

Design of an Experimental Platform for Process Control Systems

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Abstract

Control systems are lectured in various engineering fields from chemical engineering to electrical engineering. Control systems training become more efficient when the training activities are supported by experimental studies. During the experimental studies, observing control process and analyzing data captured from the process in a computer provide a significant contribution to education. This paper presents a method for the purpose of improving some process control experiment sets used by the department of chemical engineering as the computer-aided experimental sets. This method may be used by researchers who will either develop an experimental set for process control systems or improve the actual experimental set. Real experiments are performed to show the working of the developed system.

1. Introduction

Real experiments in the control systems courses constitute an important contribution for undergraduate engineering education. When students apply analysis and design methods of control systems to a physical system, the interest and apperception of the students increase. However, some researches exhibit that simulations may be preferred instead of physical experiments [1]. This paper presents the results of a research that examine the working of process control education in the level of graduate school for more than 50 various departments over the world. The reason for the preference of simulations instead of physical experiments may be low cost and ease of implementation. Another research paper emphasis the importance of laboratory experience for the engineering education and presents a structured model for process control laboratory [2]. On the other hand, a paper states that it is difficult to comprehend how to apply the concept of control theory and presents low cost experiment kits which may be used at the undergraduate level education [3].

Besides observing a physical experiment of a process control system, it is also important to capture, plot, and analyze the process data taken during the experiment in the computer environment. A paper emphasis the importance of using a graphical user interface for a process control system and presents the graphical interface design and experiments [4].

There is an important research area about using virtual environment with real control data. In a paper, a system which is enable to remotely access to a physical experiment platform and visualize the virtual process control with real data is presented [5]. Another study presents a platform design which may be used to do experiments over web. Over the internet, the

experiment is observed by cameras placed onto the experiment platform and the real-time process data captured from the platform are plotted on a graphical user interface [6].

Our paper presents a design scheme for the purpose of improving some old process control experiment kits used at the department of chemical engineering to computer-aided experimental kits. There are three different experiment kits: Temperature, level and flow process control systems. The systems consist of some common features. Each one includes a paper feed plotter. The process data is plotted on a paper by the plotter, and the students can analyze the results by inspecting the papers. The original kits are costly and time-consuming to re-do experiments with different parameters. Also, each one includes a general purpose process controller. The controller includes a led display and buttons. It is not user-friendly for students to change parameters and observe the process data from the display of the process controller. The design scheme presented in this paper provides user-friendly interface for changing parameters and observing the experiment process. The result may contribute to the researchers who will develop a new experiment kit or improve the old experiment kits.

The paper presents the study by the following titles. In Section 2, the process control systems are introduced. In Section 3, the design is given in detail. In Section 4, the results of some applications performed by using experiment kits are presented by supporting figures plotted with read experiment data. At last, the conclusion is given.

2. Process Control Systems

Mentioned systems have been used by the department of chemical engineering at Eskişehir Osmangazi University since 1995. There are three experiment sets for process control training: the temperature, level and flow process control systems. The experimental sets are not much different than the systems which are used nowadays. The superior side of the systems used nowadays is to have computer support for managing the control process and analyzing the experiment data. In this study, process control experiment sets which have been used for more than 20 years are improved to be a “Computer-Aided Experimental Sets”.

Whole experiment sets include some equipment with common properties. These are FOXBORO 731C series digital process controller and graph plotter.

2.1. Temperature Process Control System

The system hardware consists of a recirculation pump, a heater, 3 thermocouple heat measurement sensor, a cooler,

feeding canals, valve, a thyristor and thermocouple selections switch as shown in Fig.1.

In Fig.2, the circuit of experiment set is shown. The flow of water is maintained by a centrifugal pump. The water in the reservoir flows firstly through the heater via pipes, and then passes through a coiled retarder which is 4 meters long. Finally, passing through the cooler, the water pours into the reservoir again. Besides, the flow rate of the water passing through the heater is controlled by using the bypass valve which is controlled by hand.

The measurement over the system is performed by thermocouples which are located in 3 different measurement points: (i) Heat coil (T1), (ii) Output of the heater (T2), (iii) Output of the retarder (T3). The cable pins of the thermocouples are connected to a 3-way-switch. By the help of the 3-way-switch, the temperature of the selected measurement point is able to be controlled. The measurement point is observed as input by the controller and the control signal of the controller is produced and transmitted to triac which triggers the thyristor that drives the heater.

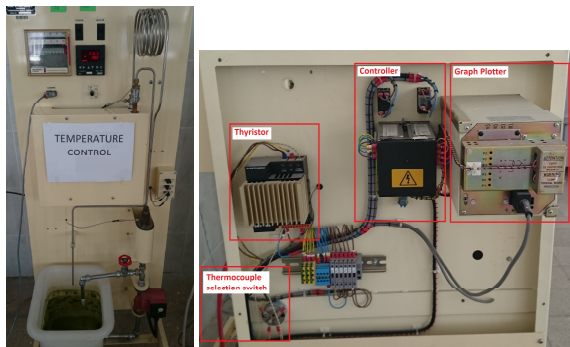


Fig. 1. Pictures of the temperature process control experiment set: (left) Front view, (right) back view

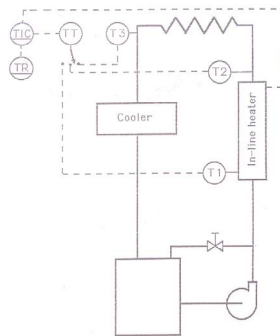


Fig. 2. Circuit of temperature process control experiment set

2.2. Level Process Control System

The system hardware consists of a recirculation pump, an electro-pneumatic level control valve, a level transducer, a water level visualizer tank, feeding canals shown in the Fig.3.

In Fig.3 (left side), the circuit is shown. The flow of water is maintained by a centrifugal pump. The water in the reservoir flows through the electro-pneumatic level control valve into the level visualizer tank, and the water in the tank pour into the

reservoir through another pipe. Besides, the flow rate of the water flowing into the tank is controlled by the electro-pneumatic level control valve.

The measurement of the tank level is performed by the level transducer which is fed by the pipes coming from the water tank. The water level in the tank is converted to the digital signal and transmitted to the digital process controller. The control signal produced by the controller is feed to the electro-pneumatics level control valve that drives the water level in the tank.

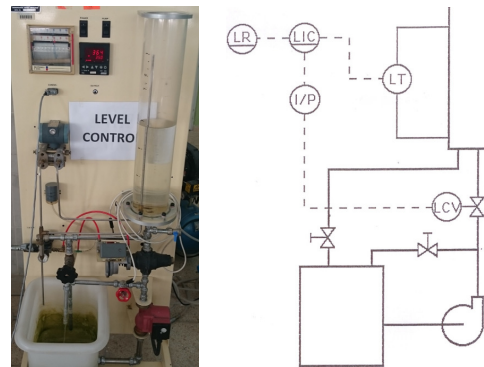


Fig. 3. Pictures of the level process control experiment set: (left) Front view, (right) Circuit of the set

2.3. Flow Process Control System

The system hardware consists of a recirculation pump, an electro-pneumatics flow control valve, a flow rate transducer, a flow rate visualizer tank, feeding canals shown in the Fig.4.

In Fig.4 (left side), the circuit is shown. The flow of water is maintained by a centrifugal pump. The water contained in reservoir moves firstly through the electro-pneumatic flow control valve and passes through the flow rate visualizer tank, then passes through the measurement throat and pours into the reservoir again.

The measurement of flow rate is performed by the flow rate transducer which measures the water passing through the measurement throat. Measured flow rate is converted into digital signal by the transducer and transmitted to the digital process controller. The control signal produced by the controller is feed to the electro-pneumatics flow control valve.

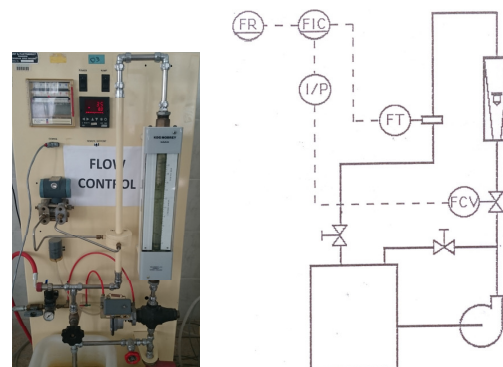


Fig. 4. Pictures of the flow process control experiment set: (left) Front view, (right) Circuit of the set

2.4. Embedded Software of Controller

All of three systems consist of a FOXBORO 731C series digital process controller as seen in Fig.5. It is a PID (Proportional plus integral plus derivative) based automatic process controller. And, it has embedded software and is configured by using six buttons on the front panel. The configuration parameters and process data can be monitored on a led display. The controller has three modes:

Run Mode: In this mode, reference set point or percentage output may be set. Also, the running state may be set to automatic or manual. In the automatic state, the controller produces output to keep the control variable at the reference value. In the manual state, controller output value is changed by the buttons manually.

Extended Run Mode: The parameters of the controller like PID parameters, threshold, dead band, etc. are able to be set.

Configuration Mode: The controller runs in this mode when a jumper is attached to the electronic card of the controller. Some structured adjustments of the controller such as serial communication speed, measurement boundaries, and alarm levels, etc. are carried out in this mode.

The controller enables serial communication via RS485 communication protocol. For the serial communication between the controller and a computer, predefined commands supported by the controller like POOL, SET, EXTENDED POOL, READ and WRITE are used. These commands are defined as follows:

POOL command: This command is utilized to obtain the set point, measured values and percentage output from the controller.

SET command: This command is used to set the reference value and percentage output of the controller.

EXTENDED POOL: The command is utilized to obtain the various parameters such as available carrier input/output, analog output values, etc.

READ command: This command is used to obtain the controller configuration parameters such as PID, alarm values, etc.

WRITE command: This command is used to set the controller configuration parameters.

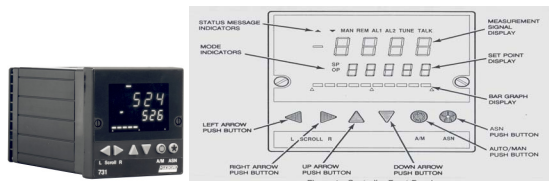


Fig. 5. FOXBORO 731C series digital process controller and front panel

The communication between the controller and a computer can be achieved via a predefined packet structure as shown in Fig.6. Each members of the message packet, except data, is 1 byte. The data block may one or more than one byte.

DLE	STX	ADRS	CMD	..data..	DLE	ETX	CRC	CRC
DLE	STX	ADRS	RSP	..data..	DLE	ETX	CRC	CRC

Fig. 6. Packet structure: (top) Message delivered to the controller, (bottom) Message delivered by the controller

The message packets consist of start (DLE, STX), address (ADRS), command (CMD), data (..data..), end (DLE,STX) and cyclic redundancy check (CRC) blocks.

The characters of DLE (Data Link Escape Character), STX (Start of Text Character), ETX (End of text Character) and CRC (Cyclic Redundancy Check) must exist in each message packet. These characters are important to determine where the message starts and ends (DLE,STX,ETX) and correctness of the message (CRC). The communication between the computer and controller is performed asynchronously.

ADRS character defines the address of the controller. CMD characters are used for command types and its size is one byte. RSP character is utilized to identify the type of the response message. For example, if the message is transmitted to the controller in a correct form, the response message which is transmitted to the computer from the controller contains 0x00 in the position of RSP.

3. Design of Computer-Aided Experimental Sets

The design of computer-aided experimental sets consists of two main parts: System software and graphical user interface. The system software includes the modules to implement the communication between the controller and computer, wrapping and parsing the message packets, keeping data in a data structure, etc. Moreover, graphical user interface provides a user friendly interface to enable users to command the experiment and observe the real-time process data numerically and graphically on the screen.

3.1. System Software

The system software is developed by using object-oriented design methodologies in C++ programming language. Since the design is modular form, the design enables integrating other process control systems easily. In Fig.7 and 8, use-case diagram and UML class diagram are given, respectively.

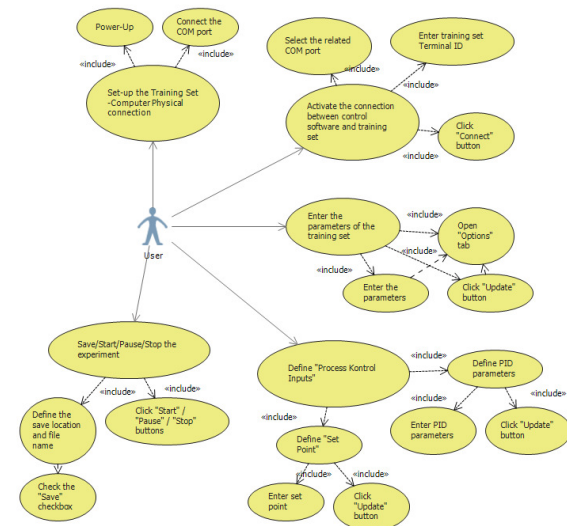


Fig. 7. Use-case diagram for system software

The classes in Fig.8 are defined as follows:

RSController: This is a base class of some classes like RSTemperatureController, RSLevelController, RSFlowController. These are used to manage system software by organizing other classes.

RSTemperatureController, RSLevelController, RSFlowController: These classes are responsible for each process control.

RSSetCommandFlag, RSStatusFlag, RSAdvancedStatus, RSAlarmFlag, RSPParameter, RSPParameters, RSCommStatusTable, RSCommStatus: These are utility classes which holds characteristic and behavioral states of the system. The instancet of the RSController class is responsible for creation and destruction of these objects.

RSICConnection: This is an abstract base class which utilizes to communicate with the controller.

RSSerialPortConnection: This is a derived class of RSICConnection class. It utilizes to communicate with digital process controller via RS485 serial communication protocol.

RSICCommand: This is an abstract base class which is utilized to package the commands which are sent to the controller.

RSTemperatureEquipmentCommand, RSLevelEquipmentCommand, RSFlowEquipmentCommand: This is a derived classes of RSICCommand class, utilized to package the commands which are sent to the controller depending on the package structure and number precision criteria.

RSIResponseParser: This is an abstract base class which utilizes to parse the messages which are sent to the computer from the controller.

RSTemperatureEquipmentResponseParser, RSLevelEquipmentResponseParser, RSFlowEquipmentResponseParser: These are derived classes of RSIResponseParser class, utilized to parse the messages which are sent to the computer from the controller depending on the package structure and number precision criteria.

RSCRCGenerator: This is a cyclic redundancy check code generator for the messages between the controller and the computer.

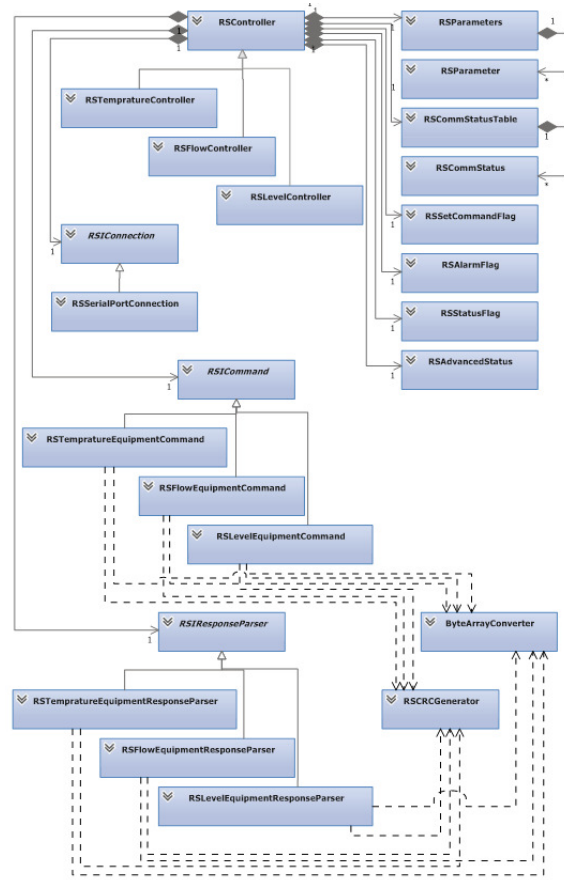


Fig. 8. UML class diagram for system software

3.2. Graphical User Interface

The system software is capable to manage the digital process control entirely. However, it is required to provide a graphical user interface to students for the purpose of making easy managing the process, setting control parameters and observing the experiment data in real-time. Therefore, a graphical user interface is written in C++/CLI and uses the instances of the classes in the system software.

The graphical user interface consists of two tabs as seen in Fig.9. One of them is experiment tabs. This tab includes the following panels: **Connection panel:** User enters the port number and controller id, and then, starts the connection. **Alarm panel:** Alarm states are shown to user. **Graphic panel:** User observes the plots of the experiment data at real-time. **Instant State monitoring panel:** The numeric values of control variables are shown here. **Settings and Record Panel:** User may prefer to record the experiment data to a file and user sets the reference value as a set point. **PID Setting Panel:** PID parameters of the controller may set. **Experiment Control Panel:** User may start, stop, or finish the process control. The other tab is used to observe or change the advanced parameters of the controller.

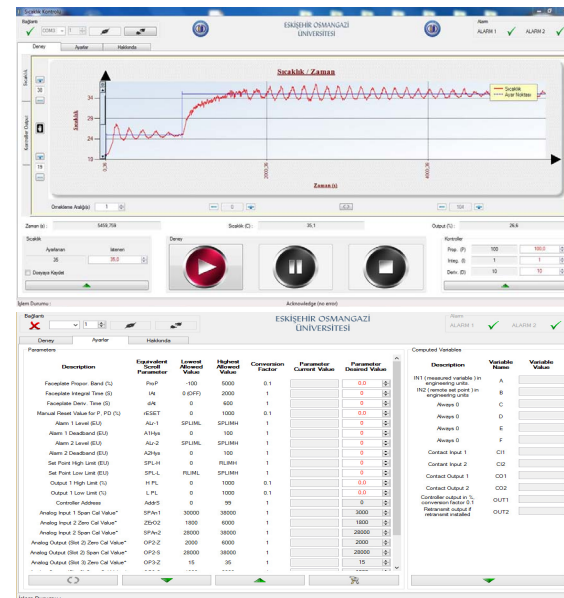


Fig. 9. Graphical User Interface: (Top) Experiment tabs, (Bottom) Settings tabs

4. Applications

Some real experiments are performed to test the designed system. The experiment carried out for three experiment sets.

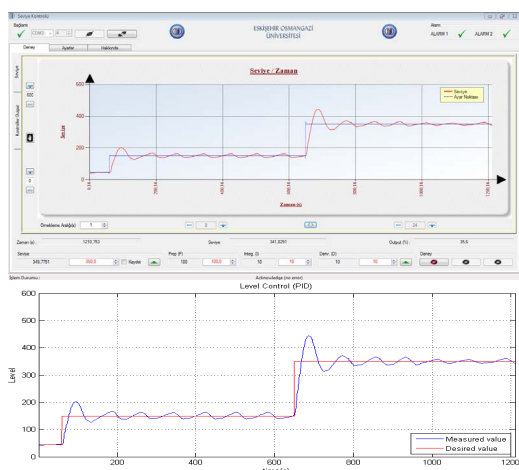


Fig. 10. Level process control experiment (water level-time):
(Top) Screenshot, (Bottom) Data plot

The experiment parameters are as follows:

Set point (SP): During the experiments, the set point is increased three times whenever the response becomes steady-state. PID parameters: For the experiments, PID parameters are assigned to values obtained by trial and error.

Table 1. Experiment Parameters

Experiment Set	Initial Set Point	1st Change	2nd Change	PID Parameter
Temperature	20 C°	25 C°	35 C°	{100,1,10}
Level	50 mm	150 mm	350 mm	{100,10,10}
Flow	1 lt/min.	3 lt/min	8 lt/min	{200,1,1}

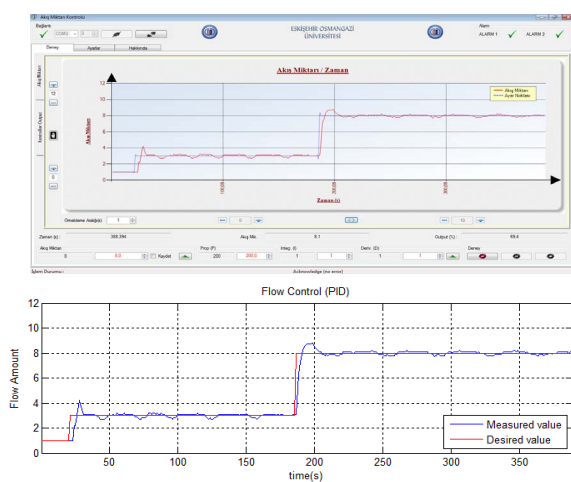


Fig. 11. Flow process control experiment (water flow rate-time):
(Top) Screenshot, (Bottom) Data plot

The result of the temperature process control experiment is given in Fig.9. Interested researchers may find the extensive

results and analysis of the temperature process control experiment in the author's another paper [7]. In Fig.10, there are two figures. The one on top is the snapshot of the screen after the level process control experiment is finished. The other figure plotted by using MATLAB shows the water level variation with time. The plotted data is taken from a file in which there is the data recorded during the level process control experiment. In Fig.11, the similar figures are given for the flow process control experiment. As seen in the figures, one can observe the control variables in a user friendly plot while the experiment proceeds. Also, the control parameters may be changed easily. The user may analyze the performance of the control system later by using the recorded data.

5. Conclusions

In this study, we present a novel design for the purpose of improving a few process control experiment sets which have been used for many years by the department of chemical engineering as the computer-aided experiment sets. As seen from the application results, a real experiment progress may be observed on the computer screen graphically. The control parameters can be changed simply and the changes in the response may be seen efficiently. After the experiment, the file including the real experiment data may be used for further analysis of the experiment results with computing software.

This software has been began to be used since 2014-2015 spring semester at the department of chemical engineering in Eskisehir Osmangazi University. The students and instructors are very pleased with the software.

6. References

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