A CAPSTONE DESIGN PROJECT FOR ENGINEERING TECHNOLOGY STUDENTS

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Abstract *— This paper describes one of the capstone engineering design projects implemented by Penn State Altoona BSEMET (baccalaureate degree in electro-mechanical engineering technology) students during their senior year. This project is titled "Design and Implementation of a Vending Machine". At Penn State Altoona, the vending machine is designed and built by individual students in one semester. The paper begins with a description of the BSEMET program. Next, the paper describes the BSEMET capstone project design course (EMET 440). Finally, the paper provides a description of one of the EMET 440 capstone design projects recently completed by students. The project consists of design and implementation of a vending machine using a PLC. The paper presents the design specifications of this vending machine and provides details regarding its design and implementation. Recommendations for design improvement are presented.*

Index Terms —capstone design projects, programmable logic controllers, electro-mechanical, engineering technology.

INTRODUCTION

The Accreditation Board for Engineering and Technology (ABET) is recognized in the United States as the sole agency responsible for monitoring, evaluating, and certifying the quality of engineering, engineering technology, and engineering-related education in colleges and universities [1]. Any educational institution seeking accreditation of an engineering or engineering technology program has to demonstrate that the program in question clearly meets certain criteria as determined by ABET. The ABET 1999-2000 criteria for accrediting engineering technology programs include the requirement for providing technical design courses in the ABET accreditable engineering technology programs [2]. As specified in the ABET criterion 1.C.2.b listed in [2], technical design courses in the ABET accreditable engineering technology courses are characterized as follows:

I.C.2.b. *Technical Design Courses -- These are courses in practice-oriented standard design applied to work in the field, such as construction, in which students acquire experience in carrying out established design procedures in their own areas of specialization. The key to this type of technical design lies in the fact that the courses would follow established design concepts developed by engineering and that there would be prime emphasis on standard design procedures and practices. Many of these design methods have already been included in handbooks or standards computer methods for various branches of engineering. These courses would require an understanding of the application of mathematics and science, for example, to such activities as air conditioning systems design, duct design, piping design, amplifier design, computer component and circuit design, plant layout, materials handling operations, and/or civil engineering technology applications such as road design.*

Quite often, a capstone engineering design course constitutes one of the many technical design courses provided by ABET accreditable baccalaureate engineering technology programs. A capstone engineering design course usually focuses on planning, development, and implementation of an engineering design project which includes project documentation, formal report writing and project demonstration. The capstone design course is usually offered in the senior year of the baccalaureate program. This paper describes one of the electro-mechanical design projects conducted by the Penn State Altoona BSEMET students in the EMET 440 course (capstone engineering design course).

INSTITUTIONAL BACKGROUND

Penn State Altoona is one of 24 campuses making up The Pennsylvania State University system. It is the second largest of the 24 campuses and is a full-service residential campus located 42 miles from the research campus at University Park. Penn State Altoona became a four-year college within The Pennsylvania State University system in 1997 and offers baccalaureate degrees in eight majors. Penn State Altoona also offers associate (two-year) degrees in nine majors. Additionally, Penn State Altoona provides two years of course work for more than 160 Penn State majors. More than 3800 students attended Penn State Altoona during Fall 1999. During the 1999-2000 academic year, 239 minority students attended Penn State Altoona.

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BSEMET PROGRAM DESCRIPTION

The Bachelor of Science in Electro-Mechanical Engineering Technology (BSEMET) program at the Penn State Altoona campus is five years old. The genesis for the program can be traced to industry's needs for people who can work on systems, machines and products that have both electrical and mechanical elements. The program emphasizes a breadth of knowledge in all fields of engineering technology related to typical manufacturing, production and assembly plant process.

The establishment of a BSEMET program at Penn State was motivated by the recognition of three facts: 1) that modern manufacturing and process industries are moving rapidly toward substantial, and in many cases, total automation, 2) that these industries are the major province for future engineering technology jobs, and 3) that much of what technologists will be expected to do in these jobs will require that they have knowledge of both mechanical and electrical systems and particularly of the problems and challenges associated with interfacing the two technologies. The goal of the Penn State BSEMET curriculum is to provide that knowledge.

The BSEMET program of study supports instruction in the following areas:

- Inter-disciplinary concepts required for an understanding of mechatronic devices and systems.
- Operation, programming, and troubleshooting of integrated systems using data networks to link smart devices and intelligent machines.
- Operation, configuration, programming, and troubleshooting of systems using pneumatic, hydraulic, mechanical, and electrical parts locators controlled by single board machine controllers, programmable logic controllers, and microcomputers.
- Operation, programming, and troubleshooting of process control systems using single-loop and distributed PID control architecture.
- Development of written and verbal communications skills needed to present and sell projects to individuals and small groups.
- Development of the interpersonal skills required for work in concurrent design and production support teams.
- Development of a broad range of project management skills including project cost and payback analysis, quality management, conflict resolution, consensus building, and concept presentation.

The Penn State Altoona BSEMET courses comprise up-to-date and current technical content and are taught using state-of-the-art pedagogical techniques.

CAPSTONE PROJECT DESIGN COURSE

The description of the BSEMET capstone project design course (EMET 440) is as follows:

EMET 440 (Electro-mechanical Project Design) is a capstone project design course required for all the BSEMET majors. The course focuses on planning, development, and implementation of an electro-mechanical design project which includes formal report writing, project documentation, group presentations, and project demonstrations. The goal of this course is to demonstrate the ability to manage a major project involving the design and implementation of products with a mixture of electrical and mechanical elements as a member of a product development team. In this project-based course students are expected to effectively manage their time and team efforts to produce a finished product in the fifteen-week semester. No textbook is required. Bi-monthly progress reports, design notebooks, formal reports, and oral presentations constitute integral components of this course. Before beginning the projects, student teams are provided adequate training in project formulation and resource analysis, performance goals and team expectations, public presentations, public presentations of project work, and individual project supervision.

DESIGN AND IMPLEMENTATION OF A VENDING MACHINE

The key objective of the vending machine project is to design and implement an electro-mechanical system using a programmable logic controller (PLC). An Allen-Bradley SLC500 PLC is used in this project. The main interface software used is known as RS Logix which creates the programming environment in which the actual PLC program is written before it is downloaded into the PLC.

The design specifications for the vending machine are as follows:

- Machine accepts only \$.05 (nickels), \$.25 (quarters), and \$.10 (dimes).
- There are two outputs, ejectors A and B.
- Returns change with \$.05 (nickels) only.
- The price for all drinks is \$.35.

The design also includes a test model in which the PLC program can be tested and operated. The test model includes a mechanism for inputting various amounts of change to the system, the output ejectors, and a change return ejector. A list of the items used for the test model is shown below.

- Two push buttons
- Coin separator/change box
- Two pneumatic ejectors
- One coin return ejector - pneumatic
- Coin input - contacts

The PLC program accepts three different coins, separates them and inputs a corresponding signal to the PLC. When certain conditions are met, the system allows for an output to be activated. Finally, the system returns change if needed and resets itself to wait for running through the cycle again.

PLC PROGRAM DEVELOPMENT

The main design for the system project consists of three phases and includes one sub-routine.

The first phase is to input all of the different possibilities to the PLC and store them as data. This is accomplished by setting three normally-open contacts on three different rungs and assigning an input location to each of them. Data inputs are stored by counters placed on the different rungs.

The second phase of the program design involves comparing input values with various conditions representing coin combinations for $.35. These combinations are represented in Figure 1. Comparing is achieved by using the *equal to* (EQU) compare instruction to determine if any of the seven conditions has been met. EQU compare statements must be in series with one another when determining if certain conditions are met. Programming the PLC to compare the input data is simply done by creating seven distinct rungs for the seven distinct possibilities. Each rung represents a certain condition and needs to have a separate EQU compare statement for each input counter.

The third phase of this systems design is the output phase. This phase of the system utilizes pushbuttons to determine which output must eject. Normally-open contacts and binary bits are used to operate the outputs. The design specifies that either outputs A or B can be energized one time when the rungs compare statements become true. To accomplish this, two normally-open contacts representing buttons A and B are placed in parallel with one another after each condition's compare statements. Following the normally-open contacts, it is necessary to include the output energize instruction and to use it to energize a binary bit. It is important to use binary bits at this point because a program cannot have an output energize instruction energize the same output more than one time. Using binary bits enables many conditions to be true to allow a single output go true. Binary bits are placed in parallel at the end of the program on normally-open contacts, so that when these contacts become true, then another output energize command will output to a device in the real world.

The subroutine that is required in this system is used to allow the PLC to return change in the form of $.05 (nickels). There are two conditions in which it will be necessary to return change, condition G must return $.05 three times and condition H must return $.05 one time. The subroutine utilizes the timer and counter commands. Starting the subroutine occurs when the outputs of conditions G or H are energized. When either condition is energized, the system sets the bits and energizes the output. The system also utilizes a move command which simply moves a value to a location within the subroutine starting the change return process. Condition G returns $.15 by moving a value of three and condition H returns $.05 by moving a value of one to the preset state of the counter in the subroutine.

The subroutine is designed to run only the number of times as the value in its counter and stops when the accumulator of that counter is equal to the preset value. This subroutine energizes an output one time for every value in the sub-routine counter and resets the counter when it completes. This is done by using a normally closed contact that has the counters done bit assigned to it allowing the sequence to stop when the counter reaches its preset value. The subroutine uses two timers where the first timer allows a second timer to begin timing when it is complete. While the second timer is timing, a normally open contact uses the timer timing bit of the second timer to energize an output. This output in turn energizes the coin return ejector. When the second timer is done, its done bit will reset the first timer allowing for the process to continue as long as the value in the counter is not equal to its preset value.

An important part of the system design is to reset all the input counters to zero after an output is energized and the subroutine stops running. This is done using two timers in parallel with the outputs at the end of the program. When these timers are done timing, they reset all the input counters.

HARDWARE DEVELOPMENT

The test model is designed to show the functionality of the program and operates in the same manner as a real vending machine. The model consists of a change box, pushbuttons, output ejectors, and a change ejector. The change box is a change-wrapping device that was converted into a coin separator and functions as the coin slots for the system. Pneumatic pistons are used as the ejectors for the outputs as well as for the change return. All the devices are attached to a console along with pushbuttons for testing and display purposes.

The change box that is used was purchased at an office supply store and include contacts for each coin. The contacts were left intact and were used as the input transducers for the system. The contacts have one common wire and three input wires that are directly connected to the PLC for interfacing with the program. The PLC recognizes a coin passing over a contact by a voltage that is produced when the contact closes. This voltage corresponds to the normally-open input contacts in the program.

SUGGESTIONS FOR IMPROVEMENT

All system designs can be modified or improved in one form or another and can sometimes be more efficient in doing so. The system design for this project utilizes all the necessary instructions and meets all the project specifications. Through the use of fiber optic sensors for coin detection it would not be necessary to use the latch and unlatch instruction. Not using these instructions the program would become slightly shorter by eliminating a few timers and some rungs. Fiber optic sensors can detect with greater accuracy and will increment the counters correctly using the original system design.

CONCLUSIONS

Completed design systems are required to meet the design specifications and to function properly. The best way to determine this is by putting the system through a testing phase. When this system was completed it went through a test phase and met all of the specifications previous stated.

The entire system described above was setup and interfaced to the PLC. The test model was wired to the corresponding inputs and outputs of the PLC and the programming software was initiated. The main test of the system was performed by repeatedly dropping coins into the slots that correspond with the predetermined combinations of $.35. When the conditions were met and a pushbutton was pressed, the systems output ejectors activated. The conditions that required the change subroutine to operate also passed the testing. For combinations that required change, the output ejectors and change ejector operated simultaneously.

Overall, this design project provides a full understanding of how programmable logic controllers operate and how to program them. It provides an understanding of the different methods that can be used to accomplish various tasks while programming the ladder logic. The vending machine test model allows for experience in interfacing the controller to real world actuators and controlling them by means of a PLC.

Combinations for $.35			
Condition	$.25	$.10	$.05
A	1	1	
B	1		2
C		1	5
D		2	3
E		3	1
F			7
G*	2		
H*		4	
*Require change			
$.25 = quarter			
$.10 = dime			
$.05 = nickel			

FIGURE 1
COMBINATIONS FOR $0.35

REFERENCES

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