RESEARCH ARTICLE OPEN ACCESS

Optimization of a Low-Cost Programmable Logic Controller Educational Trainer

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Abstract:

This study outlines the optimization of a low-cost programmable logic controller trainer. The trainer features various input and output (I/O) devices that include switches, sensors, motors, lamps and buzzer. The trainer utilizes the Panasonic FPO C32CT programmable logic controller, which has 14 input switches, 9 outputs, 2 sensors and associated components. The trainer provides also capabilities to control external I/O devices through PLC interfacing. The PLC trainer gained acceptability from survey participants who based their evaluation on parameters relative to the physical profile, functionality, mobility, harnessing, marketability, and relevance. The cost of the trainer is economical and is worthy to be replicated for possible market potential affordable for academic use.

***Keywords* — programmable logic controller, sensor, ladder programming, timer.**

I. INTRODUCTION

The trends in globalization and modernization dictate the tempo of market competition and that the key to supremacy lies on the industry's competitive strategies. Globalization enhances competitiveness, both at the level of the firm and at the level of the nation (Frenkel and Peetz, 1998). Under this scenario, industries around the world are grappling for initiatives to innovate their conventional systems and processes in order to stay competitive. The race for enterprise competitiveness fosters a level of excellence in themanufacturing, production and control systems through massive computerization and automation. This leads management and the state to adopt strategies designed to increase labor effectiveness to the benefit of capital (Frenkel and Peets, 1998). However, the introduction of modern economies and production techniques also posed stiff challenges in the industry relative to investment cost of retrofitting and systems upgrading and eventually the adoption of industrial automation.

The role of industrial automation and control play a significant influence to the attainment of increased productivity, improved quality, increased plant safety, and economic competitiveness. In the process of automation, a variety of programmable logic controllers play a very significant role in providing control and intelligence to both discrete and analog signal conditioning. Programmable logic controller (PLC) is processor driven device that uses logic-based software to provide electrical control to machines. PLC utilizes relay-logic principles in programming and control. However, there are challenges posed by industrial automation to the industry as well as to the academe. There are concerns on the capital extensiveness of the investment and the cost for systems upgrading coupled with human resource requirement challenges (Cuasito and Namoco, 2010).

As automation increased, there has developed a shortage of technically trained personnel to implement automation technologies competently. The industry's ability to incorporate new innovations to enhance their competitiveness is dependent on the ability of academic institutions to produce an appropriately skilled multi-craft technical workforce (Brazell et al., 2007). Likewise the academic ability to institute a successful industrial automation related curriculum also depend on three factors: the qualifications of current faculty with regard to the multidisciplinary integration of related industrial automation disciplines, the availability of suitable laboratory facilities and the local need for multi-crafted technicians (Brazell et al, 2007). In essence, the current technological innovations and dynamics of change in work organizations and economies will continue to fuel compelling debates on the future of the labor market and the exigency of skill upgrading requirements (Bulgarelli, 2009). These imply the need to adapt to rapid technological change and matching skills to jobs crucial to production sustainability and competitiveness. However, the supply of quality human resources that match the skill set requirements of the industry falls short of what is demanded. The jobs are plentiful but the right skill set does not match with the requirements. Skills mismatch refers to imbalances between formal qualifications and required qualifications in work settings as well as discrepancies between skill demand and supply (Bulgarilli, 2009). Handel (2003) also described skills mismatch as situations in which worker's skills exceeds or lags behind those employers seek. The labor market is confronted by jobs-skills mismatch that is something that worries education officials and the business community (Dizon, 2006) and that this predicament must be addressed.

Shen et al (2007) emphasized that the role of talent is critical to the future viability of the manufacturing sector and that improving competitiveness also requires the creation of highly educated and motivated workforce. The study further revealed that worker skills and education are dominant factor for a country to compete in the global economy. There is a remarkable mismatch between what is being taught in schools, colleges and universities and the knowledge and skills businesses and organizations are looking for in new recruits (Hall, 2009). The aforementioned arguments motivated the conduct of this study as an academic initiative towards mitigating job-skills mismatch. As North Western Mindanao State College of Science and Technology works towards fostering a higher level of quality education, the issue of job-skills mismatch may be mitigated through the development of instructional tools that help transfer technology to the clientele with high emphasis on industrial automation and control.

The development of a portable PLC instructional tool that employs multiple working elements in a compartmentalized box provides learning opportunities to students to the fundamentals of digital control through PLC programming. The study further enhances the skills set of the students in PLC programming through various PLC programming languages that opens skill set in industrial automation and control concepts adopted in the industries. The study therefore sought to address the following issues:

- The PLC-based instructional tool design.
- The acceptability and performance evaluation of the trainer.

The general objective of the study is to develop a portable PLC-based instructional tool that can be controlled electronically using the various PLC programming languages. The specific objectives are:

a. To design and develop a portable PLC-based instructional tool that utilizes multiple working elements.

b. To implement the control design parameters of the portable PLC trainer.
c. To evaluate the system's performance and acceptability of the trainer in accordance acceptable assessment instrument.

II. METHOD

A. Gathering information about the PLC

The study was jumpstarted with the gathering of benchmark information relative to the existing PLCs and other PLC based training facilities for the industrial automation. This was done through the use of books; related studies and the internet for these are the known accessible sources. With the gathered information, the study is led to recognize some considerations in choosing the appropriate specification of the Programmable Logic Controller (PLC) for the trainer and identify the possible features and capabilities of the pedagogic tool that best suit to the needs of the academic clientele in some areas of industrial automation.

B. PLC Trainer Preliminary Designing

In designing a PLC trainer, the principal consideration focused on the possible features of the trainer crucial to the skill set development of the students relative to the PLC programming courses. The process entails very significant theoretical and technical processes. This process follows the technical framework described in Fig. 1, to wit:

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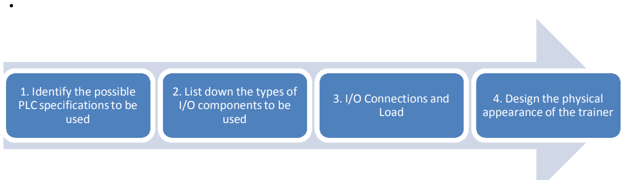

Fig. 1Technical Framework

The capabilities of the PLC trainer are mainly based on the specification of the Programmable Logic Controller (PLC). In this step, the technical specification of the Programmable Logic Controller (PLC) are identified and studied.

After identifying the appropriate specification of the Programmable Logic Controller (PLC) to be utilized, the researcher can now decide what type of input and output components to be used in reference to the identified specification of the Programmable Logic Controller (PLC).

Since the researcher already listed the possible types of I/O components to be used, in this step the researcher can now design the connections of I/O components as well as the load computations. The load computation is considered in designing the power supply for the PLC Trainer which is the next step in designing a PLC Trainer. Fig. 2 shows the control framework of the PLC trainer.

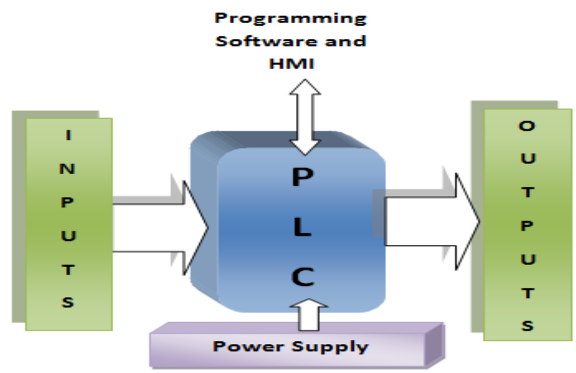

Fig. 2Setup Diagram of PLC Trainer

C. PLC Trainer Design

The study utilizes a variety of input devices such as switches and other sensor devices that are connected to the PLC. Inputs in the PLC can be either an analog or discrete type. These inputs are the prime movers, which initiate commands to the PLC and do the predefined work. The prototype have normally open push button spring return type, normally closed push button; normally open toggle switch Single Pole Single throws (SPST), capacitive sensor which detects any type of material and the inductive sensor which detects specific material having metallic properties. Fig. 3 shows the input devices placement into the trainer.

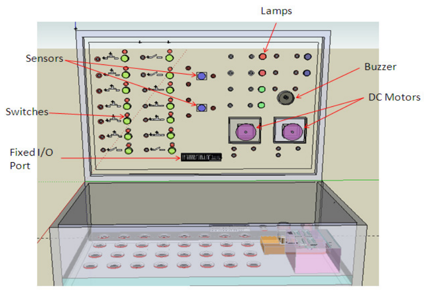

Fig. 3 PLC Trainer Front View

The prototype also utilizes a variety of discrete output devices as controlling elements. These elements are connected to the end of output points of the PLC. The output components that are used are 12VDC lamps colored as Green, Red and Amber, dc buzzer, dc motors which can be activated as forward and reverse direction. These outputs serve as the control objective of the students during testing and actual PLC programming. These indicate if the program loaded is what the student's are expected by identifying the status of the outputs. Fig. 4 shows some of the output devices that are in-placed in the trainer.

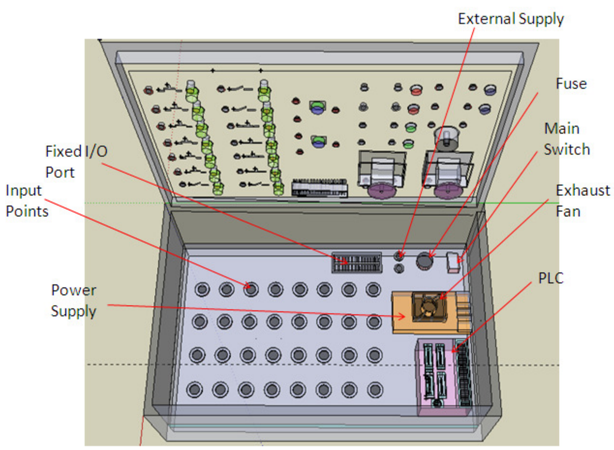

Fig. 4PLC Trainer Top View

D. PLC Trainer Enclosure

The researcher selection of materials is very critical for making the casing of the trainer. The researcher materials selection depends on these characteristics:

a. Strength

The trainer is made of acrylic plastics designed to withstand higher temperature because of its high melting point characteristics. Acrylic plastics are a good substitute of metal for its high ductility and lightweight which makes the casing compact and durable. Since the casing is purely acrylic plastics, the researcher added structural metals which would serve as the frame and protection of the casing to avoid scratches.

b.Mobility

The casing is designed for instructional purposes thus, it should be highly mobile. The trainer can be brought to any laboratory rooms, different training and seminar venues, and etc. that utilize the trainer.

c. Cost effectiveness

Acrylic plastics are not really too expensive than buying a ready- made box which is made of pure plastics. The researcher used scrap acrylic plastics just to lessen the price. If the researcher chose the ready-made plastic box because it is cheaper and no need for extra labor, the quality of the trainer that researcher produced is not preferable to the client.

E. The Evaluation

The evaluation process involves the designing of the survey questionnaire which are dispatched to the sampling population using purposive sampling. The survey participants are the students of the Electrical Technology and Management and Electro-mechanical Technology program of the Mindanao University of Science and Technology and some faculty members who are identified to be users of PLC's in the university. The sampling population is chosen based on their frequent utility of PLC in the university and that they are more credible to evaluate the trainer in the university.
Other survey participants are the industry workers of identified highly automated plants in the Misamis Oriental region. Engineers and technicians who are in actual manipulation of PLC's in the plant are the most credible respondents who can validate the utility of the PLC programming.

III. RESULTS AND DISCUSSION

A. The PLC Trainer Design

The trainer utilizes a variety of input devices such as switches and other sensor devices that are connected to the PLC. Inputs in the PLC can be either an analog or discrete type. These inputs are the prime movers, which initiate commands to the PLC and do the predefined work. The prototype have normally open push button spring return type, normally closed push button; normally open toggle switch Single Pole Single throws (SPST), capacitive sensor which detects any type of material and the inductive sensor which detects specific material having metallic properties. Fig. 5 shows the input/output (I/O) devices placement into the trainer.

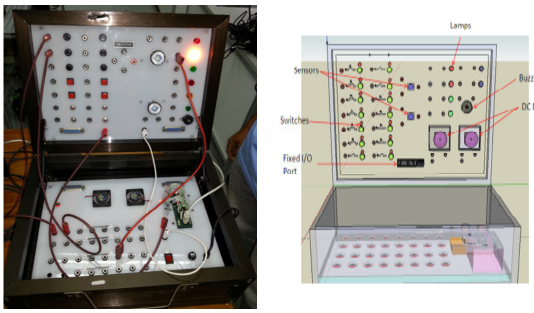

Fig. 5PLC I/O Devices Placement

The control unit has 32 I/O points capable of accepting 16 digital inputs and 16 digital control outputs. The control units are expandable. Expansion modules contain additional number of I/O points making it possible in accepting more inputs and controlling various applications. With the ability of working PLC in tandem, mounting these control units is not a problem because of its lightweight and its size. The controller unit measures 25mm X 90 mm which is very thin, thus it is lightweight. The ultra-compact body size of the PLC is beyond comparison to conventional PLC type which is very convenient to facilitate the miniaturization of target machines, equipment and control panels.

The I/O circuit cut-away serves as the bases on the actual implementation of the device interfacing into the PLC. The prototype also utilizes a variety of discrete output devices as controlling elements. These elements are connected to the end of output points of the PLC. The output components that are used are 12VDC lamps colored as Green, Red and Amber, dc buzzer, dc motors which can be activated as forward and reverse direction. These outputs serve as the control objective of the students during testing and actual PLC programming. These indicate if the program loaded is what the student's are expected by identifying the status of the outputs. Fig. 6 shows an output device being energized in the trainer.

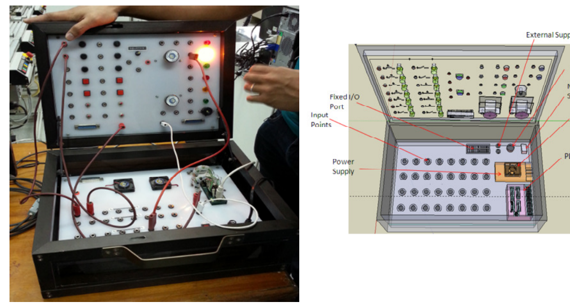

Fig. 6Energizing an Output Device in the PLC Trainer

The abovementioned I/O interface is the subject of PLC programming depending on the step diagram established. The set-up used in this initial trial used a simple actuation of lamp via a switch. After the hard wiring and/or I/O-PLC interfacing, the programmer created the appropriate PLC program in ladder diagram programming format.Utilizing the Panasonic PLC NAis, FPO-C32CT as shown in Fig. 7 and Fig. 8 shows the PLC ladder program for lamp sequencing.

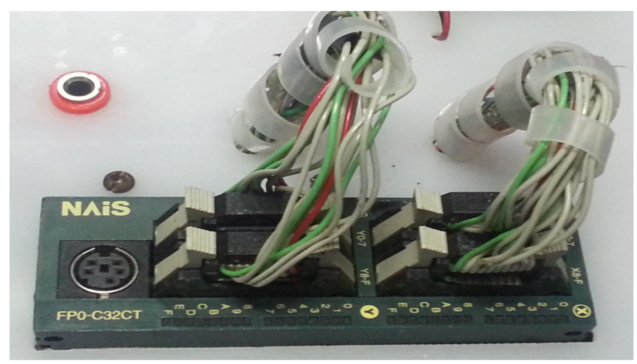

Fig. 7Panasonic PLC

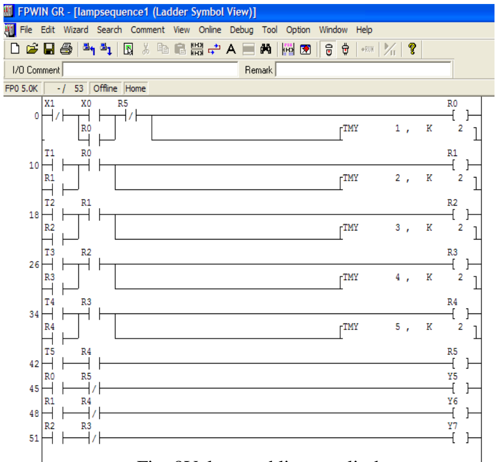

Fig. 8Valves and linear cylinder

The aforementioned ladder program was utilized to establish controllability to three pneumatic cylinders directed by three single solenoid valves. This illustration is initiated so as to show the versatility of the trainer to control not only internal I/O devices but also can be used for external I/O devices that may be used during the conduct of laboratory instruction. Fig. 9 shows the pneumatic cylinders with their corresponding single solenoid, spring return directional control valves. The solenoid coils are interfaced into the PLC output module as shown in Fig. 10

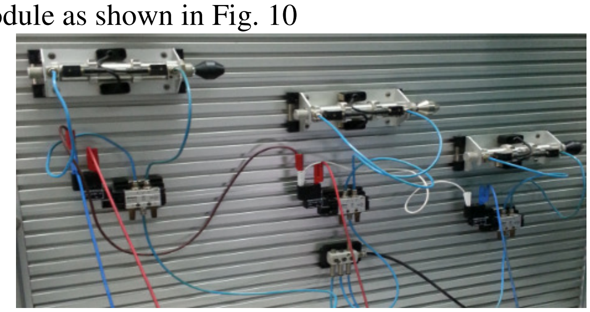
Fig.9PLC-Controlled Cylinders

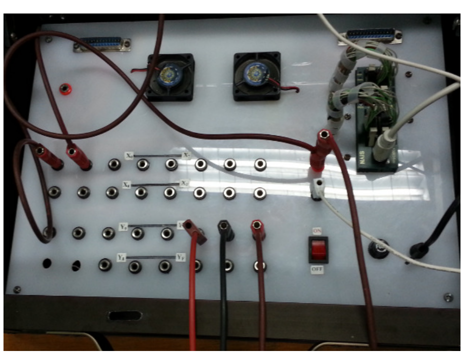
Fig. 9Solenoid to PLC Output Module

B. PLC Trainer Enclosure

The selection of materials is very critical in the construction of the trainer enclosure. The material selection depends on these characteristics:

a. Strength

The trainer is made of acrylic plastics designed to withstand higher temperature because of its high melting point characteristics. Acrylic plastics are a good substitute of metal for its high ductility and lightweight which makes the casing compact and durable. Since the casing is a purely acrylic plastic, the trainer also has structural metals that serve as frame and protection of the casing to avoid scratches. Fig. 11 shows the accomplished PLC trainer enclosure that is made of Aluminum and Acrylic Plastic.

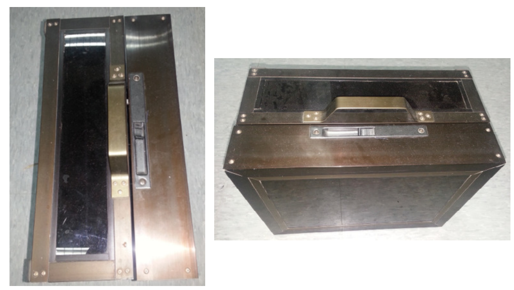
Fig. 11The PLC Trainer Enclosure

b. Mobility

The casing is designed for instructional purposes thus, it should be highly mobile. The trainer can be brought to any laboratory rooms, different training and seminar venues, and etc. that utilize the trainer.

c. Cost effectiveness

Acrylic plastics are not really too expensive than buying a ready- made box which is made of purely plastics. The researcher used scrap acrylic plastics just to lessen the price. If the researcher chose the ready-made plastic box because it is cheaper and no need for extra labor, the quality of the trainer that researcher produced is not preferable to the client.

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Other survey participants are the industry workers of identified highly automated plants in the Misamis Oriental region. Engineers and technicians who are in actual manipulation of PLC's in the plant are the most credible respondents who can validate the utility of the PLC programming. The assessment process used the five (5) point rating scale that measures the acceptability of the trainer in consonance to the established criteria as shown in Table 1 below.

TABLE. 1
ADJECTIVAL EVALUATION RATING

Adjectival Rating	Scale Range
1 Very Poor	1.4 Below
2 Poor	1.5 2.4
3 Fair	2.5 3.4
4 High	3.5 4.4
5 Excellent	4.5 Above

As to the physical appearance –the survey participants rated according to their judgment the physical appearance of the trainer in terms of workmanship, arrangement, and wire harnessing. Table 2 shows the responses in terms of aesthetics where the respondents were asked to rate the physical profiling of the trainer that includes the placement of the input, output devices, wire harness and enclosure of the trainer. The workmanship was rated at mean 4.4 which mean that the physical profiling of the trainer is highly accepted. The component arrangement was rated with a mean of 4.4 which falls under the highly acceptable rating scale while the wire harnessing aspect is excellently accepted with the mean rating of 4.5.

TABLE 2
MEAN RESPONSES IN TERMS OF PHYSICAL APPEARANCE

Parameter	Mean
Workmanship	4.4
Arrangement	4.4
Wire Harnessing	4.5

As to the functionality – this section refers to the evaluation of the performance of the input/output components with respect to their connectivity, and programming responses. The evaluation was conducted while the survey participants were observing how the trainer works. Table 3 depicts the result of this section. The technical functionality is rated by the respondents with a high acceptability with mean ratings of 4.0, 3.6 and 3.8 respectively which mean that the overall functionality of the trainer works accordingly.

TABLE 3
MEAN RESPONSES IN TERMS OF FUNCTIONALITY

Parameter	Mean
The input components functions according to the trainer design specifications.	4.0
The output components functions according to the trainer design specifications.	3.6
The overall technical functionality of the trainer functions in accordance to the design parameter established.	3.8

As to mobility – in this evaluation, the trainer's weight, size and stability are tested relative to space occupancy and transferability. Table 4shows the mean responses on this aspect. The weight and stability of the trainer were rated excellent at the means 4.7 and 4.7 respectively while the survey participants rated the foundation of the trainer with a highly acceptable mean rating of 4.4

TABLE 4
MEAN RESPONSES IN TERMS OF MOBILITY

Parameter	Mean
The trainer is light weight.	4.7
The size of the trainer is compact and does not occupy so much space.	4.7
The foundation of the trainer is stable.	4.4

As to marketability – in terms of usefulness and marketability of the trainer, the survey participants also took part in giving their thoughts on the overall quality of the training tool. Table 5 depicts the result of the mean ratings relative to marketability which shows that the aesthetics, functionality, mobility and mechatronics relevance fall under the excellent mean rating at 4.5, 4.6, 4.7, 4.6, and 4.8 mean respectively. The trainer is marketable based on the result of PLC material canvassing that yielded affordability to the Panasonic FPO Model as the lowest cost among other PLCs in the market. Table 6 shows the canvass result where the Panasonic FPO Model cost only P 6,003.00.

TABLE 5
MEAN RESPONSES IN TERMS OF MARKETABILITY

Parameter	Mean
The appearance shows attractive aesthetics.	4.5
The technical functionality depicts performance according to design parameters.	4.6
The trainer is compact in size and can be transferred easily from one place to another.	4.7
The trainer's technical application is relevant to mechatronics enabling technology range.	4.6
The components of the trainer are locally available and affordable.	4.4

TABLE 6
THEPLC PRICECOMPARISON

	Product Name	Manufacturer	Unit Price	
			$	PHP
1	SLC 500	ALLEN BRADLEY	1669	76774.00
2	CPM2C-32CDTC-D PLC	OMRON	199.99	9199.54
3	S7 200	SIEMENS	504.97	23228.62
4	FX3U64MR/ES	MITSUBISHI	1,272.00	58512.00
5	MODICON MICRO PLC	MODICON	549	25254.00
6	T2 I/O	TOSHIBA	305	14030.00
7	FPO C32T	MATSUSHITA	130.5	6003.00

As to academic impact – the survey participants were also made to evaluate the academic impact of the project with emphasis on skills development, relevance, and dynamic learning. Table 7 shows the result of the survey. The survey participants unanimously rated excellent mean ratings in these aspects.

TABLE 7
MEAN RESPONSES IN TERMS OF ACADEMIC IMPACT

Parameter	Mean
The trainer translate theory into skills	4.7
The trainer addresses real world problem	4.5
The trainer demonstrates dynamic learning to students.	4.6
The trainer concept is industry-relevant.	4.5

IV. CONCLUSIONS AND RECOMMENDATIONS

There are few but significant conclusions that are reckoned based on the results and findings of the study, to wit:

1. The low-cost programmable logic controller can be utilized for classroom and/or laboratory instruction with ease of operability using ladder programming.
2. The aesthetics of the trainer was evaluated with an excellent mean rating from the survey participants.
3. In terms of the functionality, the survey respondents also provided excellent mean ratings based on the evaluation parameters. The ratings are indicative of the respondent's observation that the input and output devices work accordingly with the PLC ladder programming.
4. In terms of mobility, the trainer is light weight, compact in size, and can be transferred from one place to another. The enclosure where the PLC trainer is secured is made of aluminum and thermoplastic.
5. The cost of the trainer is considerably low due to the affordability of the Panasonic FPO PLC. The PLC is readily available in the local market and is considered as versatile with its capability to be adopted with IEC 61131-3 PLC programming standard.
6.The trainer also signifies academic impact as per the evaluation of the survey participants as it provides learning across PLC programming, switching theory, and industrial automation concepts. The PLC trainer is industry-relevant and illustrates real world problems and solutions.

The recommendation is directed towards the additional installation of linear pneumatic cylinders with proximity sensors so as to expand the learning possibilities the students may gained during the conduct of laboratory and training. The input and output devices embedded in the trainer may be checked and repaired to optimize the use of the trainer. It must be noted that there are I/O ports that are not functioning due to some PLC hardware defects. The observation on some I/O ports malfunction in the PLC may be attributed to the careless interfacing of the devices while the PLC is in operation. These shortcomings may be avoided if extra care and testing were undertaken. Nonetheless, the PLC trainer is still operational because of the availability of suitable I/O ports of the Panasonic FPO PLC.

The overall recommendation is directed towards the possibility to mass produce the trainer. The marketability of the trainer is potentially feasible due to the low-cost PLC (Panasonic FPO). The production and marketing of the trainer may help training institutions augment training engagement relevant to the current trends of the industry

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