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Development of In & Out Water Control System Application Kit With PLC and HMI For Automation Course

Norhasnina Mokhtar, Nurul Azimah Ahmad Arzaai*, Fauzi Ghani

[1]Electrical Engineering Department, Politeknik Sultan Azlan Shah, 35950, Behrang, Perak, Malaysia
*Corresponding Author: norhasnina@psas.edu.my

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Abstract: Teaching aids are very important tools in a classroom to conduct engaging activities during the lesson, in addition it helps students understand the course content better. Teaching and learning might be boring if only conducted in verbal or chalk and talk method since students need to learn in a various way such as by observing, listening, memorizing, remembering, and describing. Appropriate teaching aids can enhance student understanding and interest in the subjects taught, especially in topics that are difficult to understand such as programming. This paper presents the development process of teaching aid for supporting the teaching and learning process in automation course, specifically in designing programming language of Programmable Logic Controller (PLC) and Human Machine Interface (HMI). It is equipped with prototyped application model. This teaching aid has three main parts namely PLC kits as the main controller to control the operation of the designed system, HMI kit as the operator control panel to the PLC, and application kit which consists of in and out water control system, input devices and output devices. The development stages consist of analysis, designing the system, hardware development, implementing the PLC programming using CX – Programmer, constructing HMI program using CX – Designer, interfacing between software and hardware, product testing and lastly the evaluation from experts. The results obtained shows that the applications of In and Out Water Control System operated accordingly and the integration with PLC and HMI were successful. This teaching aid can be applied in other institutions.

Keywords: *Programmable Logic Controller (PLC), Human Machine Interface (HMI), teaching aids, automation course, water control system*

1. Introduction

Programmable Logic Controller (PLC) and Automation is one of the core courses to be taken by students in Electrical Engineering Department of Malaysia Polytechnic. PLC and Automation became a significant subject due to many industries used PLC to control their machinery, changing from manual to automatic while replacing human power [1]. In industrial revolution 4.0 (IR4.0), for a PLC system, the automated technology is connected to internet through HMI as the interface for the input and output device between human and machine. Therefore, to ensure that the graduates produce by the polytechnic are aligned with the industrial need, the HMI and PLC as automatic control device is embedded in the PLC course.

The use of teaching aids can help both teachers and students to disseminate information regarding the lesson taught clearly and systematically. The development of teaching aid also can help to overcome the problem faced

Corresponding Author: Norhasnina Mokhtar, Electrical Engineering Department, Politeknik Sultan Azlan Shah, 35950, Behrang, Perak, Malaysia, +60137434301

during practical and teaching process at the same time improve the success of the learning subject [2]. Currently, Polytechnic Sultan Azlan Shah uses the Omron CPM2A PLC trainer for PLC and Automation subjects. The Omron CPM2A is a type of trainer kit which operation still uses a console specially provided by Omron. The use of this console makes the Omron CPM2A PLC more difficult for students to use because of its low level of flexibility and limited of application for hands-on learning.

This paper presents the development of In and Out Water Control System Application Trainer Kit with Programmable Logic Controller and Integrated Human Machine Interface for PLC and Automation course, specifically in designing programming language of Programmable Logic Controller (PLC) and Human Machine Interface (HMI). It is equipped with prototyped application model. This teaching aid has three main parts namely PLC kits as the main controller to control the operation of the designed system, HMI kit as the operator control panel to the PLC, and application kit which consists of in and out water control system, input devices and output devices. The PLC model used for this project is Omron CP1E, which can be used with a HMI unit.

In order to train students, the design and implementation comprise the wiring between the inputs and outputs devices to PLC, PLC programming using ladder logic with the using the CX-Programmer software, downloading and uploading the program to the PLC through USB cable, constructing HMI program using CX – Designer, interfacing between software and hardware, product testing and lastly the evaluation from experts. The fabrication of the trainer kit for education purpose to enhance the student's theorical comprehension and hands-on skill especially for PLC programming and applications.

2. Literature Review

A Programmable Logic Controller or PLC is a special form of microprocessor-based controller that uses programmable memory to store instructions and to implement functions such as logic, sequencing, timing, counting, and arithmetic to control machines and processes [3]. It is a specialized type of system used to control machines and processes. They have been introduced in the early 1970s to replace the existing relay control logic that became obsolete and expensive for implementing systems at that time. On the other hand, PLCs have offered flexibility, higher reliability, better communication possibilities, faster response time, and easier troubleshooting. So far, PLCs have been mainly of interest to industrial control engineers that introduced, developed, and standardized their own design methods and programming languages [4] [5].

Furthermore, PLC system is a computer system that consists of various hardware components such as the central processing unit (CPU), programming devices, internal and external hardware components, inputs/outputs devices and power supply [3]. There are many methods available to program a PLC, for example the ladder diagram, mnemonic code, sequence functional chart and block diagram. The ladder diagram makes use of a symbolic set of instructions to create a program, which can also be translated from a relay ladder logic sequence or hardwired connection. It also reduces the complexity of programming, easy to design and understand by the operator [6].

A Human-Machine Interface (HMI) is a user interface or dashboard that connects a person to a machine, system, or device. While the term can technically be applied to any screen that allows a user to interact with a device, HMI is most used in the context of an industrial process [7]. Besides that, HMI provides the user a means of controlling, monitoring, managing and visualizing device or system processes. With controls and readouts graphically displayed on the screen, the operator can control the machinery by using either the HMI's touch screen or external buttons [8].

The interaction between the HMI and the operator is presented by a screen with dynamic icons, figures, and text. The goal of interaction between the operator and then machinery at the user interface is to effectively operate and control of the machinery and receives feedback from the machine which will aids the operator in making operational decisions. The user interface of an HMI includes the hardware and software components of the system. It also provides a means of input allowing the user to manipulate the system and output allowing the system indicating the effects of the operator user manipulation [8].

Learning outcomes achievement is a crucial issue in the teaching process. However, there are several classical problems in study activities such as less attractive and entertaining for the students. Furthermore, for technical courses that require practical work, the use of teaching aids such as trainer kits, simulations, and engineering tools and equipment really help the students understand the topic better as well as prepare them for real-world applications [9]. Teaching aids are defined as all physical tools or equipment that can be used to deliver the lesson materials including textbooks, miniature, prototype, dummy object, and all multimedia devices [10].

By using teaching aids, it will help to disseminate information regarding the subject that is being taught more clearly and systematically to the students. Furthermore, it will also allow the teacher to explain the learning content more accurately and comprehensively compared to using chalk and talk method only [2].

Industrial automation covers a wide field from automation manufacturing to products development and

process. For an electrical engineering student, automation and control system is a compulsory course. This teaching was developed to fulfil the curriculum of the Department of Polytechnic Studies, Ministry of Education Malaysia by emphasizing the effectiveness level on student learning achievement by taking into consideration the needs to master the skills of designing, installing, and operating an automation system, specifically using the PLC and HMI.

3. Methodology

The development of In and Out Water Control System Application Kit with PLC and HMI referred to Addie model according to Robert Maribe Branch. The research model consists of five important stages which is Analyze, Design, Develop, Implement and Evaluate [11]. The following is a description of each stage for developing the In & Out Water Control System Application Kit With PLC And HMI.

Analysis Stage

Analysis stage is the earliest in the development of this kit. This stage determines the main elements needed to produce the In & Out Water Control System Application Kit With PLC And HMI. As the syllabus being revised which include the HMI in the syllabus, lecturer need to find a method to make sure student understand the HMI usage in practical way or as close as actual condition as possible. By having a physical HMI, students will have the experience, feel, and look on the usage of this device in actual environment as well as understand the operation of HMI itself.

The other hiccup during lecture is students have problem to relate the programming and simulation they have done with the real application of the programming. For example, for an automation that used sensor as the input device, during the simulation, the students need to manually turn on and off the sensor. But, in a real application the sensor is automatically turn on based on a preset condition or limit. Thus, resulting some students confuse between automated and manual system. Furthermore, by having a real application such as In and Out Water Control System with combination of PLC programming and HMI, lecturer can show the impact of program changes to that application easily.

Design Stage

Design stage is the most important phase in the product development which aim to be a very useful teaching aid for lecturer. In this process, criteria of the training kit are defined to make sure it achieves the objectives. The selection of hardware and component is the first criteria during this design stage. This is to make sure the selection is aligned with the syllabus and suitable for teaching practices. The main hardware and component for this build up are as below:

- Programable Logic Controller
- Human Machine Interface.
- Prototype application model.

In this build-up, the Programmable Logic Controller that being selected is Omron CP1E family. Exact model for this PLC is N20DRA. This PLC is being selected because of criteria in Table 1 below:

Table 1 PLC Design Criteria

Criteria	Description	Reason
Sizing	Compact type	This PLC is small enough to fit in training kit as well as cost effective for educational purpose.
Number of digital input and output	12 Digital Input 8 Digital Output (Relay Type)	Number of input and output is sufficient for teaching and simple application. The output is relay type which suitable for controlling most of output devices with several voltage level and type such as AC & DC.
Communication Interface	1 USB Port 1 Serial RS232 Interface	USB port is used to connect PLC to PC which used to read or write program. Serial RS232 interface is used to communicate to other peripheral (In this kit, it uses to communicate with HMI)

On the other hand, the Human Machine Interface that being selected is NS Series by Omron. Exact model for this HMI is NS5–SQ11B-V2. This HMI is selected because of criteria in Table 2.

Table 2 HMI Design Criteria

Criteria	Description	Reason
Sizing	5.7 Inch size	This HMI is the smallest HMI available for its series. Perfect fit for training kit.
Communication Interface	1 USB Port 1 Serial RS232 Interface 1 Ethernet Interface	USB port is used to connect PLC to PC which used to read or write program. Serial RS232 interface is used to communicate to other peripheral (In this kit, it uses to communicate with PLC). Ethernet interface can be further use for other communication.
User Input	Touch Screen	By having touch screen interface, it can simulate component action such as push-button operation, lamp on off state etc.

Prototype application model for this training kit is selected by adopting the water tank control application. This application is selected because the usage of this application in industry is quite large, for example in water treatment plant, beverages factory, fertigation and irrigation in agriculture and painting factory in automotive industry. This prototype model also can be implemented in many scenarios such as filling and draining tank, maintain the tank level with lower limit alarm and so on. Compared to other application such as the conveyor, it only has 2 possible scenarios which are forward and reverse movement only.

The second criteria in this design stage for In & Out Water Control System Application Kit are, the ease of use for teaching aids. In real application, the input and output devices wiring to the PLC are permanently installed, however for the teaching aids, the wiring is not permanent because the lecturer needs to demonstrate to the student the wiring connection. In addition, the students also need to do wiring as per their practical task. Even though the PLC, button and signal lamp are industrial grade, tighten and loosen the wiring terminal can cause the damage to the wiring terminal itself. Furthermore, the wiring activity for each component also take time to complete whereby student need to splice and terminate each wire. To avoid both scenarios, each terminal is connected to banana jack port and being expose to the surface of the kit. This means the kit will become a plug and play wiring interface.

Development Stage

In this stage, In and Out Water Control System Application Kit is developed to suite with the specifications derived in the design stage as well as the injection of usability and portability in mind. The kit is divided into three main kits component according to the usage during teaching. By having these kits divided it ease the kit portability during usage. Figure 1 below show the block diagram of each kit section as well as the connectivity involved.

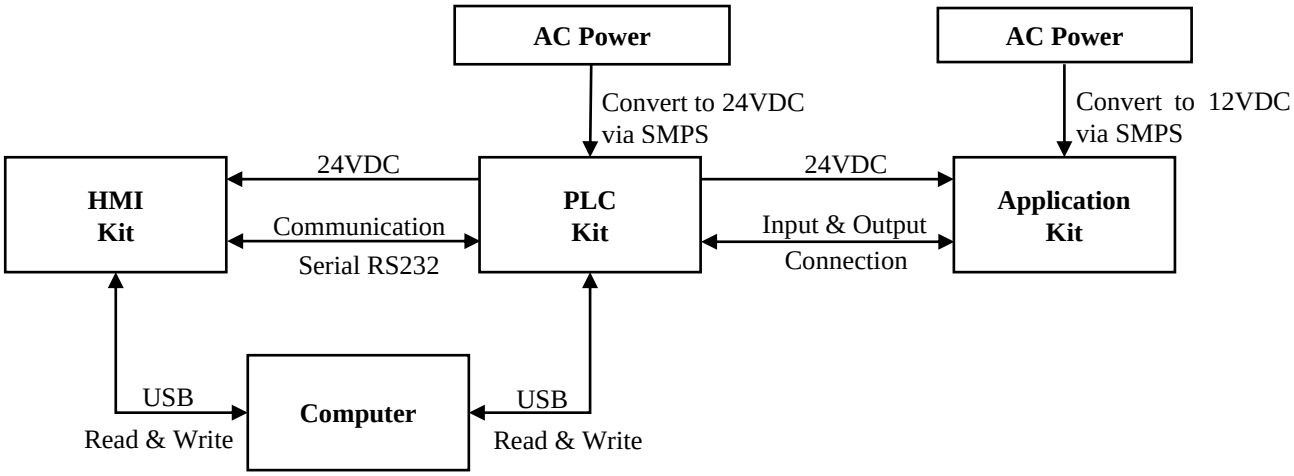

Figure 1 Development Block Diagram

The teaching aid is divided into three separate kits which is PLC Kit, HMI kit and application kit. Each of the kit components were design and installed onto metal casing with sizing of 40cm x 27.5cm x 7cm. All component that was installed are wired to female connectors and banana plug male connector with wired was used for connecting the devices. This plug and play method make easier during demonstration session [12] and take less time.

The most important kit component is the PLC Kit. It is divided into two sections, namely power supply section and PLC section. Power supply section consist of eight female connectors. The female connectors are used to represent positive and negative terminal of 24VDC power supply and match with standard connector color, which is red for positive terminal and black for negative terminal. The power supply wiring connection start from 240VAC to power up PLC CPU and switch mode power supply (SMPS). Then the SMPS convert the AC to 24VDC which will be used later to give power to HMI Kit and input or output devices in application kit. This kit component can be programmed directly using computer by plug-in USB cable to PLC. The PLC also have built in serial RS232 communication port that will be used later to communicate with HMI kit component.

The second kit component is Human Machine Interface (HMI) kit. In this kit, there are female banana connector installed and wired to the power input of the HMI. Since this HMI is powered using 24VDC, the 24VDC output from PLC kit can be used to connect to this power input connector. The HMI is panel mounted type and the communication port is at the back of the HMI. For ease of connection, USB and RS232 breakout port is installed at front of the kit and wired directly at the back of the HMI, so that the communication port can be access without dismount HMI or opening the kit box. The RS232 ports are used to communicate with PLC Kit whereas the USB connection are used to communicate with programmer software via computer.

The third kit component is the application kit. A small tank structure was installed onto this kit surface. The component of this application includes push button, pilot lamp, buzzer, float sensor and motor pump. For ease of connection, same concept with other kit component was used which was using female banana connector and wired to each component. This kit also installed with switch mode power supply (SMPS) which convert 230VAC to 12VDC. This 12VDC is later being used to drive motor pump which only accept this voltage level. Two different color of pilot lamp was installed and can be used to represent the running and stop condition. Two float sensors were installed at the tank structure as the sensing devices for upper and lower water limit.

Implementation Stage

During implementation stage, an experiment was conducted to make sure the interface between software and hardware function accordingly. A program has been developed which involve all the input and output devices. The PLC programming was created using CX-Programmer as in Figure 2. The program was written using ladder diagram. It is called ladder diagram because it is shaped like a ladder and each line is called a rung. By using the computer software which is CX-Programmer, user can design the logic, simulate the program, and monitor the real time input output status during hardware operation.

To design the HMI interface as in Figure 3, CX-Designer program is used which is part of CX-One suite. Using this application, user can create virtual devices in the HMI design such as button, indicator lamp, as well as counter or timer value. Each virtual device has their own properties that can be modify for example, button operation in HMI can be configured as momentary or latch operation. In the HMI, the application logic cannot be created, but the state of the virtual device can be configured. For example, if the virtual lamp is turn on in the HMI, the virtual lamp color will change from red to green and vice versa. The most important is to establish communication between PLC Kit and HMI kit, the communication parameter must match both sides. For example, the baud rate of serial communication must be same.

After the PLC logic and HMI interface developed, the actual wiring connection is connected using jumper wire equipped with banana male connector as shown in Figure 4. The precaution that needs to be taken is to make sure the polarity of all devices was connected correctly to avoid component faulty or damage.

Evaluation Stage

In this stage, the results were discussed based on the testing for In & Out Water Control System Application Kit With PLC And HMI. Then, the design, usability and satisfaction of teaching aids was verified based on expert validation. The selection of experts was based on her/his teaching experience and subject matter expert. Validation results were obtained from 5 lecturers from Malaysia Polytechnics.

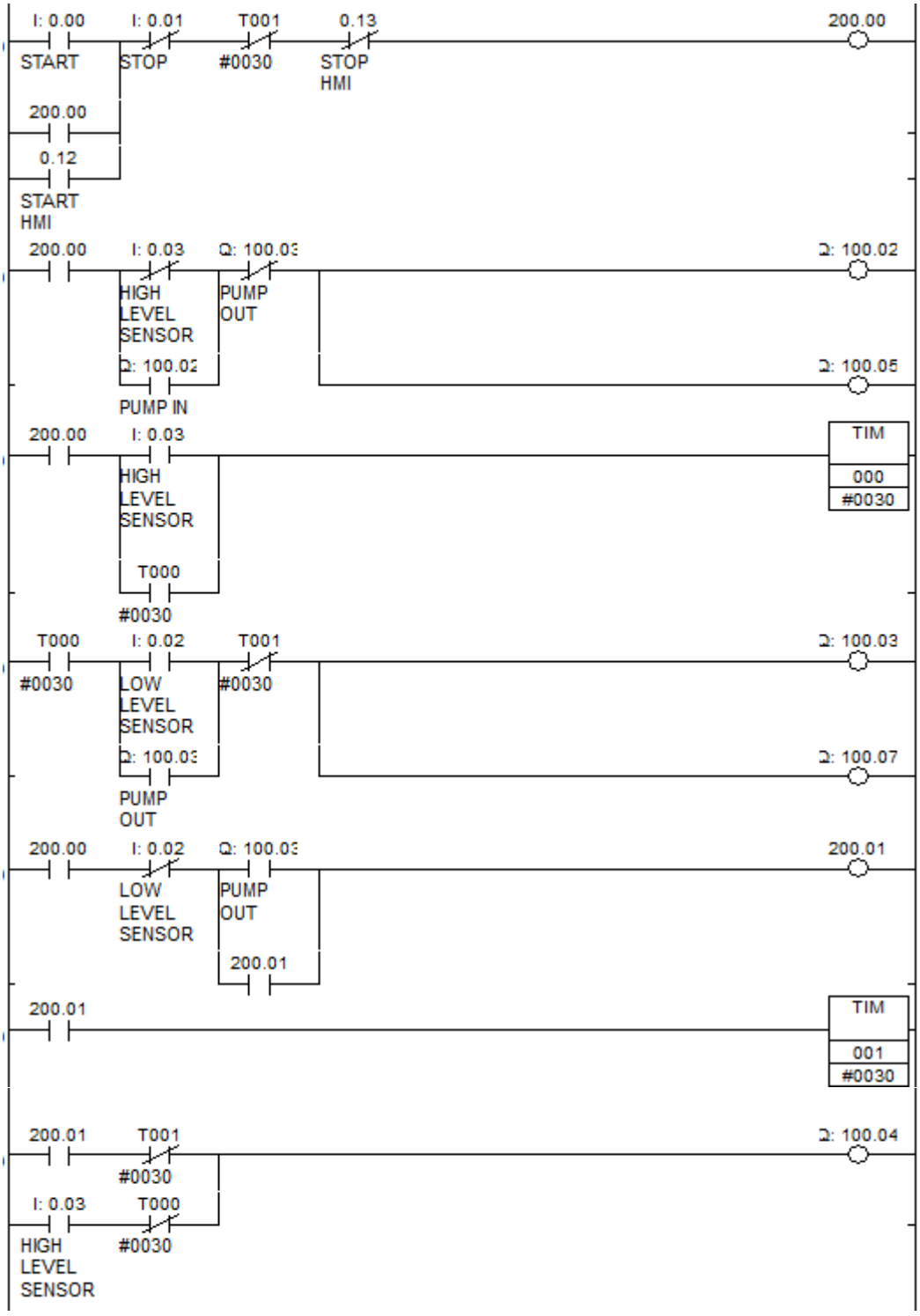

Figure 2 Ladder Diagram of PLC

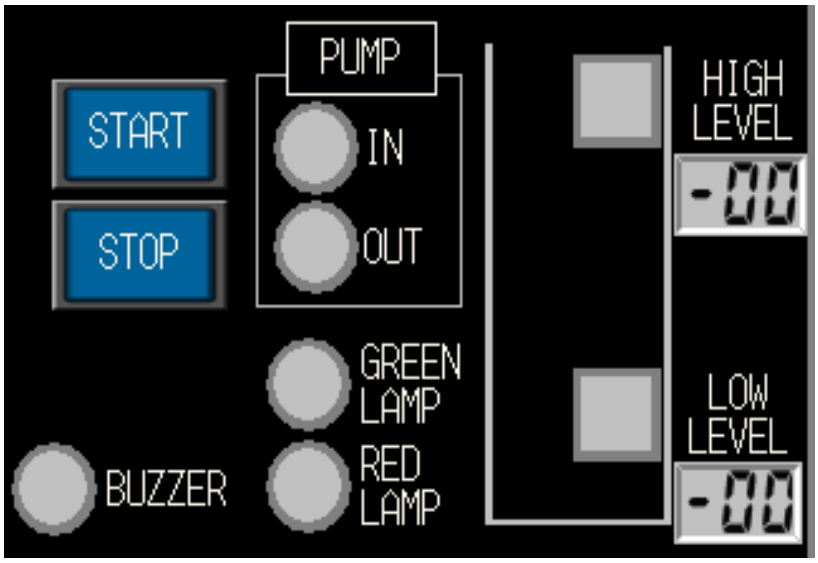

Figure 3 User Interface of HMI

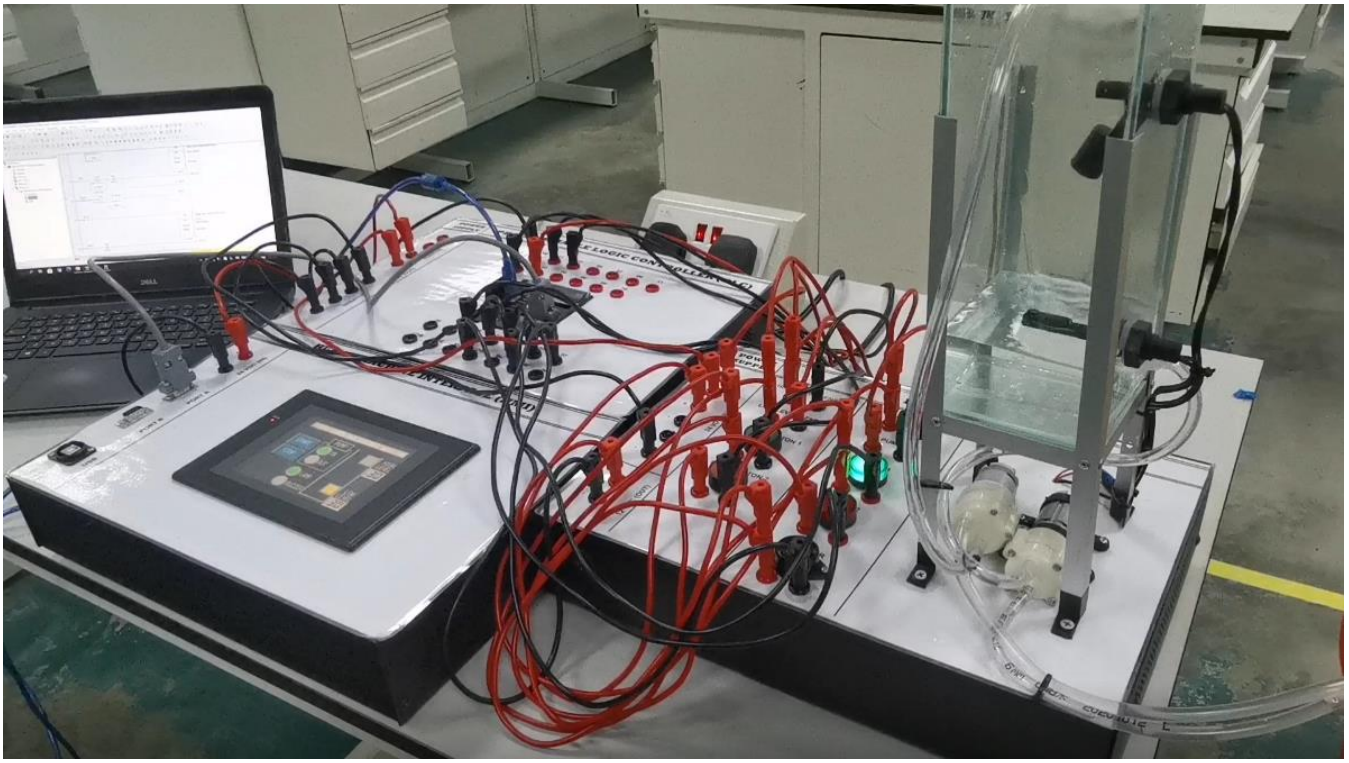

Figure 4 In & Out Water Control System Application Kit with PLC And HMI

4. Results and Discussion

Table 3 shows the result when each part of the kit was tested. The aim of this testing is to ensure that the performance of all devices in good condition and can work appropriately. Based on the result obtained, all devices perform as expected. Thus, concluded that the In & Out Water Control System Application Kit With PLC And HMI is fit for use.

Table 3 Testing Device for In & Out Water Control System Application Kit With PLC And HMI

No	Part of Device	How to test	Result
1	Power in	Connect to the normal AC power into the Kit PLC	1. Using multimeter, the voltage of AC voltage is measured between 220VAC to 240VAC. 2. The PLC also turning on based on PLC Power indicator
2	Power Supply Output 24V	Supply AC power to 24VDC switch mode power supply (SMPS)	Using multimeter, the output voltage is measured at 24VDC output port, and the reading is 24VDC.
3	Power Supply Output 12V	Supply AC power to 12VDC switch mode power supply (SMPS)	Using multimeter, the output voltage is measured at 24VDC output port, and the reading is 24VDC.
4	PLC OMRON CP1E	Execute simple program to test input and output capability	1. The input of PLC is being connected directly to 24VDC and the reading in program is turn on and vice versa 2. The output program is executed, and the build-in relay is clicking, and output indicator is turning on
5	HMI OMRON	Supply 24VDC to HMI Kit, connect RS232 cable to PLC Kit and perform simple design	1. The HMI is turning on after giving the power 2. The address in the PLC is turning on and off according to the state at the HMI
6	Float Sensor 1 & 2	Detect to a certain depth of water which activate the input section of the PLC Kit	When the water reaches at the desired level, the input PLC that being wired is turning on.
7	Push Button 1 & 2	The push button is momentary type and normally open type. The test is carried out by push or release the button	Using multimeter with continuity checker, it shows short circuit when pressed and open circuit when release.
8	Pump 1 & 2	Supply 12VDC to the pump motor and put water at the inlet of the pump	When supply is turn on, the pump is operated normally by transferring water from inlet to outlet.
9	Pilot Lamp	Turn on or off supply 24VDC to the lamp terminal	The lamp is turn on or off according to the supply
10	Buzzer	Turn on or off supply 24VDC to the buzzer terminal	The buzzer produce sound when the supply is on and stop sound when the supply is off.

Table 4 Expert Evaluation

No	Evaluation Elements		
	Design	**Usability**	**Satisfaction**
Expert 1	95	100	80
Expert 2	90	100	100
Expert 3	100	100	100
Expert 4	100	100	100
Expert 5	100	80	80

Figure 5 Expert Evaluation by Elements

The In & Out Water Control System Application Kit with PLC and HMI design, usability and satisfaction was verified by 5 expert lecturers who teach the PLC & Automation course in polytechnic Malaysia. Table 4 shows the results obtained from the expert verification of the product's design, usability, and satisfaction. The Likert Scale used is 1 until 5. based on the survey, the percentage of the mean value for each element was calculated and shown in Figure 5. It shows that overall, the teaching aid receives a very good rating by the expert.

Among the 3 main categories in the survey, the design category receives the highest score compared to the other two categories, which is 97%. The verification was made on compact teaching aids, attractive interface, good labelling and easy to install. For the usability category, the result obtained is 96%. This indicates that the teaching aid has all fulfill all functionality needed, fits with students existing knowledge, meets the course content and is suitable to be used as teaching aids for automation course. Lastly, 92% of the respondents were satisfied and interested to use In & Out Water Control System Application Kit with PLC And HMI as teaching aids.

5. Conclusion

As the conclusion, the development of In & Out Water Control System Application Kit With PLC And HMI has been achieved based on the objective identified. Based on the survey conducted, the experts among Polytechnic Malaysia automation lecturers were satisfied with the product and agreed that this teaching aids can be used to support the teaching and learning process in automation course, specifically in designing programming language of Programmable Logic Controller (PLC) and Human Machine Interface (HMI). This teaching aids can also be used in any institution that offers electrical engineering and automation program specifically the Programmable Logic Controller course. For further research, the researchers plan to continue the research especially on the effectiveness of teaching aid among students to improve their learning outcome.

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7. References

[1] M. Artiyasa, N. Destria and M. A. Desima, "Creating Kit and PLC Application with Industrial Applications for Practice Learning of PLC Technology in Electronics Nusaputra University Sukabumi," *Journal of Physics: Conference Series,* Vols. 1516, No. 1, p. 012010, 2020.

[2] Z. Hanapi, T. J. Rui, R. C. Rus, N. F. Dahalan, M. S. Sharif, U. S. Subari and R. M. Zulkifli, "The Development of Basic Electrical Circuit Kit as Learning Aids for Design and Technology Subject," *International Journal of Academic Research in Progressive Education & Development,* vol. 10, no. 2, pp. 410-415, 2021.

[3] W. Bolton, Programmable Logic Controllers, Newnes, 2015.

[4] J. J. Blakley and D. A. Irvine, "Teaching Programmable Logic Controllers using Multimedia-Based Courseware," *International Journal of Electrical Engineering Education,* pp. 305-315, 2000.

[5] D. Gawali and V. K. Sharma, "FPGA Based Micro-PLC Design Approach," in *International Conference on Advances in Computing, Control, and Telecommunication Technologies*, United States, 2009.

[6] H. H. Aung and T. T. E. Aung, "Simulation and Implementation of PLC Based for Nonstop Filling Process using PLCSIM and HMI," *International Journal Of All Research Writings,* vol. 2, no. 3, pp. 134-137, 2019.

[7] H. K. Channi, Human Machine Interface, LAP Germany, 2019.

[8] E. Normanyo, F. Husinu and O. R. Agyare, "Developing a Human Machine Interface (HMI) for Industrial Automated Systems using Siemens Simatic WinCC Flexible Advanced Software," *Journal of Emerging Trends in Computing and Information Sciences,* vol. 5, no. 2, pp. 134-144, 2014.

[9] A. R. M. Khairudin, A. A. Samah, N. S. Aziz, M. F. Azlan, M. A. Karim and N. M. Zian, "Design of Portable Industrial Automation Education Training Kit Compatible for IR 4.0," in *IEEE 7th Conference on Systems, Process and Control (ICSPC)*, Melaka, 2019.

[10] H. E. Mulyasa, Implementasi Kurikulum Tingkat Satuan Pendidikan: Kemandirian Guru dan Kepala Sekolah, Jakarta: Bumi Aksara, 2009.

[11] R. M. Branch, Instructional Design: The ADDIE Approach, New York: Springer, 2009.

[12] I. Burhan, A. A. Azman and S. Talib, "Multiple Input/Outputs Programmable Logic Controller (PLC) Module for Educational Applications," in *Innovation & Commercialization of Medical Electronic Technology Conference (ICMET)*, Selangor, 2015.