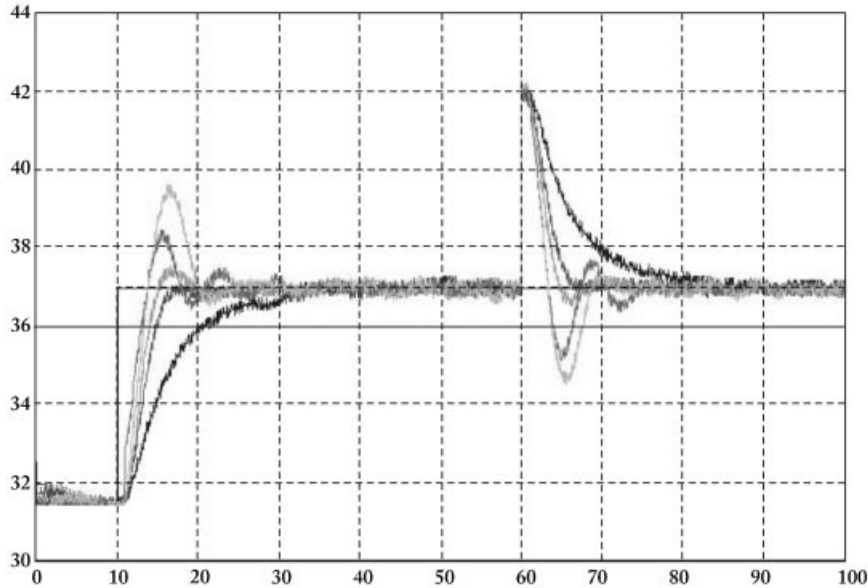


Figure 5 Responses of laboratory model in Figure 1 with a PID controller tuned Dahlin's algorithm and Ziegler–Nichols tuning.

(ST-8855 IR TC thermometer). Heater power is 400 W. The range of effects can range from 50 to 85°C. Possible tasks/questions are:

- Record the static characteristics of the heater (the excitation voltage input and the output temperature of the heater, with respect of airflow). Display static kku 3D diagram (input: excitation voltage of the heater and airflow in the pipe (excitation voltage blower), output: heater temperature).
- Is there hysteresis?
- Evaluate the settling time (parameter of dynamic characteristics) at different points in the static characteristics (present in a table form: point static characteristics, the measured/estimated settling time).

Eight sensors are located in the tunnel/connected with a 9-pin connector for the enclosure, where the eight signals (0–5) V are available for measurement (and thus enables the recording of temperature signals from all eight sensors). Four sensors L335 are set in a series and linked by 9-pin connectors for the housing, which according to the manufacturer have a coefficient of calibration 100 K/W. Besides them, the same distance from the heater, sensors of other characteristics are usually set. Also available is a MS6503 digital thermometer and an ST-8855 IR TC thermometer. Tasks are:

- Perform calibration of all sensors (or all types of sensors) in the tunnel; record the static characteristics of sensors in terms of the diagram: the temperature at a given point—an appropriate voltage signal to the PT 400 housing.
- Compare the dynamic characteristics of sensors. For available sensors compare:
 - o The response to STEP signal (e.g., entrance on the blower is 3 V. The power of the heater change by change in voltage from 3 to 4 V) and the parameters of the dynamic features that can be read on the basis of

this response (settling time, the dominant time constant, and so on).

- o The response to sinusoidal signal changes in the air temperature in the tube (e.g., entrance to the blower is 3 V; the heater power is changed by changing the voltage from 0 to 5 V, that is, $u(t) = 2.5 - 2.5 \cos(\omega t)$). Also, the input signal $u(t) = 2.5 - 2.5 \cos(\omega t)$ changes frequency ω in order to identify the frequency bandwidth of the subsystem for measuring the temperature with different temperature sensors. In addition, the frequency/filter characteristics of the sensor are demonstrated and explained.

Modeling and Identification of the Process

The main task is to present a mathematical model of the thermodynamic process of heating the air in the tunnel. In this presentation there are the following assumptions:

- The nominal airflow in the pipe is defined by the entrance blower of 3 V (deviation from these values can be treated as a disorder).
- The input in the process is an input signal of (0–5) V for the PT 400 housing that affects the power of the heater.
- The exit of the process is a temperature signal of (0–5) V on the arbitrarily selected sensor in the pipe.
- It is a slow process of a typical first-order delay.

Perform parametric identification of a mathematical model of the process:

- Perform appropriate experiments.
- If necessary, propose a new structure model or stick with the proposed.
- Perform parametric identification.
- Verify the validity of the obtained model.

Control Algorithm Synthesis, Verification of the Effectiveness of Simulation and Experiment

Perform synthesis and experimental verification of efficiency of ON-OFF (with hysteresis), of P, PI, PID controller in a system with a closed loop. In this task there are firstly three assumptions as on the previous task.

Experimental verification carried out in the following terms:

- Reference signal $r(t)$ is 0 V for the first 10 s, then V for the next 60 s, 4 V for the next 60 s, and finally 2 V for the next 30 s.
- The disturbance signal is set by software as an additive (effects of disturbance on a controlled variable) on the signal outputs. The signal $d(t)$ is 0 V for the first 40 s, then 1 V for the next 60 s, and then again 0 V.

For control algorithms (choose the parameters of these algorithms, with an understanding of the reasons for this choice in accordance with the procedures of their “calculations”) conduct experimental tests where the recorded signals are: the reference signal $r(t)$, the effect of disturbances on the signal output of the system $d(t)$, output signal $y(t)$, control signal $u(t)$, signal that affects the operation of the blower in (t) .

For the most successful algorithm of the above, repeat the experimental tests:

- For different values of the signals that influence the ventilation $v(t)$;
- For the sinusoidal signal change that affects the operation of the blower in $(t) = 2.5 - 2.5 \cos(\omega t)$ with changing frequency ω .

A student needs to describe for which frequency signal disturbance $v(t)$ the impact on output of the system is the largest and for which the smallest. Students also need to answer: whether it can be connected to the frequency bandwidth of the system with a closed loop; what is the frequency bandwidth and how it can change the control algorithm synthesis, and what are the effects from the standpoint of tracking the reference trajectory, eliminating the effects of disturbance on the output variable, suppression of noise in the system, suppressing the effects of parametric disorder. Finally, they have to comment a simulation and experimental results.

From the standpoint of achieving better performances of the system with a closed loop, students need to:

- Define the desired system’s performance.
- Give the procedure of synthesis of an arbitrary control algorithm (fuzzy algorithms, algorithms based on neural networks and any other).
- Provide verification of the efficiency of the proposed control algorithm by simulation and verification on the experimental model.

These three tasks are examples of potential usage of the training equipment for students’ training and education in different fields (process engineering, thermodynamics, control engineering, etc.).

INTERNET-BASED REMOTE CONTROL AND MEASUREMENT

In order to provide open access to a wider range of users, and to be cost-effective, control of the laboratory device is enabled via the Internet. In order to provide remote control of the model the links between the device and the control server, local and remote computers/servers should be supported by an appropriate software solution. Generally there are two different approaches in the development of web laboratories and support for remotely controlled experiments concerning programming languages:

- for the link between the device and control server (dedicated proprietary software such as: MatLab with Simulink, LabVIEW; a developed solution based on different programming languages mainly C#, Java), and
- for the link between local and remote computers (dedicated proprietary software such as: Matlab and Simulink, LabVIEW, front panels as virtual instruments, or a different variation of dynamic solutions based on HTML—Hypertext Markup Language, XML—Extensible Markup Language, ASPX—Active Server Page Extended, PHP—Hypertext Preprocessor, Java Applets, Visual Basic, VRML—Virtual Reality Markup Language).

All approaches have their advantages and disadvantages, but in this article we have selected an approach based on LabVIEW. There are many examples of usage of LabVIEW for the support of remote laboratory experiments [9–13]. The usage of LabVIEW provides useful tools (LabVIEW Remote Panels, Web Publishing Tools), it is easy to learn, has single software (language) for a complete solution; and is well suited to control setup and collect data. On the other hand LabVIEW is mostly used to conduct experimental sets using data acquisition (DAQ) cards, this limits the number of experiments connected to the server computer [10,14,15] and Virtual Instruments (VI) in LabVIEW could become large files [16].

Anyway, this concept of WebLab consists of three parts:

- (1) Theoretical basis—which presents the basic concepts for monitoring and understanding of a proper exercise.
- (2) Simulation model—to help students prepare for the simpler practical part of the exercise, it is possible to get familiar with the expected behavior of the system through simulation.
- (3) Execution of the experiment—after students master previous two steps—enables them to practically run the experiment.

Structure of Web Lab—one of the implemented concepts of the use of laboratory resources via the Internet—is presented in Figure 6.

As a container for the realization of the experiment via the Internet DotNetNuke version 5.3.2001 was selected. DotNetNuke is an open source platform based on Microsoft .NET technology and has built in additional modules for authorization and authentication. It is also possible to easily develop modules in programming languages C#, .NET, and VB.NET.

DotNetNuke is a portal with collaborative CMS (Content Management System) functionality. As such, it is a good choice for the portal solution, because it combines, on the one hand,

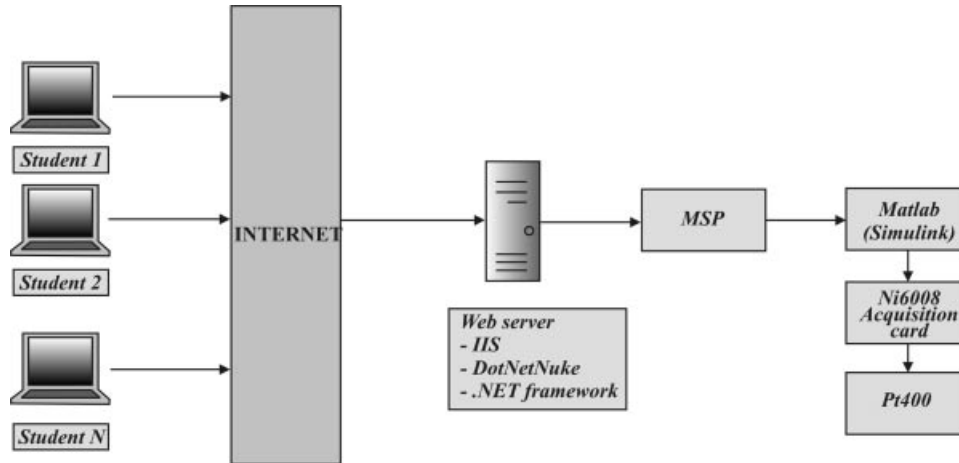


Figure 6 Structure of Web Lab—one of the implemented concepts of the use of laboratory resources via the Internet.

easy maintenance and modification of copyrighted content, and on the other hand offers the possibility of creating special-purpose modules, in this case modules that use functionality Simulink models through the MSA.

MSP (Matlab Server Pages) is a complex system that supports three-tier architecture (web-business environment-database). It belongs to a group of so-called open-source solutions and has proved itself as an acceptable replacement for commercially available Matlab add-ins for a web server (Fig. 6).

An alternative way for online operation—remotely, over the web, with the PT 400 system is using LabVIEW software (product of the company National Instruments) that allows rapid development of applications for measurement and control using an intuitive graphical language G.

LabVIEW directly supports a large amount of acquisition—measurement hardware via the library NiDAQ Mx, which could also still be used with various types of software such as Matlab, MS Visual Basic, and C#, C, C++.

LabVIEW software is based on the so-called Virtual Instruments (VI) that have a form with elements of a graphical user interface (GUI) by which it controls the experiment.

The form with elements has been associated with a Functional Block Diagram (FBD) representing the program in the language G (consists of features that could be used to implement the required functionality of the virtual instrument). Function block diagrams are linked with connections which are called wires and represent the flow of data and they must comply with the type of inputs and outputs of functional blocks that connect. The development of desktop applications using LabVIEW software can be relatively quick, depending on the complexity and demands of the application that is developed. There is no faster and more elegant way to develop measurement/control applications than is possible using LabVIEW.

When the virtual instrument starts, the form of virtual instrument has the look as in Figure 7.

Each of the eight diagrams in Figure 7 shows the change of temperature at one of the eight temperature transducers of the PT 400. The PT 400 has temperature transducers with a positive and a negative temperature coefficient, where the downward and upward curves of temperature change in the panels.

Two instruments with vertical slider bars are used to manually adjust the blower speed and temperature of the heater. The value in the “Select (ms)” specifies the time interval between two consecutive measurements of the temperature with the PT 400 in milliseconds, while the value of the field “Duration (S)” determines the duration of measurement in seconds. After completion of the measurement results are saved in a file which is selected using the control “data file.” The appearance of the corresponding block diagram of a virtual instrument for PT 400 is presented in Figure 8.

Once developed, desktop applications, with a few simple adjustments of the LabVIEW environment could be activated as a LabVIEW embedded web server. So access to the developed virtual instrument via the web and using a web browser could be allowed. Previously, the additional software LabVIEW Run Time Engine (that can be downloaded from the site of National Instruments at: <http://joule.ni.com/nidu/cds/view/p/id/861/lang/en>) must be installed on the client computer from which users access the laboratory trainer. The general structure of the Web Lab, shown in Figure 6, remains similar in using the LabVIEW software, with the difference, being that the web server in this case is installed on the same computer on which the measurement system operates with the experiment. Using the additional web server installed on a different or the same computer, it is possible to implement scalable system experiments with web access where some experiments could simply be added to the existing structure of web experiments by connecting a new PC with a web server. The general structure of the scalable structure of a Web Lab is presented in Figure 9.

The role of the main web server in Figure 9 is to provide user access to the system of various experiments. Each server in the network of servers in Figure 9 is linked to an experiment, directly or through an appropriate data acquisition server. The data acquisition server is a computer using an appropriate interface (usually card system); it enables the acquisition, management of an experiment over a computer network and it is connected to a local web server or the main web server. In the case when LabVIEW software is used, the web and data acquisition server could be on the same computer. If some other technology is used, then the data acquisition server could be connected directly to the main server Web Lab system. Also,

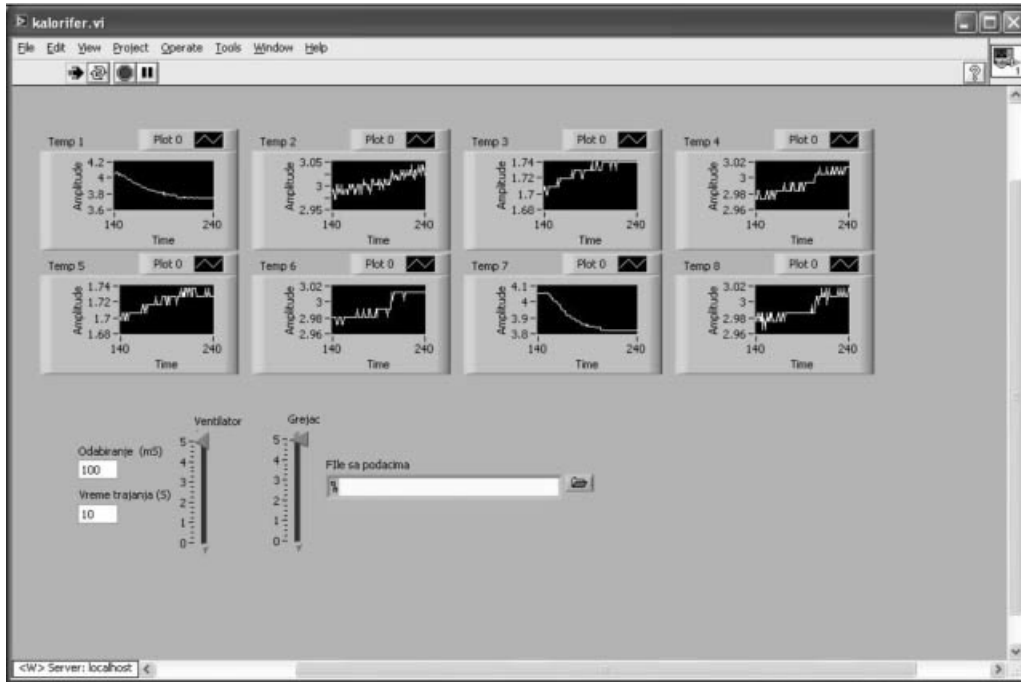


Figure 7 Virtual instrument in the execution phase.

some experiments may have their own dedicated local web server in the network that is developed to specific requirements.

CONCLUSION

In education for different engineering fields it is very important to provide quality knowledge and skills in the field of process control. In this article we have presented the development and

implementation of a laboratory setup for engineering training. The model has successfully met its primary function, which is to provide faster and more flexible ways of analyzing a thermo-process with a time delay.

In this article we presented the design and implementation of a laboratory trainer. The detailed requirements were defined starting from technical characteristics, followed by a precondition of safety usage and software support. Part of the specification was developed according to the performances of similar

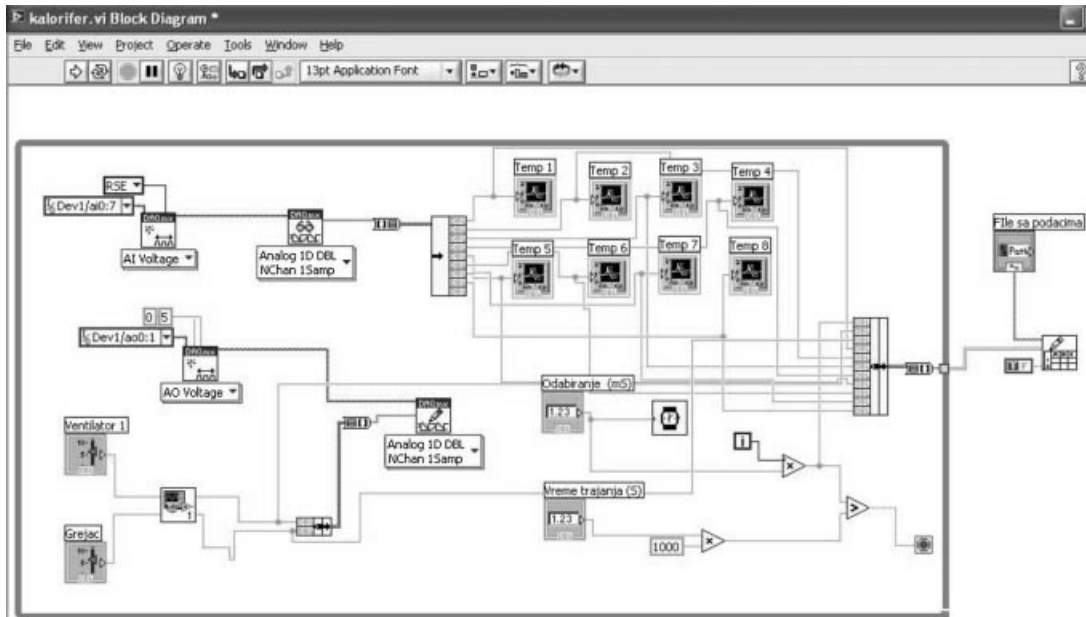


Figure 8 Block diagram of a virtual instrument for the PT 400.

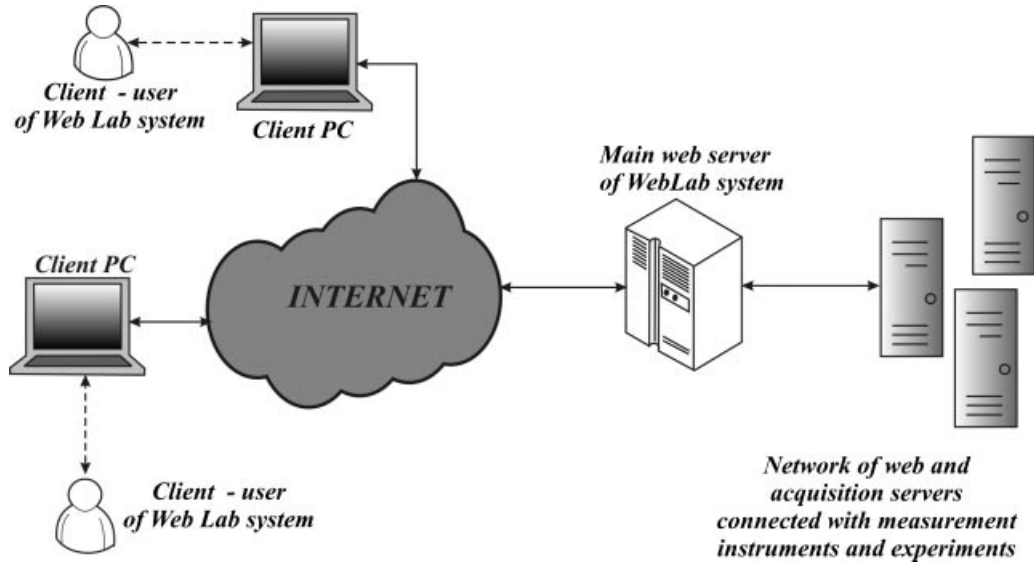


Figure 9 General structures of a Web Lab system.

devices; in addition this model has a few specific features: the possibility of fast and simple change of the control unit (which enables the usage of PLC, PC, microcontrollers), and the simultaneous implementation of temperature sensors with different characteristics (which allows the comparison of different sensors, and the testing of effects of the different sensorial groups at the same moment). All functional schemes as well as the technical characteristics of the laboratory model PT 400 are provided. The verification of the laboratory model was tested by the measurement of responses of the laboratory model in Figure 1 with a PID controller tuned to Dahlin's algorithm and Ziegler–Nichols tuning. In order to demonstrate usability of the model in practical engineering training three possible educational tasks we have suggested three possible educational tasks:

- (1) Testing of static and dynamic characteristics of sensors and actuators.
- (2) Modeling and identification of process.
- (3) Control algorithm synthesis, verification of the effectiveness of simulation and experiment.

This laboratory trainer could be used for training and learning in different engineering fields and for different purposes:

- (1) The process of the construction, design, selection of the components and assembly process could provide an illustrative example for students in many different courses (construction, sensors and actuators, and electronics as well). Furthermore, the blueprint for the design of this laboratory setup will be given to student teams for complete implementation and verification of the results.
- (2) The model could be used for training in the field of process control for the simulation of thermal processes. This model could be used for training having in mind different real life applications such as different

environments with controlled temperatures (different industrial driers, etc.).

- (3) It could be used for the demonstration of different control approaches. The trainer could demonstrate closed and open loop continuous control as well as disturbance. Students could perform system identification on the heat flow experiment and design a controller in the frequency domain to control the air temperature at selected points in a duct using a heating element and a blower. In addition students could design a simple PI control system to control the air temperature at selected points for lower courses or to develop more complex controllers for advanced course.
- (4) In addition this model could be very useful for training for different software solutions. In this case we used LabVIEW and its libraries, which could also be used with various types of software such as Matlab, MS Visual Basic, and C#, C, C++.

A solution for the remote control of a laboratory setup, based on LabVIEW, has been presented. The WebLab concept has significantly expanded capabilities of the training in many different fields. Different remote users can perform experiments on a single setup, results can be easily downloaded, and the procedure can be repeated irrespective of the time of usage or the location of users.

Finally, the results obtained in this research can be practically applied in a micro-environment, such as in cars or buses, in complex housing units, as well as in factory plants where it is necessary for strictly controlled conditions of heating such as in the use of a dryer.

REFERENCES

- [1] M. Al-Khedher and B. D. McDonald, Development of a global web-based industrial process control laboratory for undergraduate and graduate engineering technology education, IAJC-IJME International Conference, IT301 (2008), 108–118.

- [2] V. Ramakrishna, Y. Zhuang, S. Y. Hu, J. P. Chen, C. C. Ko, B. M. Chen, and K. C. Tan, Development of a web-based control experiment for a coupled tank apparatus, *Am Control Conf* 6 (2000), 4409–4413.
- [3] M. Chaabene, K. Mkaouer, and M. Ouali, A web based interactive real laboratory for process engineering education, *J Comput Sci* 3 (2007), 541–545.
- [4] C. C. Ngo, M. J. Voon, and F. C. Lai, Online heat transfer and fluid mechanics laboratory, *Comput Appl Eng Educ* 13 (2005), 1–9.
- [5] R. Dormido, H. Vargas, N. Duro, J. Sánchez, S. Dormido-Canto, G. Farias, F. Esquembre, and S. Dormido, Development of a web-based control laboratory for automation technicians: The three-tank system, *IEEE Trans Educ* 51 (2008), 35–44.
- [6] Quanser, Heat Flow Experiment, System identification & Frequency domain design, www.quanser.com/english/downloads/products/Heatflow.pdf. Accessed: November 18, 2010.
- [7] Feedback, Process control, www.quanser.com/english/downloads/products/Heatflow.pdf. Accessed: November 18, 2010.
- [8] S. H. Yang, X. Chen, and J. L. Alty, Design issues and implementation of internet-based process control systems, *Control Eng Prac* 11 (2003), 709–720.
- [9] M. Stefanovic, V. Cvijetkovic, M. Matijevic, and V. Simic, A LabVIEW-based remote laboratory experiments for control engineering education, *Comput Appl Eng Educ*, Early View, Article first published online: 22 APR 2009, DOI: 10.1002/cae.20334.
- [10] A. Kutlu and K. Tasdelen, Remote electronic experiments using LabVIEW over controller area network, *Sci Res Essays* 5 (2010), 1754–1758.
- [11] A. Kalantzopoulos, D. Karageorgopoulos, and E. Zigoridis, A LabVIEW based remote DSP Laboratory, *Int J Online Eng* 4 (2008), 36–44.
- [12] S. Bogosyan, M. Gokasan, A. Turan, and R. W. Wies, Development of remotely accessible Matlab/Simulink based electrical drive experiments. In: *Industrial electronics (2007)*, International Symposium on ISIE 2007. IEEE Volume, Vigo, 4–7 June 2007, pp 2984–2989.
- [13] M. Abdulwahed and Z. K. Nagy, Developing the TriLab, a triple access mode (hands-on, virtual, remote) laboratory, of a process control rig using LabVIEW and Joomla, *Comput Appl Eng Educ*, Early View, Article first published online: 1 DEC 2010, DOI: 10.1002/cae.20506.
- [14] H. I. Abu-Mulaweh and D. W. Mueller, The use of LabVIEW and data acquisition unit to monitor and control a bench-top air-to-water heat pump, *Comput Appl Eng Educ* 16 (2008), 83–91.
- [15] S. Azaklar and H. Korkmaz, A remotely accessible and configurable electronics laboratory implementation by using LabVIEW, *Comput Appl Eng Educ* 18 (2010), 709–720.
- [16] M. Engelbarts, Distance experiments, Socrates program, Retrieved August 21, 2010, <http://www.nmc.teiher.gr/activities/MASTERS/JOINT/Material/Utrecht/DE.ppt>.

BIOGRAPHIES



M. Matijevic received his PhD from Department of Automatic Control, Faculty of Mechanical Engineering University of Kragujevac, Serbia. He is currently an associate professor in Department of Automatic Control and Applied Mechanics. His current research interest includes digital control, computer added measurement and control.



M. Stefanovic received his PhD from Department of Production and Industrial Engineering, Faculty of Mechanical Engineering University of Kragujevac, Serbia. He is currently an assistant professor in Department of Industrial Engineering. His current research interest includes web services, information systems, and CIM systems. He is a member of International Federation for Information Processing—Council TC3—Education.



V. Cvijetkovic received his PhD in Faculty of Science University of Kragujevac, Serbia. He is employed at Faculty of Science, Department of Physics as assistant professor. He teaches subjects in informatics for the students of physics: object oriented programming, information systems, web programming, data acquisition, expert systems. His scientific interest and field of research includes informatics support for physics, expert systems for spectra analysis, data acquisition, measurement and control, web laboratories.



V. Joković received his BSc (5 years, former Diploma) degree from School of Electrical Engineering in Belgrade in 2006. He is a PhD student in Faculty of Mechanical Engineering, University of Kragujevac. Currently he works at Inovatec Systems Corporation as a project manager. He is interested in robotics, human interface devices and algorithms, and supporting information systems.



N. Babajić received his BSc (5 years, former Diploma) degree from Mechanical Engineering from the Faculty of Military and Technical Sciences in Zagreb. He is a PhD student in Faculty of Mechanical Engineering, University of Kragujevac. His research interests are in the area of robotics and informatics support for data acquisition, measurement and control, web laboratories.



M. Ravlić received his BSc degree from Military Technical Faculty in Zagreb in 1989, and MSc degree from Electrotechnical Faculty from Belgrade in 1993. He is a PhD student in Faculty of Mechanical Engineering, University of Kragujevac. Currently he works at Prizma Kragujevac as a designer of electronics. He is interested in embedded systems and automated test equipment.



S. Nestic is a PhD student in Faculty of Mechanical Engineering, University of Kragujevac. She is currently an associate a Center for Integrated Manufacturing. Her scientific interest and field of research includes computer integrated manufacturing.