ENGINEERING AND PRODUCT DESIGN EDUCATION CONFERENCE
7-8 SEPTEMBER 2006, SALZBURG UNIVERSITY OF APPLIED SCIENCES, SALZBURG, AUSTRIA

IMPLEMENTATION ISSUES AND BENEFITS OF INTEGRATING MICROCONTROLLERS IN AN EXISTING DESIGN AND BUILD PROJECT

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ABSTRACT
The last twenty years has seen an increase in the level of integration of electromechanical devices in many products and engineered systems. Today's undergraduate engineers should therefore be provided with appropriate knowledge, methods and the opportunities to design and develop products using microcontrollers, sensors and actuators in order to mirror industrial product development trends. This paper concerns the issues surrounding the recent adoption of microcontrollers in an existing team-based design and build project, part of the First Year MEng course in Mechanical Engineering. As part of the process of continuously improving the delivery and learning outcomes year on year, the use of microcontrollers has also benefited staff, students and the Department in a number of areas, including: reduction in time to conceive, build and test the electrical system, increased project flexibility, greatly increased electronic reliability and nearly 100% recovery of components and devices.

Keywords: Microcontrollers, design & build project, teamwork, implementation issues

1 INTRODUCTION

The popularity of electromechanical devices has increased substantially over the last few years assisted by developments in microcontrollers, sensors and actuators. They are integrated into products and applications as diverse as cars, computer equipment, plant instrumentation, aerospace controls and domestic appliances [1-3]. There is a demand for engineers with an appropriate background to design and develop these products [1] and it is essential that Mechanical Engineering students know how these technologies can be integrated in product design [4], especially at the early stages of their study. Consequently, the first year Design and Make Project (DMP) was reviewed two years ago to make effective use of microcontrollers and the programmable interfacing of sensors and actuators to create a new mechatronics-based application.

DMP is a team-based design and build project lasting approximately 60 hours over eight weeks in the last two terms of the Design and Manufacture course. Each team is required to design and build a vending machine that stores and dispenses on command a standard opaque plastic cup (white polyethylene) from a store of 10. In this machine, a cup must be dispensed to a receiving chamber, accessible from the front of the machine, through a protective door, only after the cup has been filled with the beverage (simulated with a time delay of 10 seconds). The door (normally closed) opens automatically only after the simulated fill and only after one dispensing/simulated filling/retrieving sequence can a second cup be demanded, with 10 dispensed in total. In addition, the vending machine must utilise a 12V DC power supply, have maximum design elegance, reliability, simplicity and maintainability, and use the minimum number of bought-in components and resources during manufacture to a budget of £75.

Three weeks are spent brainstorming, evaluating and selecting sub-system concepts. Four weeks are spent on the embodiment and detailed design, and one week on manufacture and assembly. The students work closely in their teams through a guided schedule of work, but essentially manage the project themselves. The vending machine is built during a post-examination phase. Figure 1 shows students engaged in the final stages of this phase. The recently adopted microcontroller is shown top left-hand side of the fascia board and will be discussed later. On the last day, students present their vending machines to the Mechanical Engineering Department but are judged by members of the Department's Industrial Advisory Board. Assessment of the final vending machines is based on innovation, fulfillment of the PDS, quality of manufacture, presentation skills, salesmanship and response to questions. Each group has 20 minutes for their presentations, including a demonstration of the vending machine working at least 10 times. In addition to coursework marks, prizes are awarded to the wining teams; £100 for first place and £50 for the runner-up.
After several years of delivering this part of the course to the students, it was felt that significant improvements could not only be made to the success rate of the completed vending machines coupled with a simplification of the build phase in time and resources, but ultimately modernise the project in-line with industrial practices. This paper concerns the issues surrounding the recent adoption of microcontrollers in DMP and discusses the reasons for adoption, its financial and technical implications and learning and resource benefits experienced, both for students and the Department.

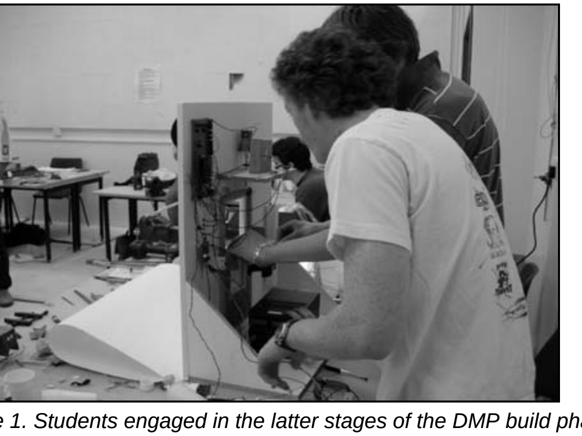

Figure 1. Students engaged in the latter stages of the DMP build phase (microcontroller shown top left-hand side of fascia board)

2 REASONS FOR ADOPTING A MICROCONTROLLER

After several years of delivering DMP to the students, the authors felt that significant improvements could be made to the project concentrating on the electrical system design and manufacture. Each electrical solution generated by the students was bespoke and placed a very heavy demand for technical support. Last minute changes were also difficult to implement and most machine failures were blamed, rightly or wrongly, on the electrical systems. A small but significant number of undergraduates failed to see the relevance, to them, of the electrical and associated skills required. Because of the bespoke nature of the electrical systems, recovery of the major components used was also difficult. Previously, discrete logic gates, timers, operational amplifiers, power amplifiers were used. Sensors ranged from micro-switches to analogue optical sensors, actuators from solenoids to motors. Since the solutions tended to be unique for each group, the electronics were normally built on breadboards. This involved circuit design, circuit layout, soldering and discrete wiring. Digital logic was not taught until the year two and access to logic design skills and soldering practice was limited. All of the skills required by the students to complete the task had to be acquired before attending University. Consequently, the design and build quality for the electrical systems varied from group to group. The students found it difficult to use a systems approach to the electrical design and inter-group communications were confused.

Microcontroller technology seemed to have everything we needed for the electrical side of the project in terms of logic and timers. The logic functions and timer values could be changed quickly and easily by changing the program rather than changing the hardwired breadboard. Minimal soldering skills were required usually limited to connecting micro-switches and diagnostic Light Emitting Diodes (LED). In turn, the repeatability, functionality, failure rate, etc of the completed vending machines coupled with a simplification of the build phase in time and resources could be achieved through their adoption.

The teaching and use of microcontrollers has traditionally been aimed at electrical and computer science undergraduates and the associated 'cloud of complexity' has tended to put off the rest of the engineering cohort. Traditionally all microcontroller programs were written in assembly language (this can be different for each microcontroller manufacturer) and required a very thorough understanding of the internal architecture and associated registers of that particular device. We did not want to teach microcontroller architecture or assembly language programming. It was our intention to show how these inexpensive (£2 to £10 each) but complex devices could easily be taught to mechanical and other engineering students designing electro-mechanical products. Microcontroller requirements were non-volatile (keeps the program in the event of a power failure) an electrically erasable and programmable device with the absolute minimum of external components needed to get a working system. The software requirements were an affordable easy to use high-level language program capable of simulation and generation of the final hexadecimal code suitable for burning into the microcontroller.

As a Mechanical Engineering Department, not equipped with the electrical resource in people or equipment enjoyed by an Electrical Engineering Department, a simpler solution had to be found. At the time a reasonably priced development kit, at approximately £90, was produced by Arizona Microchip [5] based on their new 16F877 40 pin flash device. A substantial educational discount of up to 25% was available to qualifying institutions under their University programme. This development kit connected to a PC and using Arizona Microchip's free assembly language programmer MPLAB allowing the 16F877 to be programmed. We purchased two of these kits and after evaluation of both MPLAB and the development kits we decided to build our own simplified printed circuit board based on their original design and investigate alternative high-level programming software packages. Screw terminals were attached to the board connected to the two eight channel ports. The inputs and outputs of the motor driver and Darlington driver chips and some other key connections were also made available via screw terminals.

After evaluating most of the available C programming packages available for the Arizona Microchip microcontrollers only one met our requirements of low cost and ease of use for new users of microcontrollers and the C programming language. A Visual C programming language called WIZ-C (£100 for the professional version or £35 for a LITE version) available from Forest Electronic Developments [6] was chosen. WIZ-C meets the requirements for minimal knowledge of the microcontroller architecture and also has a simulation feature.

3 ELECTRICAL SYSTEM DESIGN USING A MICROCONTOLLER

During the design phase, students are provided with two documents, a basic introduction document describing what a microcontroller is and the diverse use of microcontrollers in every day products, and tutorial exercises on Top Down Design explaining how to produce the 'English' top level descriptions of their system logic. The students responsible for the electrical system design are required to treat the vending cycle as a sequential system with no feedback loops. They are asked to produce a 'Top Down Design' in 'English' describing how they would like their system to work in no more than eight simple steps.

This modular approach helps students to identify electrical sub-systems broadly in line with each of the mechanical sub-systems thus improving group communications. Using this method gives an insight into the number and type of sensors required to perform each of the steps. The final choice of sensors and actuators is of course based upon the system performance requirements linking to the key mechanical sub-systems. At the concept design phase, no programming language information has been introduced or required. Each of these simple 'English' steps can be expanded and refined into testable stand alone procedures. In week 4, a demonstration board with a microcontroller and power drivers (see Figure 2) is used to show how to connect a selection of typical sensors and actuators. This allows the students to see which type of sensors and actuators might be appropriate for their concept system. Advice is also provided on the performance and suitability of each of the sensors and actuators shown and the preferred devices for use in different scenarios, as specified from recommended suppliers [7][8].

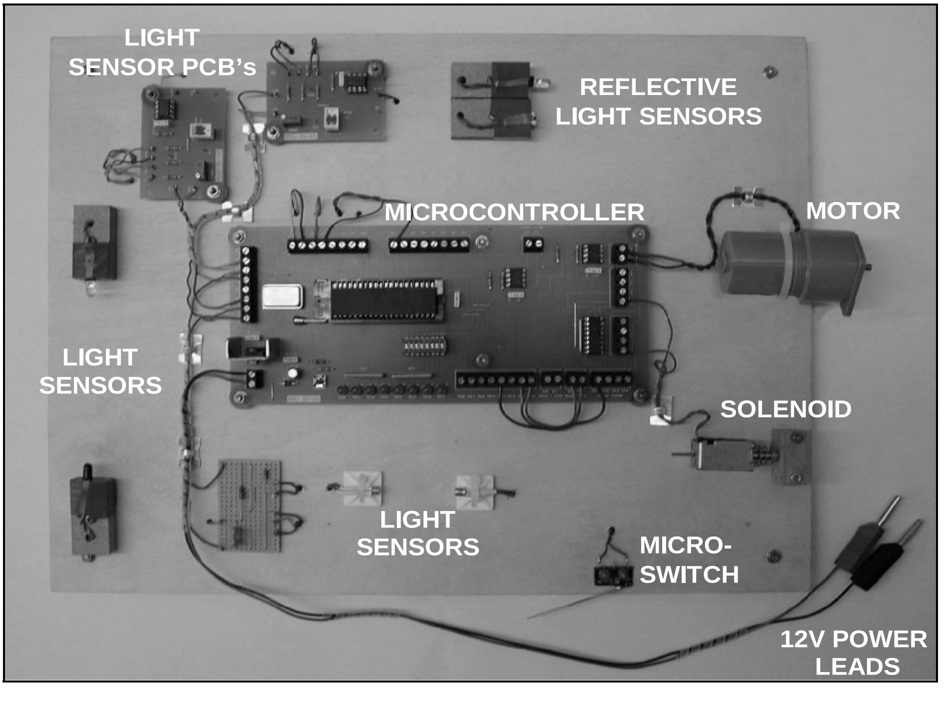

Figure 2. A microcontroller connected to a selection of actuators and sensors

In the build phase, the three computer laboratory based tutorial exercises introduce the student to WIZ-C [6], the Visual C programming environment they will be using to implement their electrical design. Each of the exercises is a totally separate stand alone project. They are not allowed to copy or modify any of the other exercises to complete the next exercise. The first exercise starts with the equivalent of ‘Hello World’ in programming languages to the microcontroller equivalent of flashing eight LED's. The second exercise builds on the first and eight switches connected to the input ports are read and the result displayed on the eight LED’s connected to the output ports.

Using the second exercise as a demonstration of WIZ-C in use, Input and Output ports are selected and connected to the microcontroller pins using mouse clicks in the Application Designer window. Compiling the project for the first time automatically generates two code files (main and user) which contain all the programming structures based on the particular application of input and output ports connected in the Application Designer window and the main file must not be modified by the students. The user code file also has an automatically generated structure and this is the only file that needs to have code added by the students to perform their required functions.

The final exercise demonstrates how to continually test an input until it changes and then perform some action based on that change. It also demonstrates how their ‘English’ description of one simple step can be changed into the programming language. Each of the exercises must be checked using the simulation element of the programming environment. When all three of the exercises are completed the students are given the microcontroller board, a microcontroller chip and the power supply that they will use for their vending machine. They are then are required to download (burn) each of their programs into their microcontroller and check that the tutorial exercises produce the same results on the microcontroller board as in the computer simulations.

The vending machine is treated as a sequential system with no feedback loops. A switch is used for the vend request. Sensors are used to detect whether cups are present, door open or closed, and when the cup stack is full. Motors or solenoids are used for the actuation typically. Motors run at a fixed speed and can rotate in either direction. Gearboxes can either be bought-in or manufactured from standard packs for reduction or increasing speed or torque. Status LED’s may be used to indicate the various processes of the machine and any subsequent fault conditions, however, by this stage in component selection, students learn the benefit of judicially selecting actuation devices as they are the most expensive. Other ‘luxuries’ if the budget allows are safety mechanisms, particularly for the door e.g. the ‘customer’ cannot put their hand back in the closing door causing injury as a photo detector is broken and opens the door again.

4 CONCLUSIONS

The Design and Make Project continues to make a valuable contribution to student education. It is intended to mirror industrial product development, providing the opportunity to develop a product to satisfy a detailed specification, create engineering drawings, manufacturing plans and hardware within a compressed timescale. Students develop essential personal and team skills through the high level of interaction necessary to meet the deadlines and deliverables. The project has also been very successful in providing students with hands-on manufacture and assembly practice. Importantly though, the adoption of microcontroller technology has added an extra dimension to the project, allowing all the electronics required in terms of logic and timers to be contained within one programmable device. Logic functions can quickly and easily be altered by modifying the program and fault-finding is easier and more identifiable by students as system simulation is used to debug basic programs leading to an almost virtual prototyping and testing process. The nature of the project now allows students to learn about the interface of sensors and actuators through the use of a recently adopted microcontroller package and student feedback has so far been positive.

It is anticipated that they will benefit from this hands-on experience at the very early stages of their studies as they progress with their studies in later years.

A number of resource and utility benefits for staff, students and the Department have also been realised through the adoption of a microcontroller:

- Reduction in build phase from originally 7 days to 5 days due to a reduction in time to conceive, build and test the electrical system in particular.
- Improved discussion and team-working between team members and disciplines.
- Increased electronic reliability and overall repeatability of built vending machines.
- Almost full recovery and recycling of components. Microcontroller board, sensors and actuators are now recoverable for reuse in future projects to keep costs down.
- Increased flexibility. Microcontrollers used for research projects in the Department.

There are however a number of cost and resource issues that must be considered before adopting or adapting similar projects. Intensive technical supervision is required during the build phase (although now less than previous years), one academic supervisor and four technicians are required for one week per 100 students. The initial costs to buy-in or manufacture in-house the microcontrollers is also high, the latter being the more cost-effective option, but is more reliant on technical expertise in-house. The microcontrollers have a useful life of maybe five years or more, making these initial costs worthwhile in the long term, especially when considering their potential application in other undergraduate projects as already experienced. A concern is that only two students really need to be involved in the electrical system design, rather than three or four as in previous years, therefore not all students are fully exposed to the microcontroller technology, making it a specialised role in a team-based project. It is interesting to note that the students seem to have accepted without comment the use of microcontrollers as a part of the project and the practice of learning by doing was the most important benefit for them. Nevertheless, the process of microcontroller integration has been a valuable experience for all, and enhancing the undergraduate project work in the Department. It provides a useful introduction to microcontrollers in a mechatronics environment using simple sensors and actuators and promotes a modular and system based approach to product design.

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