Applied Research on Product Development between the Engineering Technology Program and Industry Applications

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Abstract: The Engineering Technology (ET) program differs from traditional engineering in several ways. In addition to a *hands-on* approach, the program emphasizes a *minds-on* approach as a technical way of solving problems. These combined approaches can best be described as "Applied Engineering". Over the years, ET graduates have had a difficult time presenting themselves to potential employers, due to the nontraditional nature of technology programs. The following is a collaborative product development project that will present a better idea of what ET majors can do, and what a potential employer might expect when hiring technology graduates.

This applied research project utilizes the expertise of the ET program by assisting the food industry with the design and implementation of an effective food-processing machine. In addition, the project spotlights cost analysis by efficiently designing hardware and coding software to fulfill the industry request. As a result, production costs are minimized and profits are maximized.

I. Collaborative Specifications

This applied research project is based on the interests of the local food industry. The requirements of the design are to have a simple microcontroller-based system that is capable of providing full automation with minimal operator intervention in marinating different varieties of poultry, meat, cheese, etc. The objectives are to develop a system that is standalone, fully automated, affordable to manufacture, upgradeable, and easily maintained. After a proposal to Utah State University, the initial design and development cost was funded by the State and the local food industry. The system is designed to be automatic in operation and cost effective in volume production.

To better evaluate the cost effectiveness of the proposed system, this local company has also developed a comparative version of the automated system, which is controlled by a Programmable Logic Controller (PLC). The microcontroller-based system and the PLC prototype systems were to be analyzed and compared according to the cost and effectiveness of the system performance. The sponsoring company's goal is to have at least one thousand copies of the final system for marketing within two years.

II. The Hardware Design Considerations

The mechanical design requires a transfer platform to shift an object (i.e., food to be marinated) to different locations for ingredient injection. The precision of the displacement of the object needs to be within a tolerance of 0.5 cm. An 18” dual axis linear position table, manufactured by Arrick Bobotic Inc., was chosen for this project [1].

A stepper motor is used to control the actuator and in turn the actuator moves the transfer platform. The selection of a stepper motor over a DC motor is based on, not only cost, but also the ability to precisely control the hardware for the many platform design related considerations. Mainly, there are two types of stepper motors available in the market today, the bipolar and the unipolar stepper motors. A detailed comparison of the two, under the same loading condition, is presented in Table 1.

Type of Stepper Motor	# of Coils	# of Wires	Stepping Sequence	Control Steps	Coils Resistance	Physical Size	Torque Kg-Cm/	Control Circuit	Control Current
Bipolar	2	4	$8(0X8), $C(0XC), $6(0X6), $3(0X3)	Two Phases/One Phase	Two Identical Coils Resistance	Small	High	Two H-Bridges (8 FETs)	I Amp
Unipolar	4 (2 with Center Tap Split)	5 or more	$8(0X8), $C(0XC), $6(0X6), $3(0X3)	Two Phases/One Phase	Four Identical Coils Resistance	Large	Low	Four Switches (4 FETs)	0.5I Amp

Table 1: Comparison between the Bipolar and Unipolar Stepper Motors under the Same Load

During the design and test stages of the control circuit the bipolar stepper motor appeared to be a superior choice over the unipolar motor. This was based on the torque and the physical size features of the bipolar motor. Therefore, this led to the bipolar stepper motor being chosen for the hardware prototype design. The control circuit’s design is based on the requirement of the bipolar stepper motor controls. This means 8 H-Bridges that need 16 power field-effect transistors (FET) for all the control sequences on two bipolar stepper motors [2]. Due to the PCB layout restriction and board size accommodation, 8 power FETs were set on each side of the printed circuit board (PCB). With this physical arrangement of the FETs, a custom-made heat sink has to enclose on both sides of the PCB since the FETs are on both sides of the PCB board, as shown in Figure 1 [3]. It was not taken into consideration while choosing the bipolar stepper motor for the design. This choice made the heat sink manufacturing very difficult and the layout of the PCB extremely time consuming. Also, the shape of the assembled PCB, with all the needed heat sinks, is unusual when compared with the majority industry implementations. The associated components for the heat sink assembly and hardware fixture requirements to the circuit added extra complexity, not to mention increased manufacturing costs.

When testing the bipolar stepper motor prototype design on the18” dual axis linear position table for analysis and testing, the existing bipolar stepper motors did not meet the PCB design needs of the system. The theory assumption of using the bipolar stepper motor turned out to be unjustified in the efficiency of PCB design. A design change in favor of unipolar stepper motors was then made. The unipolar stepper motor has a 14.2 Kg-Cm holding torque, which meets the system requirements [4]. Also, a current limit resistor of 2 Ω was added to each coil of the motors, as a result of a +4.8V supply and a 2A current required in the manufacturer specification. The adding of the wire wounded resistors to the two stepper motors actually provides other benefits to the motors' counter electromagnetic field effect on the contamination of the control signal. This turned out to be advantageous to the stability of the system control. In the end, two actuator stepper motors, manufactured by Shinano Kenshi Corp., were used to ensure a sufficient payload and precision control of the X-Y movements. Each stepper motor is powered with +12 Volts and uses a 1.8^0 per step precision [4]. Figure 2 and Figure 3 illustrate the modified prototype and the final PCB assembly.

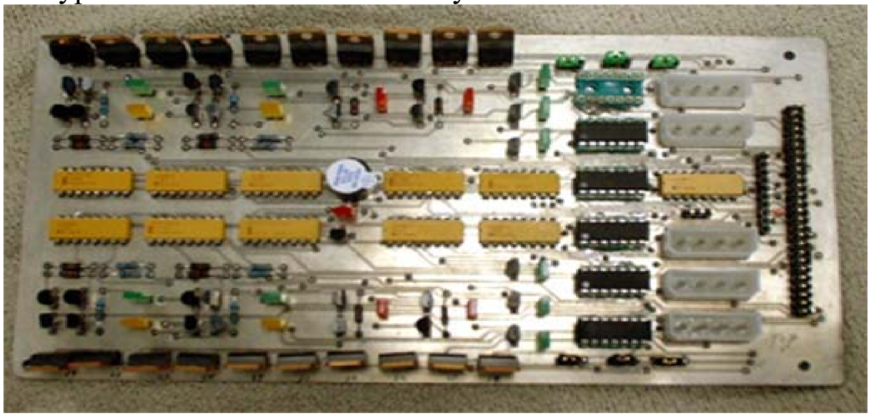


Fig. # 1: Prototype of Bipolar Stepper Motor Control PCB

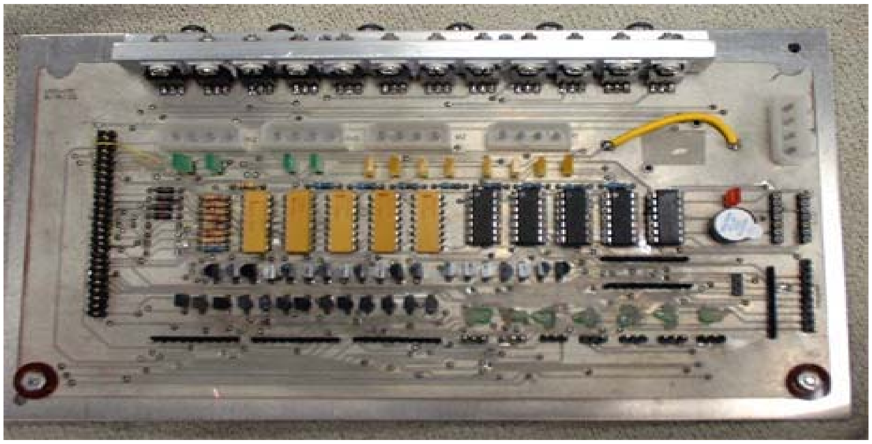


Fig. # 2: Prototype of Unipolar Stepper Motor Control PCB

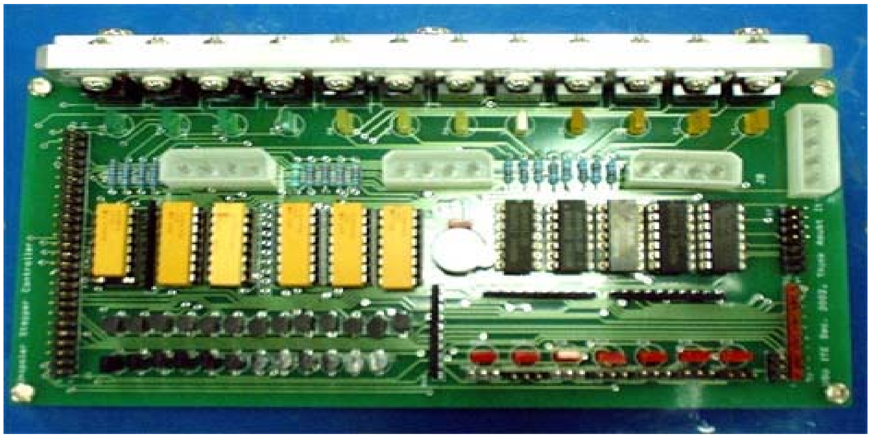


Fig. # 3: Unipolar Stepper Motor Control Final PCB Assembly

Four separate Parker Solenoid Pneumatic valves [5], powered with +24V, are designed for a variety of tasks. Among such tasks include the cleaning and purging of the controls and the injection of the ingredients.

Another design consideration was selecting a microprocessor/microcontroller to ensure design and application flexibility. The system should have the ability to be easily upgraded for manufacturing cost reduction when industry develops new microprocessor/microcontrollers. This led to the implementation of two separate PCB designs. The first PCB was used for the central processing unit (CPU), and the second board, as discussed above, is the interface for hosting the stepper motor controller and other sensing circuits. This dual PCB system actually makes an easy switch from one type of CPU to another. Currently, the CPU board is based on the Motorola MC68HC11 [6]. The MC68HC11 is a 52 pin package, and as a result, there are 52 interface pins placed on both PCBs. This allows the system to accept any CPU, as long as it can mate with the 52 pin connector. Ultimately, this design setting increases flexibility when considering the production costs of the system hardware and the software development to operate the system. The MC68HC11 system development board and the experimental setup were initially chosen because of its availability at the institution. The Motorola CPU system board is shown in Figure 4 [6],[7].

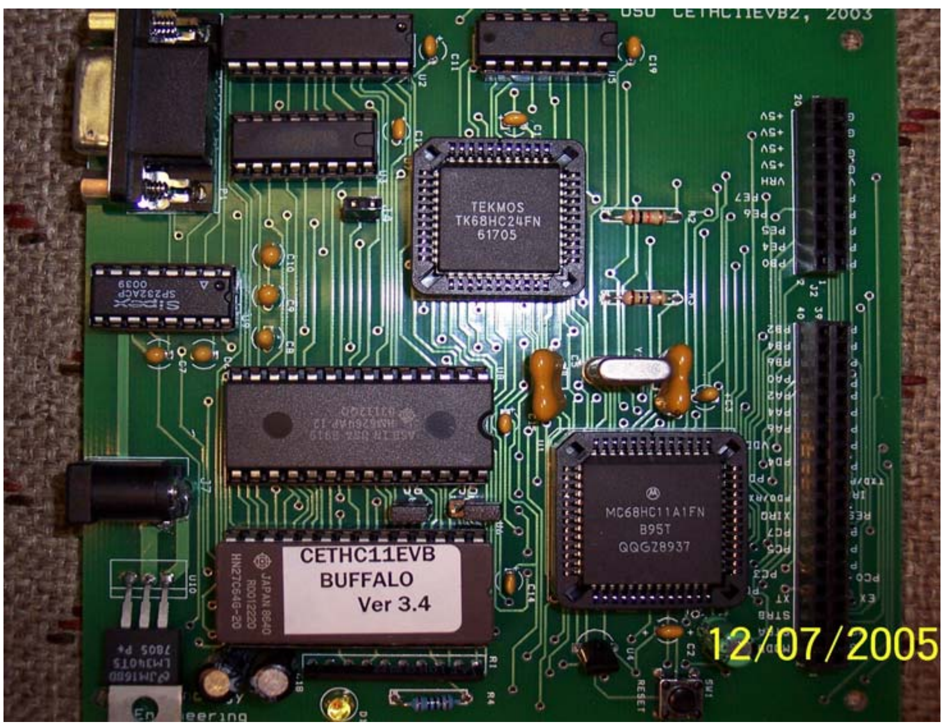


Fig. # 4: The Microcontroller System Board.

The entire system, including the X-Y table assembly, stepper motors, Motorola MC68HC11 development board and the PCB control circuit board are shown in Figure 5.

There is a 16-key keypad, shown in the lower right hand corner of Figure 5, and a Liquid Crystal Display (LCD) module that is used to display codes and instructions to the user for system control. These components are interfaced by way of the J1 header, shown in Figure 6 (b). The header also connects the PCB control circuit and eight different sensors that are used to monitor doors, interlocks, and positioning the table platform. There are also four ports, which drive injection valves for controlling ingredient injection, purging, and cleaning connected to the J1 header. Figure 6, 7 & 8 are schematics that show the design circuits [9].

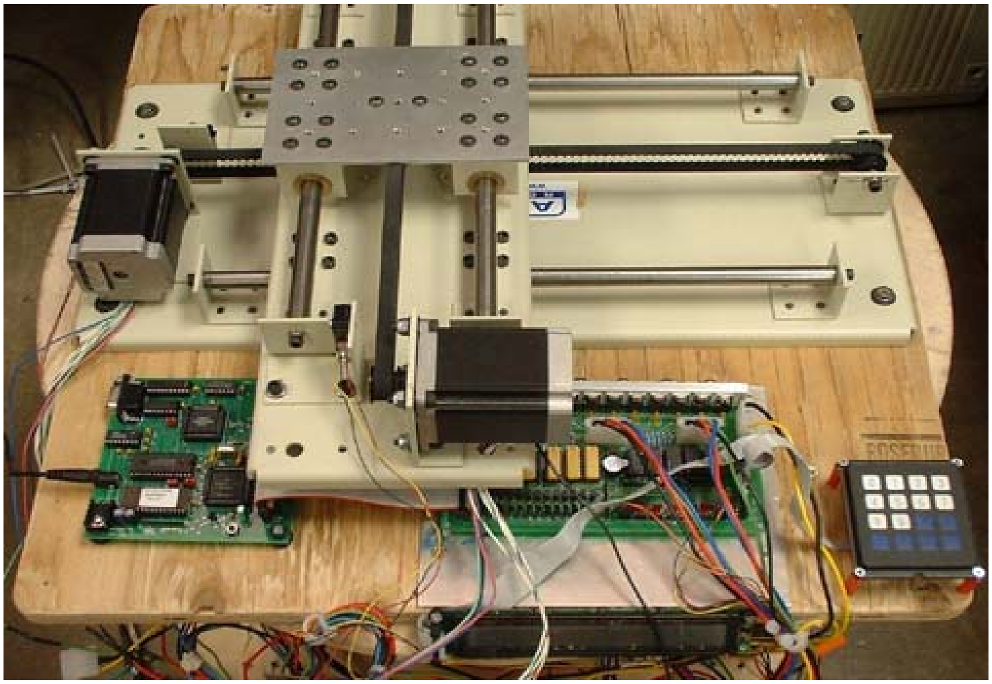
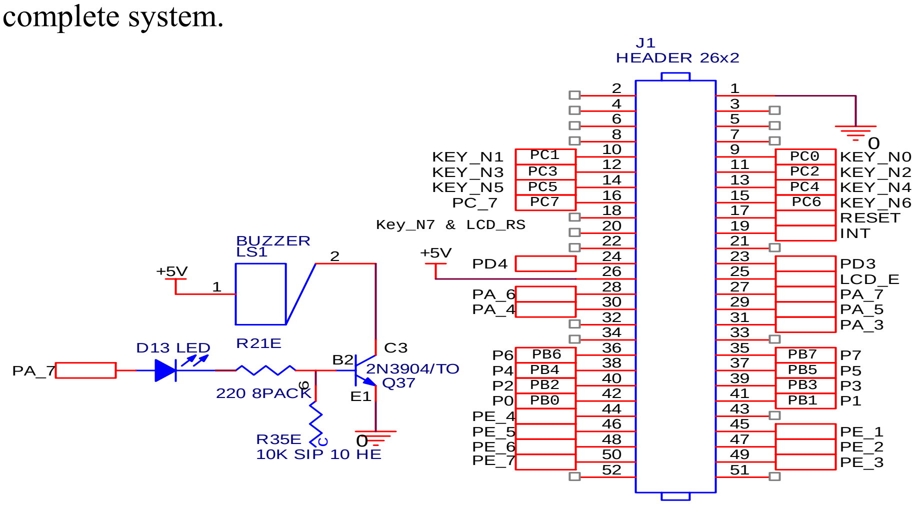


Fig. # 5: The X-Y Table System Assembly

- Figure 6 (a) shows a buzzer circuit that is connected to the J1 header by pin 27 of Figure 6 (b). The buzzer circuit will be activated whenever the high-pressure injection cabinet is opened or the CPU connection interface is not connected. It is a safety-warning device for the complete system.

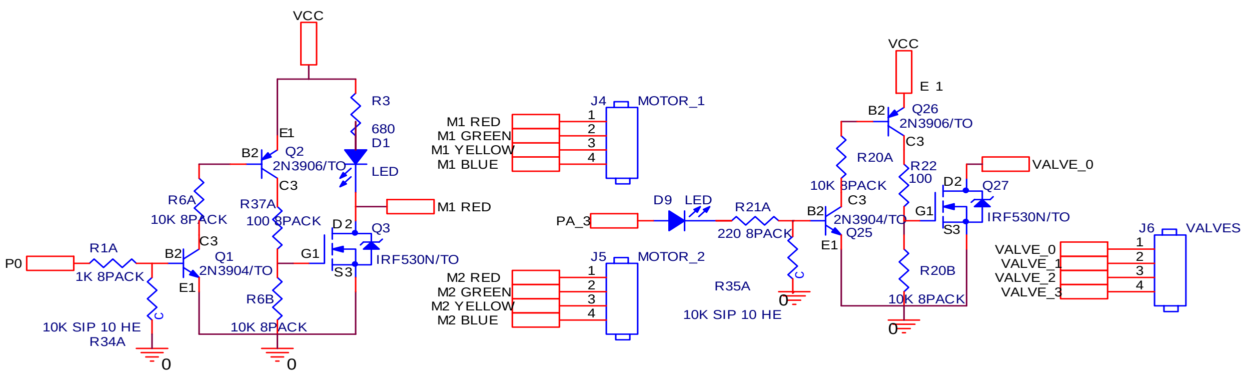


(a) **(b)**

Fig. # 6: Warning Buzzer and CPU Connections

- Figure 7 (a) is one of 8 duplicate circuits used to drive the unipolar stepper motor_1 and stepper motor_2, which is driven at the input P0 by the microcontroller. Each stepper motor requires four driving circuits, one driver for each coil, and there are four coils per motor. For example the output of the driver circuit is shown as "M1 RED." This output connects to the "M1_RED" input of MOTOR_1.

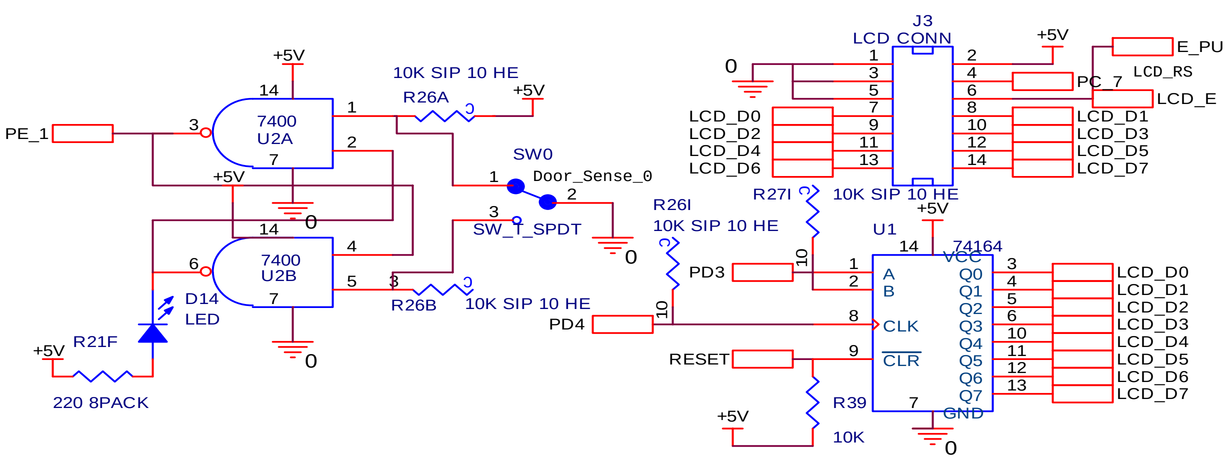
- Figure 7 (b) is one of four pneumatic valve control circuits. The four valve control circuits are connected to the corresponding J6 input. For example, the output of the drive circuit being at Valve_0 is connected to the VALVE_0 input of J6.



(a) **(b)**

Fig. #7: Stepper Motor and Value Control Circuit

- Figure 8(a) is one of 8 identical sensors. For example, one sensor switch is connected to the cabinet door. If the cabinet door happened to be open the door sensor switch would trigger an alarm.
- Figure 8(b) is used for LCD module control. PD3, PD4, and RESET are connected to the J1 Header. /the outputs for U1 are connected to the J3 LCD connector.



(a) **(b)**

Fig. # 8: Sensors and LCD Module Control Circuit

Figure 9 shows the fully assembled high-pressure injection cabinet system. The system consists of the CPU and stepper motor control PCBs, a power supply, a pneumatic air pump, and a stainless steel cabinet.

Fig. # 9: High Pressure Injection Cabinet System

III. The Software Designs

The software is written in the 68HC11 Assembly language code format. The language allows the user easy and direct access to the hardware controls. The software is implemented in a menu-driven form and gives the user a top/down selection of the marinated food processes. The LCD module and the 16-key keypad are the means of communication between the user and the system. Table 2 is the list of the function keys that the software design uses to interact with the system.

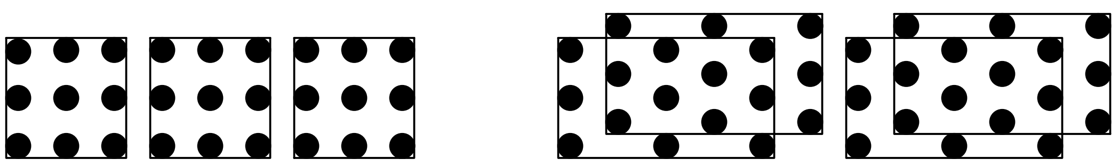
The software code is stored in an EPROM on the CPU system board. This allows the user to easily update the program software with an exchange of the EPROM chip [9]. There are two selectable injection patterns: single and double density as shown in Figure 10. The choice of the injection pattern is embedded in the software program according to the choice of the product being injected, such as chicken wings, chicken breasts, chicken quarters, steak, pot roast/ribs, pork, cheese and or fish. These patterns were chosen by the food industry to be incorporated in the project. Figure 11 shows the flowchart of the complete system operation. There are four products (cq = chicken quarter, pr/rib = pork rib, cheese, fish fillet) to be injected with ingredients. Each product has two different injection times. These injection times depend on the thickness of the object, which can be less than one inch or greater than one inch.

Keypad Key	Attribute	Meaning
0	no	
1	cw	Chicken wings
	yes	
2	cb	Chicken breast
3	cq	Chicken quarter
4	rs	Round steak

5	stk	Steak
6	pr/rib	Pot roast and ribs
7	pch	Pork chops
8	pk	Pork
9	cheese	cheese
A	Start /next	Start program or next option
B	fish fillet	Fish fillet
	1	Injection area number 1 (5*5 in)
C	2	Injection area number 2 (5*9 in)
D	3	Injection area number 3 (7*9 in)
E	< 1in	Thickness less than 1 inch
	4	Injection area number 4 (9*9 in)
F	clean cycle	Start clean cycle
	≥ 1in	Thickness greater or equal than 1 inch

Table 2: The Keypad Function Keys Distribution

An example of how this program is implemented using the keypad keys in Table 2 and the Software Control Flow Chart in Figure 11 is as follows. First, one would push “A” to start the process. Then if “2” is selected in block MSG 1/p-2 it would mean that a chicken breast is to be injected. Next, selecting “F” in block MSG 5/p-6 indicates that the chicken breast is greater than one inch thick. If “E” is then selected in MSG 6/p-16 for the next step it would indicate an injection area of 9.9 inches. If “D” is selected instead of “E” it would mean an injection area of 7.9 inches.



(a) Pattern 1 Single density (b) Pattern 2 Double density

Fig. # 10: Choices of Injection Pattern

IV. The Cost/Effect Analysis

There is no significant difference in the expected performance of the PLC implementation and the microcontroller-based design. However, there is a difference in the cost of producing the PLC and microcontroller-based system, as shown in Table 3.

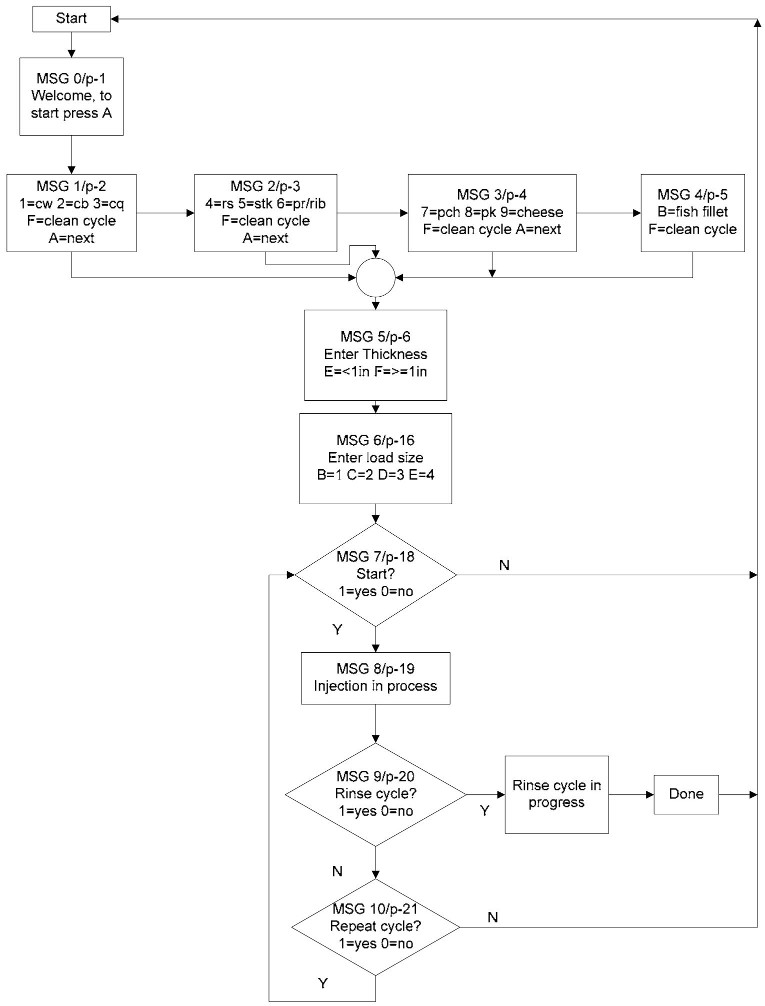


Fig. # 11: Software Control Flow Chart

PLC Implementation					Microcontroller Implementation			
Item	**Unit Cost**	**Unit**	**Total Cost**		**Item**	**Unit Cost**	**Unit**	**Total Cost**
PLC & Peripheral	$260.00	1	$260.00		Microcontroller PCB	$60.00	1	$60.00
Stepper Motor PCB	$95.00	2	$190.00		Stepper Motor PCB	$100.00	1	$100.00
Temperature Sensor PCB	$65.00	2	$130.00		4*4 Keypad	$15.00	1	$15.00
Touch Screen	$739.00	1	$739.00		LCD Module	$12.00	1	$12.00
Grand Total			**$1319.00**		**Grand Total**			**$187.00**

Table 3: PLC and Microcontroller-Based Systems Cost Comparison

The PLC system uses a touch screen, and the microcontroller system uses a keypad and an LCD module. If the touch screen and sensor PCB are excluded from the PLC system the difference in cost will be within an amount of $290.00. Based on the above analysis of both systems, they both fulfill the requirements of being standalone and fully automatic. As far as the cost in manufacturing and upgrading, the microcontroller-based system is superior to the PLC.

Considering mass production of the injection system, the preferable choice is obviously the microcontroller-based system design.

V. The Potential Applications

There are many different applicable implementations for this microcontroller-based design, some of which are real time data logging, sequential logic controls, and automated laser welding. The system application in a welding environment has already commenced and Figure 12 shows the X-Y table system used for laser welding applications.

Fig. # 12: The X-Y Table System in Laser Welding Applications

VI. Conclusion

The applied research project has had an extremely positive impact in the classroom, laboratory experiments, and the students' approach to project implementations. During the development stage of this project, there were several demonstrations to classes that were related to the microcontroller concept. Thanks to this real world application it has triggered students' interest and motivation to learn how software and hardware interact to create a finished product.

The overall process to develop this product took a little over one year. Among those involved in the design, development, analysis, and evaluation of the system were faculty, one graduate student, and three senior undergraduates. Although the development of an automated system was a challenging task for the group, it was a worthwhile effort and will pay off financially for years to come. There are several factors that make this project attractive to students, faculty, and the administration.

From the student's point of view, this project puts the material learned in the classroom into a real world application. There are several challenges presented to students who are willing to take on a large-scale project such as this one. These challenges force the students to exhibit a *hands-on* and *minds-on* knowledge in order to achieve functionality. Without this project, or a similar type project, it would be difficult for students to gain the same level of experience than what a sole classroom experience could offer. The classroom and laboratory integration provides interesting concepts that offer students a better understanding of the links between hardware and software and the potential applications for the students' future workplaces.

From the faculty point of view, it was a great demonstration of how the course concepts and principles taught in the classroom interact in a real world application. A working model is worth thousand words and it makes for a better instruction tool when one has a product to explain the entire concepts being taught. This also helps the faculty keep in contact with the private sector of industry. It not only benefits the faculty professional development but also demonstrates their abilities to assist the needs of local industry.

From the administration point of view, the collaboration with industry on product design and development is priceless. This will not only educate the industry about what the ET program can do, but it will also acquaint the industry with our institutional products, the students. It is a valuable recruiting tool to let the students know that science or engineering are not the only curricula to choose from, and that Engineering Technology as an Applied Engineering is also a rewarding professional career choice.

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