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Harmonizing Programmable Logic Controller Programming to IEC 61131-3 on A Multi-Axes Pneumatic Educational Trainer

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Abstract:

This study outlines the development and innovation of a multi-axes pneumatic educational trainer. It highlights the enhancement of a three (3) axis electro-pneumatic trainer into a programmable logic controller-based training tool. The conversion into a PLC-based trainer is also augmented through the harmonization of the PLC programming languages into the current International Electro-technical Commission (IEC) 61131-3 standard. The purpose of adhering into the current PLC programming standard is to provide the most recent PLC applications and enabling technologies into the academic requirements of the students of the University of Science and Technology in Cagayan de Oro City, Philippines. The conventional PLC programming languages that used to be undertaken independently among other languages can now be combined in one programming synthesis in accordance to the preference of the end-user or programmer. Siemens S7-300 is preferred to be used in the study as it has the capability to run under IEC 61131-3 framework. The outcome of the study confirms the excellent mean ratings of most of the evaluation parameters established. Results and findings indicated the survey participant’s excellent acceptability ratings relative to functionality, aesthetics, mobility, marketability and relevance.

Keywords — **programmable logic controller, function block diagram, ladder diagram, statement list, structured text, sequential function chart**

I. INTRODUCTION

The evolution of industrial automation has been remarkably changing the pace of development in the industrial arena. Continuing enhancements are now setting trends for competition to reckon with and be the basis for market supremacy. The race for enterprise competitiveness fosters a level of excellence in the manufacturing, production and control systems through massive computerization and automation.

The current trends in globalization and modernization compel the industry to strive towards increased productivity, product quality, safety and environmental protection. The role of industrial automation and control process plays a significant influence to the attainment to its common goal. It has been recognized that automation and control stages the economic viability of the industry in particular and the sustainable development of the country in general. Automation and control provided powerful leverage against traditional methods of production which resulted to increased productivity; high product quality; and cost competitiveness. Tight profit margins and network manufacturing emphasize the need for integration of multiple technologies and global optimization of production facilities. Mechatronics is at the heart of diverse systems applications that enables traditional industries to be more efficient by automating redundant processes, improving quality and increasing productivity (Bettersworth, 2009).

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. Through the use of PLC, systems motion sequencing can be changed from time to time according to the desire of the programmer without changing the hard wired connections. 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. PLCs are becoming more and more intelligent. In recent years PLCs have been integrated into computer a network which is usually hierarchically organized. The PLCs are then supervised by a control center. There exist many proprietary types of networks. Thus, difficulties on compatibility among PLC's specifically on the aspect of programming persist to exist. PLC's comes with different brands and different proprietary programming languages. Although it utilizes relay logic principles but their systems' environment restricts operational compatibility.

The International Electro-technical Commission (IEC) tried to address the aforementioned issues through the use of IEC 1131. However, problems relative to compatibility and interoperability continue to linger which prompted the commission to further enhance their rules and regulations. The birth of IEC 6-1131 provided solution to the severe issues which led to the adoption of the PLC standard to open control software bearing the IEC 61131-3. IEC 61131-3 is the first vendor-independent standardized programming language for industrial automation. The language was established by the International Electro-technical Commission (IEC), a worldwide standard organization founded in 1906 and recognized worldwide for standards in the controls industry by over 50 countries. The standard is already well established in Europe and is rapidly gaining popularity in North America and Asia as the programming standard for industrial and process control. The adoption of IEC 61131-3 by the industry is driven by the increasing software complexity of control and automation requirements. The creation time, labor cost, and maintenance of control software has a major impact on control projects that can be improved using the IEC 61131-3 vendor-independent programming language standard. Applying a standard programming language has a positive impact on the software life-cycle that includes requirements analysis, design, construction, testing (validation), installation, operation, and maintenance. The impact on maintenance is important since control software maintenance, including upgrades, is generally two to four times the labor of initial programming.

The IEC 61131-3 standard, combined with powerful new Free-scale chip architectures, enables an entire controller to be delivered in an embedded device. Control programs can run distributed and independently rather than concentrated in large controllers. No longer are thousands of lines of control programs required to run in one controller for complex automation applications. This increases performance, improves reliability, and simplifies programs. IEC 61131-3 provides multiple language support within a control program. The control program developer can select the language that is best suited to a particular task, greatly increasing their productivity. Plus, with a standardized programming interface that is completely independent of the hardware platform, users can greatly reduce the cost of program maintenance and training across company- wide automation applications. IEC 61131-3 is the international standard for programmable controller programming languages. As such, it specifies the syntax, semantics, and display for the following suite of PLC programming languages namely: Ladder, Sequential Function Chart, Function Block Diagram, Structured Text, and Instruction List. These PLC programming languages can be combined in a programming network that provides seamless control to automation sequences better than the traditional proprietary PLC control.

Since the industry has long been adapting the IEC 61131-3 standard in PLC programming and control, it is crucial to the academe and training institutions to keep abreast with the current trend and jibe training programs towards IEC. As the academe continue to play its crucial role in providing quality human resources, the adoption of IEC 61131 standard into the theoretical and skills training should be of paramount importance to keep abreast with the current trends in industrial automation. It is deemed necessary that hands-on application on IEC 61131 should be incorporated into relevant courses so that theories can be transformed into skill set through actual hands-on manipulation.

The general objective of the study was to develop a PLC-based instructional tool that can be controlled electronically using the IEC 61131 standard. The specific objectives were:

a. To design and develop a PLC-based instructional tool that utilizes multi-axes pneumatic cylinders and motorized drill.

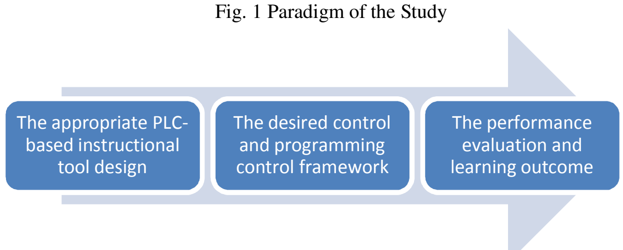
b. To implement the control design parameters of the training tool using IEC 61131-3 standard.

c. To evaluate the system's performance of the training tool according to established assessment instrument.

II. METHOD

The paradigm of the study shown in Fig. 1 reflected the research framework utilizing the input, process, and output (IPO) paradigm. The selection of appropriate PLC-based instructional tool design served as crucial input to the study in such a way that the application of PLC programming would not pose tremendous problem during the adoption of the current PLC programming standard.

Fig. 1 Paradigm of the Study



The PLC-based multi-axes instructional tool are processed and configured into the current PLC programming standard based on the International Electro-technical Commission (IEC) 61131-3. The working elements embedded in the trainer were wired to a PLC compatible with IEC 61131-3 programming software. Appropriate programming was initiated demonstrating the various applications of combinational programming in one network. The control sequence of the program was initiated at the discretion of the programmer based on a motion sequence diagram established.

The outcome of the study entails the performance evaluation of the PLC-based trainer in terms of aesthetics, functionality, mobility, and operability. The study was highlighted by the expected learning outcome of the students. The framework of study was organized in the following sequence:

A. Design and Development

In this context, the designing and development of a PLC-based multi-axes pneumatic trainer are undertaken which utilizes linear cylinders and motorized drill as output components. Proximity sensors, switches, and other safety gadgets were also used as input devices. The input and output devices were connected into the PLC. The PLC-based multi-axes pneumatic instructional trainer concept design shown in Fig. 2

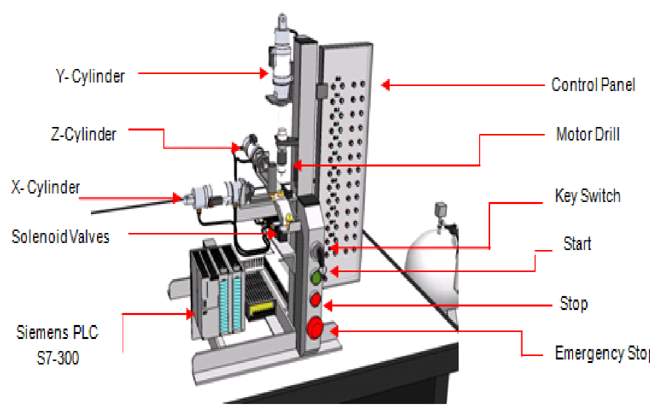


Fig. 2 The PLC-based Multi-axes Pneumatic Trainer

B. The IEC 61131-3 Implementation

In this context, the application of the IEC 611331-3 PLC programming standard was used in the actual programming demonstration of the PLC-based pneumatic trainer. Fig. 3 below showed the five (5) PLC programming languages which can be utilized in a combinational manner depending upon the preference of the programmer. The programming tools are: sequential function chart (SFC), ladder diagram (LD), function block diagram (FBD), instruction list (IL), and statement list (SL).

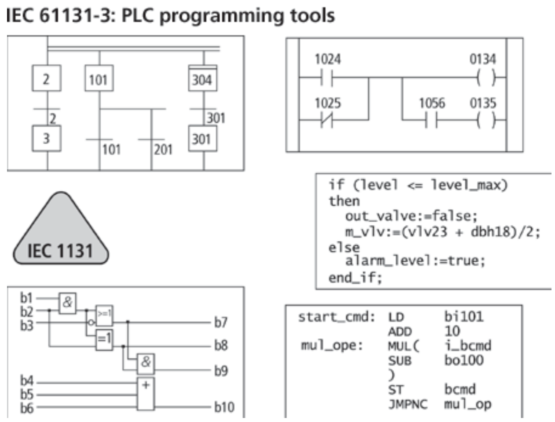


Fig. 3 The PLC Programming Languages in IEC 61131-3

C. *The Performance Evaluation*

The evaluation process involves the designing of the survey questionnaire were dispatched to the population using purposive sampling. The survey participants were the students of the Electro-mechanical Technology program of the Mindanao University of Science and Technology and some faculty members who were identified to be users of PLC's in the university. This sampling population was chosen based on their frequent utility of PLC in the university and that they were more credible to evaluate the trainer in the university.

Other survey participants were the industry workers of identified highly automated plants in the Misamis Oriental region. Engineers and technicians who were in actual manipulation of PLC's in the plant were the most credible respondents who can validate the utility of the PLC programming standard. Industry practitioners were invited to evaluate the trainer in accordance to pre-established evaluation parameters. The assessment process utilized the five (5) point rating scale as shown in Table 1.

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

III. RESULTS AND DISCUSSION

The results and findings of the study are based on the stipulated methodology involved in the conduct of the study that highlighted the design, development, and evaluation

A. *Design and Development*

The pneumatic trainer depicted a fluid power system powered by pneumatics that utilizes three (3) linear cylinders in x-axis, y-axis, and z-axis. These linear cylinders are serves as output devices that actuate accordingly to perform pushing motions to position a work-piece that is to be drilled by a drill bit. The switching of these output devices are triggered by the input devices which are classified into switches, sensors, and memory contacts.

The input and output devices are designed in such a way that their respective functionality is accessibly situated within the trainer. The cylinders are embedded with proximity sensors that serve as the confirming sensors of every cylinder positions.

The actual physical view of the multi-axes pneumatic trainer is shown in Fig. 4 along side with the design, which depicted the linear cylinders in a mechanical system that performs material set-up to material drilling and sorting. Included in the set-up is the Siemens S7-300 PLC, the power supply, the control switches and the input/output modules for the student's easy access and manipulation.

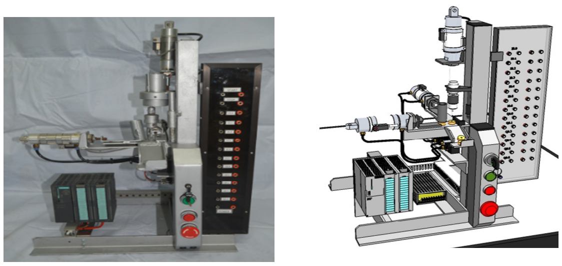


Fig. 4 The multi-axes pneumatic trainer

Fig. 5 shows the actual positioning of the three (3) axes linear cylinders that point into one common direction where the work piece is to be drilled and sorted into the storage bin. These linear cylinders are controlled by three (3) single solenoid directional valves. Polyurethane pneumatic tubing is used as pressure lines that connect the valves into its respective pneumatic cylinders. Fig. 6 also shows the directional valves that control the actuation of the linear cylinder.

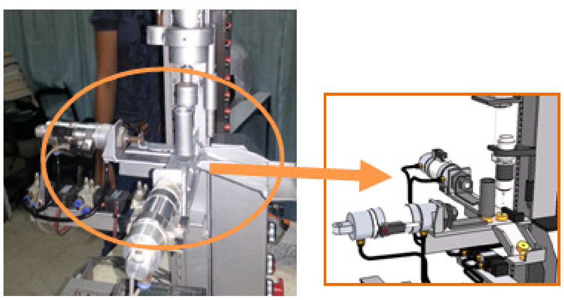


Fig. 5 The linear cylinders and valves

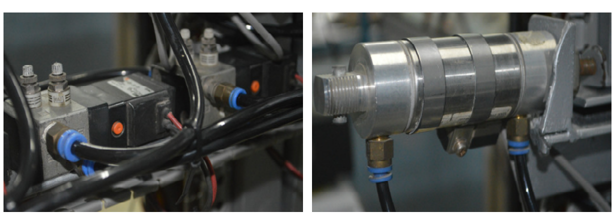


Fig. 6 Valves and linear cylinder

The programmable logic controller used in the conduct of this study utilizes the Siemens S7-300 model. Fig. 7 shows the actual PLC and its I/O interfaces. These I/Os represent all the input and output devices utilized in the study. Proximity sensors and switches are classified as input devices while solenoid valves are addressed in the output devices.

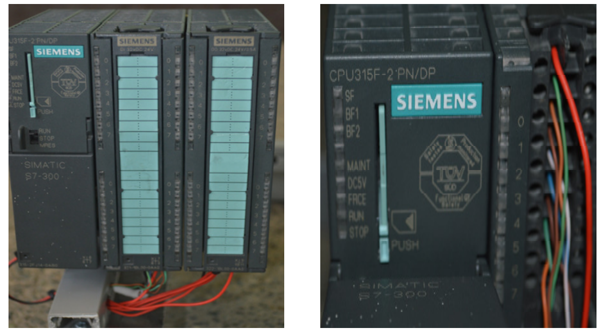


Fig. 7 The Siemens S7-300 PLC

The details of the PLC-based multi-axes pneumatic trainer are depicted in the figures below for easy reference and detailed identification of dimensional data. The actual trainer showing the PLC, the working elements, and the input/output module is presented besides the dimensional details for comparison. Fig. 8, 9, and 10 show the dimensions as reckoned in the front, top, and side views of the trainer.

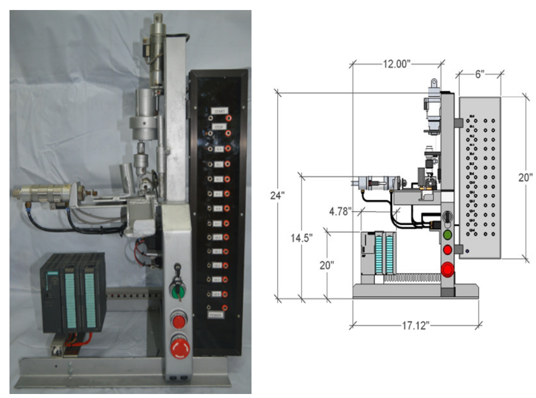


Fig. 8 The front view

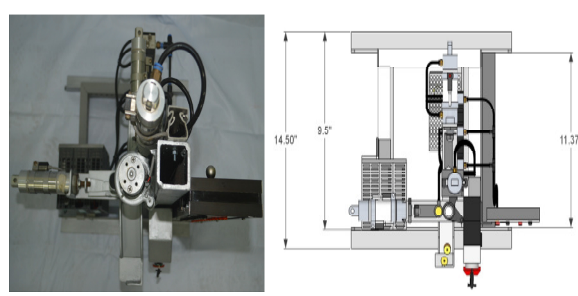


Fig. 9 The top view

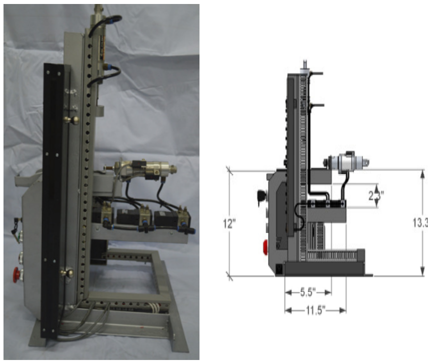
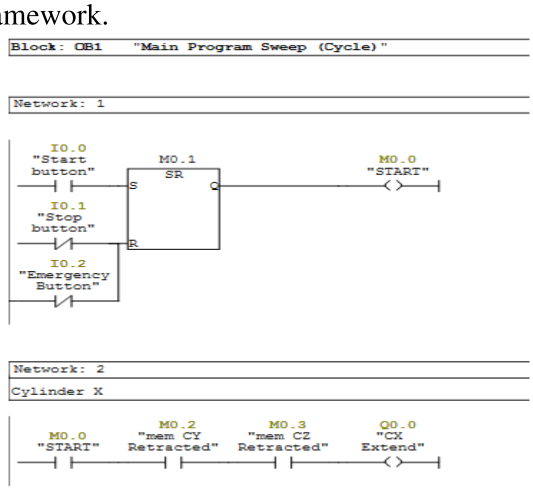


Fig. 10 The side view

B. The Implementation of IEC 61131-3

The application of the IEC 611331-3 PLC programming standard in the study provided opportunities to the students on the updated PLC programming language adopted by the International Electro-technical Commission (IEC). The final program is presented so as to demonstrate the capability of IEC 61131 standard to utilize diversified PLC program preferences that depends upon the comfort of the programmer. The program utilized in this study is presented also to show the versatility of IEC 61131 in interpreting combinational PLC programs in one control framework. The fundamental program of each working elements aforementioned earlier played very important role in the program synthesis. The IEC 61131-3 program below shows the overall program synthesis where the combination of PLC programming languages is combined in one control framework.



C. The Evaluation

The multi-axes pneumatic trainer is evaluated using descriptive statistics utilizing the five-point rating scale that measures the acceptability of the PLC-based pneumatic trainer in accordance to acceptable criteria.

TABLE 2
MEAN RESPONSES IN TERMS OF AESTHETICS

Parameter	Mean
Workmanship	4.7
Arrangement	4.4
Wire Harnessing	4.8

TABLE 3
MEAN RESPONSES IN TERMS OF FUNCTIONALITY

Parameter	Mean
The input components functions according to the trainer design specifications.	4.9
The output components functions according to the trainer design specifications.	4.9
The overall technical functionality of the trainer functions in accordance to the design parameter established.	4.9

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.	4.4
The foundation of the trainer is stable.	4.8

TABLE 5
MEAN RESPONSES IN TERMS OF MARKETABILITY

Parameter	Mean
The appearance shows attractive aesthetics.	4.8
The technical functionality depicts performance according to design parameters.	4.8
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.	4.8
The components of the trainer are locally	3.3

available and affordable.	

TABLE 6
MEAN RESPONSES IN TERMS OF ACADEMIC IMPACT

Parameter	Mean
The trainer translate theory into skills	4.8
The trainer addresses real world problem	4.9
The trainer demonstrates dynamic learning to students.	4.9
The trainer concept is industry-relevant.	5.0

IV. CONCLUSIONS AND RECOMMENDATIONS

Based on the results and findings of the study, the following conclusions are reckoned:

1. The multi-axes pneumatic trainer can be enhanced using an updated PLC programming language regulated by the International Electrotechnical Commission (IEC) 61131.
2. The physical profile of the trainer was evaluated with an excellent mean range which means that the survey participants accepted the improved aesthetics of the multi-axes pneumatic trainer.
3. In terms of the functionality, the survey respondents provided excellent mean ratings on the stipulated parameters which mean that the input and output devices work in accordance with the set-up program framework.
4. In terms of mobility, the trainer was evaluated in consonance with the terms of the survey instrument which yielded an excellent mean rating. The trainer is light weight, compact in size, and can be transferred from one place to another.
5. The trainer is potentially marketable due to its attractive aesthetics, operational control framework, and training impact to the students. The economic and academic impact of the trainer provides dependable marketability.
6. The trainer's utility concept is presentable and relevant to current industrial needs of the country.

The recommendations were anchored on the least significant advantage of the trainer which was attributed to its expensive controller the Siemens S7-300 PLC. However, the controller plays an important role in the marketability. Though it may be considered expensive but the resultant benefit of its utility was tremendously feasible, the fact that relevant skills set in industrial automation will boast the occupational placement of the clientele in the industry.

Another recommendation was directed towards the lubrication of the air service unit. It must be noted that the actuation of the linear pneumatic cylinders do not have the same speed and that is due to the frictional factor that keeps the actuation inconsistent. If properly oiled, these deficiencies may be complemented. Mechanical linkage between the Y cylinder and the motorized drill may be properly aligned in such a way that its movement does not indicate misalignment that affects the efficiency of the Y cylinder.

The overall recommendation was directed towards the mass production of a smaller version of the trainer where smaller size actuators and valves may be used with less expensive PLC. Thus, canvassing of lower-cost PLC may be well expedited in a manner that achieves cost advantage. The production of the trainer will help other institution to acquire such at a lower cost compared to the Original Equipment Manufactured (OEM) trainers.

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