การพัฒนาพีแอลซีแบบฝังตัว สำหรับการสอนทางวิศวกรรมเมคคาทรอนิกส์

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บทคัดย่อ

อุปสรรคหลักในการเรียนการสอนเกี่ยวกับตัวควบคุมที่สามารถโปรแกรมได้หรือพีแอลซี (PLC) ก็คือความหลากหลายของพีแอลซีและการเปลี่ยนแปลงของเทคโนโลยีที่มีอย่างรวดเร็วด้วยโมเดลและนวัตกรรมใหม่ ๆ นอกจากนั้นต้นทุนในการจัดเตรียมเพื่อให้ได้ครอบคลุมถึงพีแอลซีใหม่ ๆ และสิ่งอำนวยความสะดวกในห้องปฏิบัติการ รวมทั้งระยะเวลาในความต้องการปรับปรุงวัสดุอุปกรณ์ที่ใช้ในการเรียนการสอนให้ทันสมัยอยู่ตลอดเวลายังมีมูลค่าที่สูงอีกด้วย หลังจากศึกษาหลักการและลักษณะเฉพาะของพีแอลซีและระบบสมองกลฝังตัว ดังนั้นงานวิจัยนี้มีวัตถุประสงค์เพื่อพัฒนาพีแอลซีแบบฝังตัวสำหรับการสอนทางวิศวกรรมเมคทรอนิกส์ ด้วยการผสมผสานของซอฟต์แวร์แลบวิว และ เออาร์เอ็ม (ARM) ไมโครคอนโทรลเลอร์เข้าด้วยกัน จึงทำให้พีแอลซีที่พัฒนาขึ้นมีความยืดหยุ่น ใช้งานง่ายและมีต้นทุนต่ำ โดยทั้งนี้เพื่อใช้สอนหลักการพื้นฐานของพีแอลซีซึ่งมีอยู่หลากหลายและมีการเปลี่ยนแปลงที่รวดเร็ว พีแอลซีแบบฝังตัวที่พัฒนาขึ้นได้มีการนำไปทดลองใช้และประเมินผล ซึ่งผลที่ได้จากการประเมินพบว่าพีแอลซีแบบฝังตัวสามารถนำมาใช้สอนได้อย่างน่าพอใจ

คำสำคัญ : ตัวควบคุมที่สามารถโปรแกรมได้, ระบบสมองกลฝังตัว, พีแอลซีแบบฝังตัว, วิศวกรรมเมคคาทรอนิกส์

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An Embedded PLC Development for Teaching in Mechatronics Engineering

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Abstract

The major obstacles to teaching Programmable Logic Controller (PLC) is a variety of PLCs and the rapid pace of technological development with new models and innovations. Moreover, costs incurred in the setting up of comprehensive and modern PLC laboratory facilities, and in the required periodic updating of teaching material and equipment are, as a result, very high. After investigated the conception and features of PLC and embedded system, the development of the embedded PLC for teaching machatronics students is proposed in this paper with the seamless combination of the LabVIEW software and the ARM Microcontroller with the LabVIEW embedded module. The flexibility of the proposed PLC makes it relatively easy and less costly to teach the basic principle of different kinds of PLCs due to their variety and rapid change. The implementation of the embedded PLC is discussed and evaluated. The results of evaluation shows that embedded PLC can be taught satisfyingly.

Keywords: programmable logic controller, embedded system, embedded PLC, mechatronics engineering

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1. Introduction

Programmable logic controllers (PLCs) are a specialized type of embedded systems 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 for industrial control engineers that introduced, developed, and standardized their own design methods and programming languages [1], [2].

According to mentioned above, a detailed understanding of the operation and use of PLCs is important for many undergraduate students, particularly those who seek eventual employment in these industries. However, problems and obstacles in the study and experiment on PLC is the rapid pace of PLC technological development, with new models and innovations continually being introduced by manufacturers. Future, PLCs are dedicated industrial controllers and, once purchased for laboratory use cannot be employed for a wide range of other useful applications. Costs incurred in the setting up of comprehensive and modern PLC laboratory facilities, and in the required periodic updating of teaching material and equipment are, as a result, very high [1].

An embedded system is a computer system designed to perform one or a few dedicated functions often with real-time computing constraints. It is embedded as part of a complete device often including hardware and mechanical parts. By contrast, a PLC is designed to be flexible and to meet a wide range of end-user needs for industrial control application. Embedded systems control many devices in common use today. Embedded systems are controlled by one or more main processing cores that are typically either microcontrollers or digital signal processors (DSP). The key characteristic, however, is being dedicated to handle a particular task, which may require very powerful processors. Since the embedded system is dedicated to specific tasks, design engineers can optimize it to reduce the size and cost of the product and increase the reliability and performance [2], [3], [4].

In general, "embedded system" is not a strictly definable term, as most systems have some element of extensibility or programmability. For example, handheld computers share some elements with embedded systems such as the operating systems and microprocessors which power them, but they allow different applications to be loaded and peripherals to be connected. Moreover, even systems which don't expose programmability as a primary feature generally need to support software updates. On a continuum from "general purpose" to "embedded", large application systems will have subcomponent at most points even if the system as a whole is "designed to perform one or a few dedicated functions", and is thus appropriate to call "embedded" [2], [3], [4].

Having investigated the conception and features of PLC and embedded system, in this paper the development of low-cost embedded PLC for teaching mechatronics students at KMUTNB is proposed. The conceptual design of embedded PLC is combine the advantage of PLC and embedded system together. The architecture of embedded PLC is being developed by the LabVIEW Embedded Module for ARM

Microcontroller. The work of this development involves:

1) To design a PLC based on embedded system technology.

2) To develop a prototype embedded PLC.

3) To implement the prototype with mechatronics students.

4) To evaluate the embedded PLC.

2. Development of embedded PLC

The aims of the embedded PLC are that it must support the sub-disciplines of software engineering, computer programming and panel wiring. While the basic system must support digital I/O, it should be expandable to support analog handling. The detailed objectives being that it must [5]:

- Be safe
- Be low cost
- Interface to a PC
- Incorporate an industrial standard PLC
- Support the IEC 6-1131 programming languages
- Interface with common industrial electrical components
- Be able to translate engineering ideas from theoretical description to practical tutorials

2.1 Hardware design

We select to use the ARM microcontroller to develop embedded PLC because it is widely used across many embedded designs due to its low price, low power consumption, and wide variety of peripherals for many of the major silicon vendors. In addition, we can use the LabVIEW Embedded Module for graphical programming to the ARM microcontroller also. At the same time, the properties of the LPC2378 microcontroller of ARM7 will be used as a determinant specifications and features of embedded PLC, as shown in Fig. 1 and Table I respectively.

Besides the LabVIEW Embedded Module for ARM Microcontroller includes support for the RealView µVision ARM simulator, which provides cycle accurate timing and logic simulation. With this capability, a large portion of the application could be developed and tested before the hardware design is complete [6].

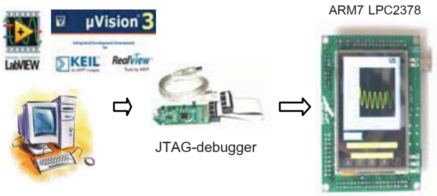


Fig.1 Main components used in this work.

Table 1 Specifications of Embedded PLC.

Feature	ARM7 LPC2378, 72MHz core speed
Flash Memory	512Kbytes
SRAM	32Kbyte
Digital Inputs	8, Sink/Source, 24V DC
Digital Outputs	8, Sink up to 200mA each, 24V DC
Analog Inputs	One 10-bit resolution, input range 0-10V
Analog Outputs	One 10-bit resolution, output range 0-10V
Serial Ports	RS-232

Because the input and output signals from the Microcontroller board are limited at 3.3V, so its re-design of input and output of embedded PLC to allow for usage with external industrial equipment, is shown by Fig. 2.

1) Digital input: Most equipment to be connected to digital inputs use 24VDC such as switches, proximity sensors etc., therefore they require a circuit to isolate and reduce the signal. Fig. 3 shows the internal circuit of the digital input.

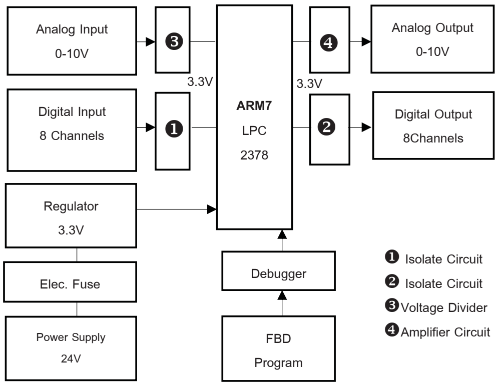


Fig.2 The architecture of an embedded PLC.

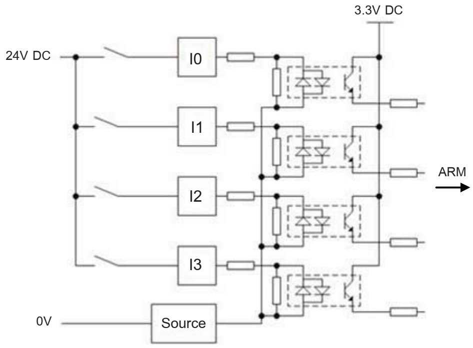


Fig.3 Internal circuit of digital input.

2) Digital output: Similarly to the digital input, most equipment to be connected to the digital output use 24VDC such as relays, solenoid valves of pneumatic and hydraulic system etc, therefore, they require a circuit to isolate and amplify the signal. Fig. 4 shows internal circuit of the digital output.

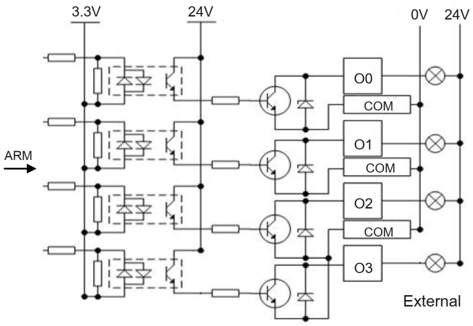
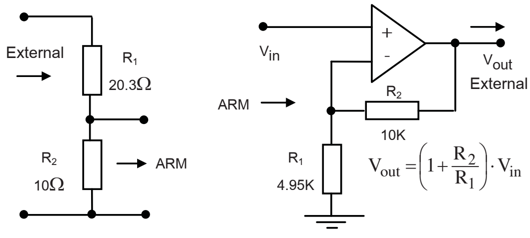


Fig.4 Internal circuit of digital output.

3) Analog input: Since the standard of voltage output of the sensor to be connected to the analog input has voltage between 0 to 10V, it requires reduce voltage to 3.3V. For this, we use the voltage divider circuit, as shown in Fig. 5 (a).



(a) Analog input (b) Analog output

Fig.5 Internal circuit of anlog input and output.

4) Analog output: Analog voltage output from the Microcontroller is 3.3V. Therefore, it is necessary to use the circuit to amplify the voltage from 0-3.3 to 0-10V, as shown in Fig. 5 (b).

2.2 Software Design

IEC 61131-3 currently defines five programming languages for programmable control systems: FBD (Function block diagram), LD (Ladder diagram), ST (Structured text, similar to the Pascal programming language), IL (Instruction list, similar to assembly language) and SFC (Sequential function chart). These techniques emphasize on logical organization of operations [7].

In this work, we use the FBD programming language for control of embedded PLC because the LabVIEW Embedded Module for ARM Microcontrollers is a comprehensive graphical development environment for embedded design. This module seamlessly integrates the LabVIEW graphical development environment and ARM microcontroller.

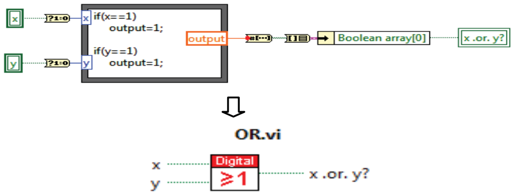


Fig.6 Creating function of FBD language.

Table 2 The example of Basic functions of FBD language.

Instruction	Symbol
LOAD	Array, index — CONTACT NO — element
IN (Digital)	Input Number — Digital I — DO
OUT (Digital)	Input Number, x — Digital O — output array
AND	x, y — Digital & — x .and. y?
OR	x, y — Digital ≥1 — x .or. y?
NOT	x — Digital !1 — .not. x?
SET, RESET	x, y — Latch SR — output
TIMER	index 1, Boolean, ms — Timer !Sec. — output array
COUNTER	Counter.vi: Count Value, Input, RESET — Count Up — Output Signal
AI (Analog Input)	Analog AI — Voltage
AO (Analog Output)	Condition, Voltage — Analog AO

This module builds on LabVIEW Embedded technology, which facilitates dataflow graphical programming for embedded systems and includes hundreds of analysis and signal processing functions, integrated I/O, and interactive debugging interface. With the Embedded Module for ARM Microcontrollers, we can optimize linking and view live front panel updates using JTAG, serial, or TCP/IP. The Embedded Module for ARM Microcontrollers includes the LabVIEW C Code Generator, which generates C code from the LabVIEW block diagram [6]. For the creation of FBD language, we use the available tools in LabVIEW, as shown in Fig. 6.

A basic function of FBD language is created according to IEC 61131-3 standards required for PLC which can be shown in Table II and Fig. 7 respectively.

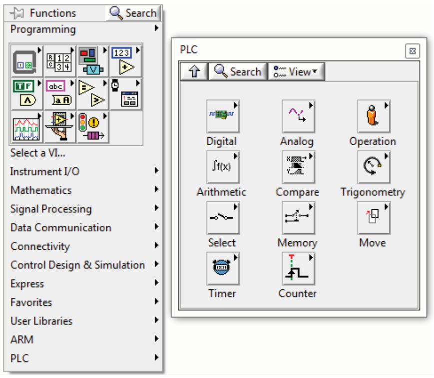


Fig.7 The basic function for usage.

We can lower development costs and achieve faster development times by using the Embedded Module for ARM Microcontrollers to program ARM targets.

3. Implementation of Embedded PLC

For the purpose of prototype testing, the system architecture has been implemented in the PLC course during the first term of year 2010 with twenty two mechatronics students. Architecture, operation, and programming language of PLC were conducted by an instructor. Moreover, parts of programming and control exercises were conducted also. The laboratory exercises included developing a FBD based on a scenario provided by the instructor, testing it via the "simulated" model, after transfer proven program to the embedded PLC, then interfacing external equipment to embedded PLC, and finally executing the PLC program on the physical system. Fig. 8 shows steps of implementation of embedded PLC.

- The example of interfacing industrial equipment to embedded PLC: Fig. 9 shows the application of embedded PLC to controls the hydraulic system. Fig. 10 depicts the actual work of mechatronics students to bring embedded PLC to controls the hydraulic system.

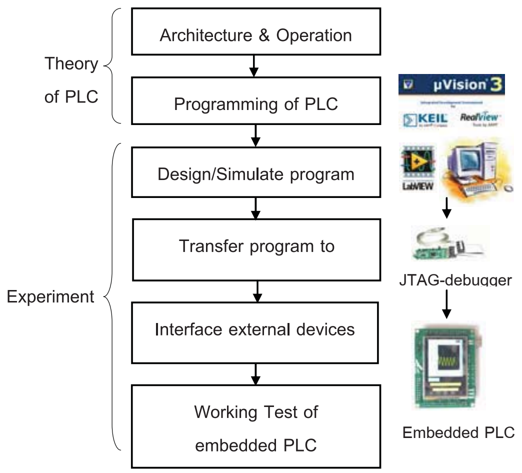


Fig.8 Steps of implementation of embedded PLC.

However, the authors have created a laboratory manual for the embedded PLC systems laboratory that contains the laboratory assignments and discusses all the necessary details on how to complete the laboratories. It is our hope that this laboratory manual will help students learn and experiment with case.

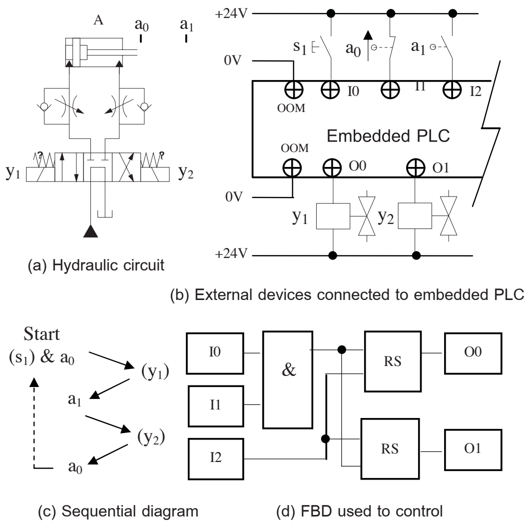


Fig.9 Applications of an embedded PLC.

4. Evaluation of Embedded PLC

After completing their laboratory exercises, the students were asked to provide feedback by filling out questionnaire that consisted of thirteen statements broadly gauging the effectiveness of the embedded PLC. For each statement, five options were provided: poor, fair, good, very good, and excellent. The students were asked to rate the statements [8],[9] that are listed in Table 3.

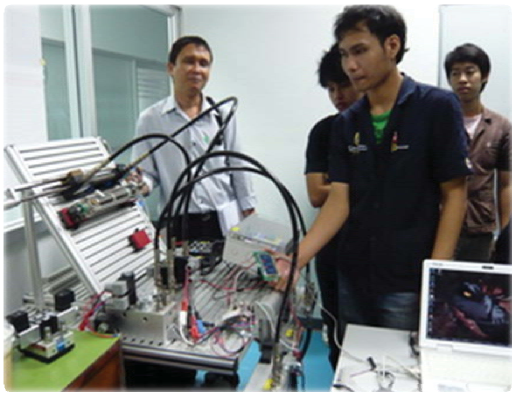


Fig.10 Students use embedded PLC controls the hydraulic system.

Table 3 Student Evaluation Questions and level of satisfaction.

No.	List of Question	Mean	S.D.
1	The embedded PLC and all the other hardware are safe.	4.25	0.32
2	The embedded PLC is setup in a relatively easy to understand and use format.	4.10	0.47
3	The programming language has typical functionality such as logic, latching, timing, mathematics, etc.	4.20	0.28
4	Input/output were appropriate.	4.00	0.34
5	Able to interface with PC.	4.55	0.18
6	To simulate the functionality of designed program before actual usage.	4.35	0.27
7	PLC program file was easily downloaded to the embedded PLC.	4.17	0.24
8	Able to interface with common industrial electrical components.	4.10	0.43
9	Stability and reliability of embed PLC.	4.10	0.36
10	Appearance of embedded PLC motivates to usage and experiment.	4.32	0.25
11	The time to study and learn not long.	4.25	0.58
12	Able to translate engineering ideas from theoretical description to laboratory experiment.	4.40	0.28
13	Able to enhance learning.	4.20	0.34
	Total Average	4.23	0.33

Overall, the students have responded positively to the questionnaire. The average value (4.23) attendance was observed during the laboratory sessions, which demonstrates the success in generating interests among the students. The questionnaire, as well as the discussions with the students, showed that the students were able to learn at their own pace owing to the user friendly and open architecture of the system. Feedback received during the embedded PLC is being explored to improve the overall user-experience and the system functionality.

5. Conclusions

Because of the variety and the high cost in setting up PLC laboratory. After investigating the conception and features of PLC and embedded system, in this paper the development of a low-cost embedded PLC for teaching in mechtronics engineering at King Mongkut's University of Technology North Bangkok (KMUTNB) is proposed. The conceptual design of embedded PLC is combines the advantage of PLC and embedded system together. The architecture of embedded PLC is being developed by an ARM Microcontroller. The reason for the selection of the ARM microcontroller because it is widely used across many embedded designs due to its low price, low power consumption, and wide variety of peripherals for many of major silicon vendors. In addition, we can use the LabVIEW Embedded Module for development of standard language to ARM microcontroller (embedded PLC) also, using design the FBD language. The implementation of the embedded PLC is discussed and evaluated. The results of evaluation show that the developed embedded PLC is an effective teaching tool for students.

6. Acknowledgment

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