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Low-cost and Portable Process Control Laboratory Kit

Ade Gafar Abdullah*[1], Dadang Lukman Hakim[2], Muhammad Afif Auliya[3], Asep Bayu Dani Nandiyanto[4], Lala Septem Riza[5]
[1,2,3]Electrical Engineering Department, Universitas Pendidikan Indonesia, Bandung, Indonesia
[4]Department Kimia, Universitas Pendidikan Indonesia, Bandung, Indonesia
[5]Department of Computer Science Education, Universitas Pendidikan Indonesia, Bandung, Indonesia
*Corresponding author, e-mail: ade_gaffar@upi.edu

Abstract

The purpose of this study was to demonstrate a new design of low-cost and portable laboratory kit that is prospective for supporting teaching and learning on the automation process. The kit consists of the water tank filling system (sizes of 50 mL; as a model for describing reallistic tank in the plant) equipped with a programmable logic controller (PLC) integrated with SCADA system, human machine interface (HMI) monitor, reservoir, temperature, water level sensors, mixer, and heater. To be adaptable in any types of classroom, the kit was placed on the portable table (length x width x height of 100 x 50 x 150 cm). To approach the industrial tank system in industry, the tank was designed to be mixed and connected to other tank, and the temperature and water volumetric (water level) was controllable. To examine the impact of the designed kit on the improvement of teaching and learning process, the problem based learning (PBL) approach was also conducted in class. The economic analysis result showed that the present kit is inexpensive and portable, compared to other commercially available kits/devices. The PBL results showed that the kit is simple and to give better illustrations for students to comprehend the process control system in the realistic application in industry. Further developments of this kit is potentially implemented as an experimental tool for undergraduate students.

Keywords: *control system prototype, water tank filling systems, programmable logic controller, SCADA system, problem based learning*

1. Introduction

Industrial automation is one of the important subjects for electrical engineering students. To get minimum requirement in this course, students have to understand about the process control. To consider realistic conditions, the course must be comprehended with experimental studies [1-2]. In the developed countries, the course is usually supported by sophisticated teaching devices for conducting the experimental process in the ideal condition. However, in the developing countries (such as Indonesia), this course has a limitation, making students to memorize the concept without deep understanding on the subject. Due to the limitations of lab tools in the laboratory, students often have difficulty in obtaining contextual experience in their learning process [3]. Though the experience of applying practical knowledge can make it easier for engineering students to handle their work in the future [4]. Laboratory practice is an important activity in engineering education [5]. It's associated with their first experience in learning, thinking and problems solving [6-7]. Limitations of learning resources and laboratory equipment have always been the main problem cause of students not gaining practical experience in learning [8-9]. The learning process becomes not optimal, because laboratorium devices are inadequate. The alternative to solve this problem can be done with computer-based simulation. The analysis and design of this control process requires software such as Matlab [10], Labview [11], and Wonderware in Touch [12] etc., to purchase licenses unreachable by the laboratory budget. The use of physical plants for industrial automation learning is even more difficult to realize, because the price is very expensive. Therefore to overcome these problems we have to develop their own equipment.

To solve the problems, several researchers have suggested the use of strategies: interactive remote laboratory for practicing control engineering process [13], LEGO prototype for control system laboratory [14-16], SCADA for monitoring hybrid wind-PV [17], and digital converter design [18]. The suggested strategies are effective and can be implemented in the

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class [19-22] and user friendly for student [23]. However, several problems are still persisted. The laboratory kits can not describe in detail about their applications to illustrate students for the realistic condition [24]. Further, the kits are complicated and sophisticated, creating conflicts to the limitation of experimental rooms.

Here, the purpose of this study was to demonstrate a new design of low-cost and portable laboratory kit that is prospective for supporting teaching and learning on the automation process. Different from other laboratory kits, our kit is categorized as an easy-to-assemble device. Further, the kit is relatively portable with relatively small in dimension *(length x width x height of 100 x 50 x 150 cm)* and adaptable for being used in various places and classrooms. These novelty makes the kit suitable for developing countries that have many limitations in the experimental rooms and fund. The kit consisted of water tank filling system tank with various features, including control in temperature, water volumetric (water level), and mixing process. Water tank filling system was used as a model in this study because of its widely used in some industries.

2. Design and Implementation of the Process Control Laboratory Kit

2.1. Design of Process Control Laboratory Kit

Figures 1 and 2 are the layout of the devices. The apparatus consisted of two water tank filling systems [25], which was equipped by Programme Logic Controller (PLC) [26] integrated with Supervisory Control and Data Acquisition (SCADA) [27] system, Human Machine Interface (HMI) monitor [28], a reservoir, two plastic tanks with a volume size of about 50 mL, temperature and water level sensors, mixer, and heater. The apparatus was set and put on the table (141 x 106 cm) as shown in Figure 1. Table legs can be detached, making this table flexible, easy to be carried, re-assembled, and set in various places. We also attached shelf (for placing unused plant panel) and put wheels in every table leg (for facilitating mobility and access when the table is carried out) as shown in Figure 2.

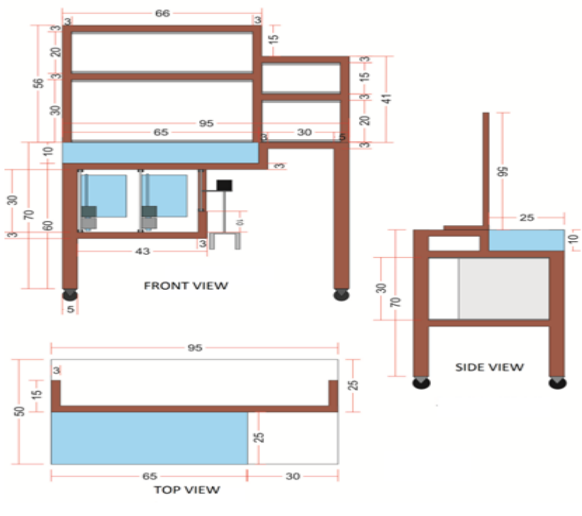

Figure 1. Dimension of the present process control laboratory kit

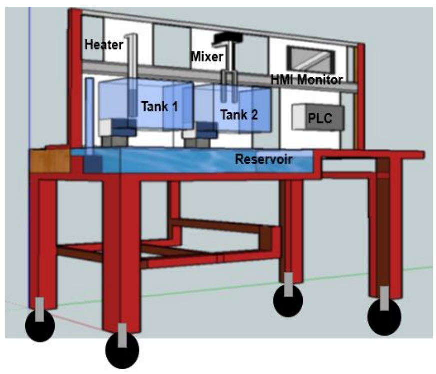

Figure 2. Illustration of the present process control laboratory kit

HMI monitor is used as an interface between operator and machine. The size of monitor is 7 inch, whereas the dimension of HMI panel is 28 x 20 cm. We used a PLC with input-output (I/O), equipped with a voltage of 220V AC, 24V DC, and 12V DC. DC voltage source can be controlled until maximum voltage of 21V. To connect HMI and PLC, we used connector RS-232 type. Transfer USB cable from HMI to the computer was also attached, which was used for collecting experimental data.

Figure 3 shows an illustration image of the process control laboratory kit. We used two types of tanks, in which these tanks were filled with water during the experiment. Every tank was equipped with a pump for flowing water from one tank into another. Solenoid valve was also attached on the bottom of the tank, which was used to drain the water. To control the water level, four sensors were added in the tank. For the first tank, we added a heater equipped with a temperature sensor to control the temperature of water. Voltage sources for water level and temperature sensors were 24V DC. Then, for the second tank, we added mixer.

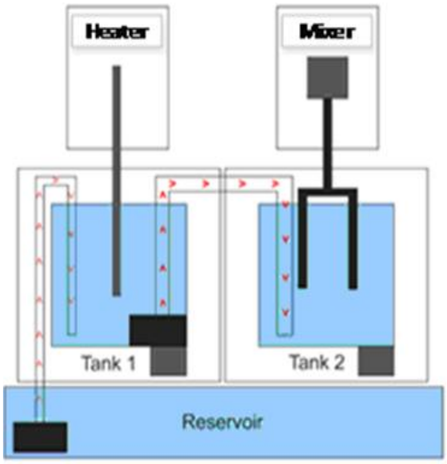

Figure 3. Illustration of the present process control laboratory kit

2.2. Implementation and Application the Kit

2.2.1. Operating Mode

The kit is controllable in two types of modes: manual and automatic. The first mode is the automatic mode (the process are controlled by computer system) and the other is manual mode. In the automatic mode, the process was conducted automatically, which agreed with the parameters set in the initial time using a PLC program. Several parameters were tested, in which detailed parameter test was described in the following: (a) Temperature. Specifically, temperature was tested in the first tank. If the temperature of the water reached the set point, the pump flowed the water from the first tank to the second tank; (b) Processing time. This test is conducted in the second tank that is supported with the mixer. When the time reached the set point, the mixer stopped and solenoid valve was activated to drain the water to the reservoir; and (c) Water level. This parameter was tested in both tanks. When water level reached the set point, water flowed from the first tank to the second tank.

Regarding the manual mode, all processes conducted manually. Thus, all parameters depended on operator’s command. This mode can be applied for the random system. In this mode, STOP process is also added for stopping the process completely as well as returning the process condition to the initial condition.

2.2.2. I/O Wiring Diagram

Figure 4 shows I/O wiring diagram. The software for applying this system is GX Developer. In this system, the output control was done using direct addressing, in which this directly focused on the relay to the plant. Both modes (i.e., manual and automatic modes) can be used for this system.

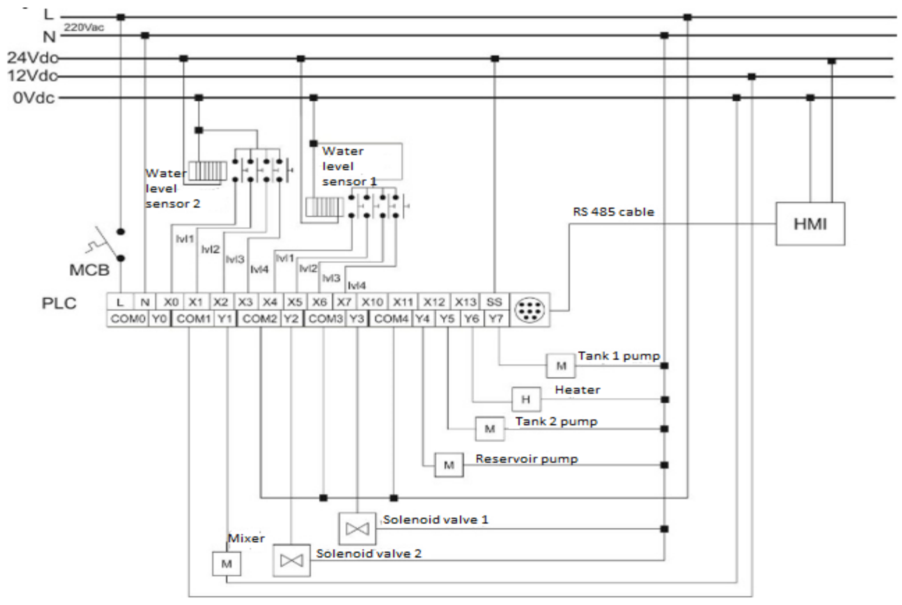

Figure 4. I/O wiring diagram

2.2.3. Human Machine Interface

Figures 5 and 6 are HMI results for automatic and manual modes, respectively. The experimental results from the process can be observed in the computer monitor. The design of HMI was equipped by controlling buttons for start, stop, and reset. The HMI was also equipped by an indicator lamp to show whether the process was conducted or not.

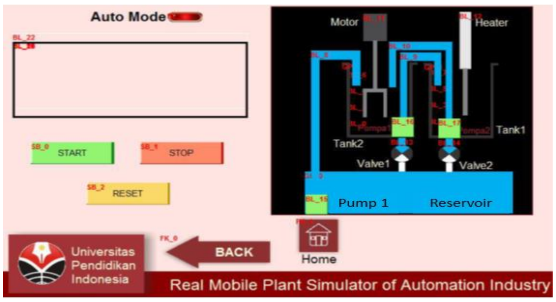

Figure 5. Photograph image of HMI auto mode

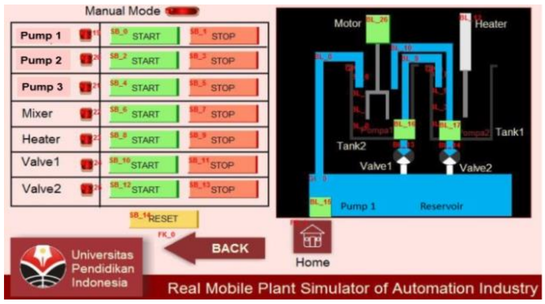

Figure 6. Photograph image of HMI manual mode

2.2.3. Application of Control System for Undergraduate Students

To confirm the effectiveness of the process control laboratory kit, we tested this kit to 40 students of Electrical Engineering Education Department in Universitas Pendidikan Indonesia. The test was conducted in the process control course, including eight theoretical and eight experimental class sessions. In the theoretical class session, the class was started with introduction of industrial otomation, plant system, control system and PLC, design of control system, field bus, SCADA, industrial communication protocol, ability analysis, and safety analysis. In this session, students also have to understand about PLC and SCADA system. In the experimental session, Problem Based Learning (PBL) [29-32] was adopted. Students were divided into several groups, in which each group consisted of 5 students. The groups would be assigned for solving the different process control problems. Students have to make presentation and reports, including work description, work flow system, wiring, as well as testing control system.

3. Results and Discussion

3.1. Results

a. Economic Analysis

Table 1 shows detailed materials used for designing the laboratory kits. Based on these materials paneled in Table 1, the kit is constructed from IDR 10.515.749. Economic raw material cost analysis result that the total cost for designing the process control laboratory kit is less than 1000 USD. Since the kit is constructed from inexpensive raw materials, the total cost for the kit will be competitive against commercially available kit/device.

Table 1. List of Materials for Process Control Kit

Devices/Materials	Quantity	Price (Rp)
HMI Weintek MT6070IH	1 pcs	1,869,200
Pump 24 V DC	3 pcs	1,275,000
Pow er Supply	1 pcs	917,058
PLC Mitsubishi FX1s 20 I/O	1 pcs	1,039,866
Stainless Steel Table	1 set	2,424,533
Acrilic	1 set	579,731
DC motor for mixer	1 pcs	90,933
Heater	1 pcs	126,533
Probe	80 pcs	775,900
Banana plug	80 pcs	376.000
Solenoid Valve	2 pcs	305,400
Cable	1 roll	358,400
Temperature sensor	1 pcs	121,062
Reed sw itch magnet sensor	8 pcs	210,133
Alumunium	6 meter	210,000
Relay	4 pcs	20,000
Fitting valve	6 pcs	192,000

b. Performance Test

Figure 7 presents performance test results of the present kit. In short, the figure compiled from the HMI image, the appearance for the flow of water from from tank 1 to tank 2 after water level is reached, and the appearance for the water condition after the flow is stopped, corresponding to Figure 7a, 7b, and 7c, respectively. In general, the performance test verified that all components worked well. Pump, temperature and water level sensors, mixer, heater, and solenoid valve worked well. Excellent connection between PLC and HMI was found, verified by the flow of water after specific condition in the experiment. Then, after heating the water until up to 80^{o}C, the system was flow the water to the second tank as shown in Figure 7c.

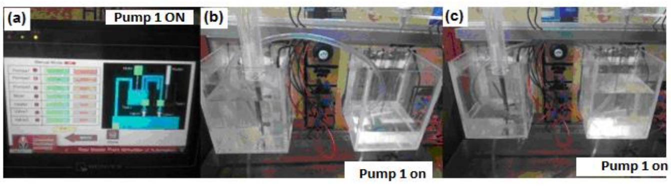

Figure 7. Performance test of the designed laboratory kit: (a) the photograph image of HMI result; (b) the photograph image of system when flowing water to the first tank from the reservoir; and (c) the photograph image of system when flowing water from the first tank to the second tank

This performance test stage simulates the mixing process of hot liquor solution in tank 1 and tank 2. Water solution composition is 25% in tank 2 and 75% of tank 1. Thus, the water position in tank 2 is only up to the water level sensor level 1. Process this performance test simulates the manufacture of refinery sugar [33]. In that process, the affine syrup is heated and then mixed with ground cane and stirred with a mixer.

c. Process Control Laboratory Kit

Figure 8 shows a photograph image of kit in the experimental room. The kit was simple and portable. Compared to the class room size, the kit is typically small and portable in many types of room size. Indeed, this will be adaptable for developing countries that have limitations in classroom. This device consists of 7 panels, namely: mixer, heater, tank 1, tank 2, HMI, PLC, dan power supply. The mixer panel serves as a place to store DC motors. It consists of two pieces of probes that serve as a voltage source. Both sources can be provided with 12-volt power supply or voltage from the DC regulator voltage. Panel heater serves as a stored heater. There are only two pieces of a probe that serves to provide a voltage source to the heater.

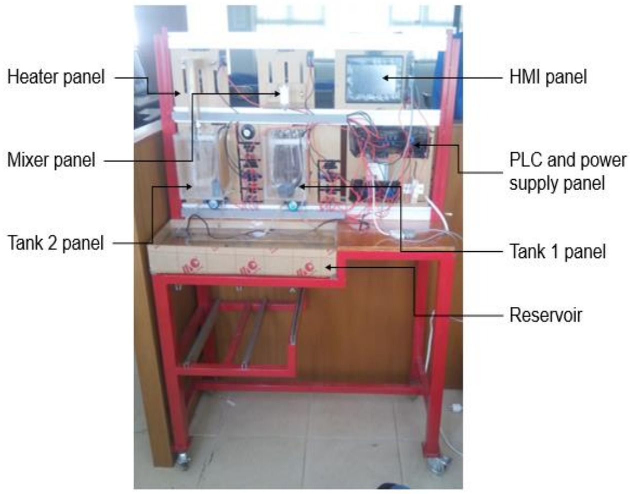

Figure 8. Process control laboratory kit in the experimental room

Tank panels have a function to accommodate the fluid to be processed. The pumps on both panels have a duty to move the fluid. Solenoid valve serves to drain fluid and water level sensors that handle to check the water level (consisting of four levels with level 4 is the highest point). Especially in tank 1 is equipped with a temperature sensor that serves to measure the temperature of the fluid. This temperature sensor has a working principle like a switch. The current will be interrupted when the temperature reaches a predetermined limit. Thus the tank1 serves as a place for fluid heating. Water level and temperature sensors have a 24 Vdc.

The HMI panel is designed to control and monitor the process. This panel material is acrylic with 5mm thickness. This panel consists of 7-inch screen, 24 Vdc power probe, connector to PLC, which serves as a communication medium between PLC with HMI, and USB transfer cable from HMI to computer, function to download program layout that has been made in computer. The PLC panel and power supply serve as a source of control and simultaneously as a power-supply panel. In this panel, there is a Mitsubishi PLC with FX1s type, which has 20 I/O as well as various power supplies ranging from 220 volt AC, 24 Vdc, 12 Vdc and an adjustable source up to a maximum of 21 Vdc. Tabel 2 show the full description panel of PLC and power supply.

Tabel 2. Function of PLC and Power Supply Panel

Panel	Device	Function
PLC	Input	12 input start from X0, X1, X2, X3, X4, X5, X6, X7, X10, X11, X12 and X13. PLC power supply, serves to provide voltage to the PLC. Consists of 3 probes ie L, N and Ground. S/S serves as a conduit of the input voltage at the input. The amount of voltage depends on the sensor characteristics. In this simulator each sensor has a 24 volt DC.
	Output	PLC output voltage: 24 volt DC. Output Y0 and COM0. Output Y1 and COM1. Output Y2 and COM2. Output Y3 and COM3. Output Y4, Y5, Y6, Y7 and COM4.
Power supply	Voltage source 220 volt AC	Consists of phase L and N. This source aims to provide voltage to the PLC and its output requiring 220 Vac, eg heater, pump and solenoid valve.
	Voltage source 24 volt DC	Consists of poles + and -. This source serves to provide voltage on the HMI device.
	Voltage source 12 volt DC	Consist of poles + and -. This source to serve voltage on a DC motor requires a fixed voltage of 12 Vdc.
	Volt DC Regulator	Consist of poles + and -. It has a maximum voltage of up to 21 Vdc. This regulator serves to provide a source to the mixer so that the speed of the motor can be adjusted.

d. Wiring and testing the control system

Figure 9 shows photograph image of students when doing wiring experiment. Students' work was categorized to be successful because their design is appropriate to the standard of control system (including panel and port connection). The developed system was connected to the computer, as well as installing PLC for controlling the experimental condition. However, students faced problems for connecting the control system to the computer. The average time for wiring process was 60 minutes, however the average time for connecting the control system to the computer was 30 minutes.

Figure 9. Wiring process using process control laboratory kit

3.2. Discussion

Learning process control is one of the subjects studied in the curriculum of electrical engineering. This course requires practical experience for students. Therefore, this lecture should be equipped with laboratory sessions. Industry automation learning competency standards require students to operate an integrated PLC with SCADA system to control the process. The availability of experimental support equipment has always been an obstacle for higher-education institutions in developing countries, because the price is very expensive. In addition, the limitations of the laboratory room make it an obstacle to carrying out the ideal lab work. Technological change is very fast, while the teachware includes software and innovation laboratories develops more slowly [34].

Laboratory kits are designed to train basic logic and advanced logic so that students are skilled at operating the process control equipment. Completeness of control process equipment is stored on a table that has dimensions of 141 x 106 cm. This device is modular. The panels can be easily assembled. Because of its mobile concept, it is very easy to carry into the classroom or to places that have a great range of distances. At the bottom of the table is a shelf that serves to keep the plant panels unused. The wheels on each leg of the table are installed to facilitate the mobility of the device, especially if you want to be taken for learning activities in a classroom away from the laboratory. This equipment simulates the fluid transfer and mixing process in two tanks. Device consists of PLC, HMI Monitor, reservoir, tank, level sensor, mixer and heater. The actuators in this equipment consist of two pumps and two solenoid valves.

This device consists of a programmable logic controller (PLC) integrated SCADA system with the plant in case of a water tank filling system, aims to provide an overview of fundamentals to advance on the practical concept of discrete control systems. This device has a simple I/O plug-in board, controller module, plant module and power supply module. For measuring its performance, the equipment is trialed in the automation industry learning with problem based learning approach. The implementation results provide evidence, this device capable of providing real examples the process control in industry, and can improve students' ability in designing of the process control systems. Problem-based learning provides learning experiences for students to work in teams, respect the opinion of other students, sharpening the ability to argue and present the results of the project. This device very suitable for use in lectures with problem-based learning. Features of this device can be implemented as instructional media for undergraduate students from electrical engineering faculties. These laboratory kits have a real plant concept [35]; that is the process of control that takes place involving various components can be seen clearly in the actual industry. This is the main attraction, so students are interested to practice. The layout of each panel was very informative. Students can easily understand the example of the given case and apply the case to laboratory kits. The instructions for using this device are described in the manual book that has been prepared.

4. Conclusion

This paper shows a method for developing a simple, low-cost, and portable control process laboratory kit. Our analysis confirmed that the kit was categorized as a low-cost and portable device, which is prospective to be implemented in developing countries. To show the effectiveness of our kit, we also tested how to design this laboratory kit to 40 students. The result showed that this kit can be used for a tool for improving student comprehension in the control process in the realistic application in industry.

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