UNDERGRADUATE ENGINEERS FOR CURRICULUM AND LABORATORY EQUIPMENT DEVELOPMENT: A FREESCALE S12 MICROCONTROLLER LABORATORY TRAINER

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Abstract

For over five years we have used student designed and developed laboratory equipment with great success. Typically a student team will design and fabricate a prototype of a next – generation piece of laboratory equipment. Other students are then hired to fabricate multiple production run pieces of the equipment. Student developed laboratory equipment solves two challenging problems confronting most engineering programs: 1) the need to update laboratory exercises and equipment without adequate funds and 2) satisfying Accreditation Board for Engineering and Technology (ABET) requirements for a major design experience within the curriculum. In this paper we will briefly review previous projects completed such as a Motorola HC12 microcontroller based teaching platform, a Freescale S12 microcontroller based teaching robot, and a Verilog HDL based robot. We will also review the lessons learned in such a venture and potential challenges. We then focus on the most recent student developed laboratory equipment – a Freescale S12 based laboratory trainer.

Background

Engineering departments are often faced with the need to update laboratory exercises and equipment without adequate funds to do so. Another challenge faced by departments are satisfying Accreditation Board for Engineering and Technology (ABET) Engineering Accreditation Commission (EAC) criteria for a major capstone design experience within the curriculum. ABET Criterion 4. Professional Component guidelines state, “Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and multiple realistic constraints.” These constraints are further defined in Criterion 3. Program Outcomes and Assessment which states, “Engineering programs must demonstrate that their students attain: (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability[1, 2].

In this paper we will describe how we solved these two challenges by updating our microprocessor laboratory facilities on a limited budget using student engineers. We have successfully used student engineers in the past to develop custom laboratory equipment and teaching aids including a:

- Verilog HDL controlled robot [3],
- Labview based digital signal processing and bioinstrumentation laboratory program[4],
- Robot to teach complex real time embedded systems concepts[5],
- Visual simulator to teach real-time operating systems[6], and

- Teaching platform based on the Motorola/Freescale HC12 microcontroller [7].

This highly successful program provided state-of-the-art computer engineering laboratory equipment using student designed, fabricated, and tested laboratory equipment. Furthermore, the students were completely responsible for developing all of the supporting courseware such as laboratory assignments for the new equipment. From the department's point of view, state-of-art, custom laboratory equipment was obtained at a lower the cost than commercially available trainers. Furthermore, students were exposed to a real world design problem and all of the inherent related issues such as: working on a design team, interacting with highly skilled technicians, budget constraints, timelines, manufacturability issues, reliability issues, and customer satisfaction [2].

It is interesting to note that the project described in this paper is a follow-on project to a student developed microcontroller laboratory trainer that was developed and fabricated six years ago [5]. Since completion of the project, fifteen of the trainers have been used daily in our senior level microprocessors course and also used extensively in our senior design course. The trainers have served well but it was time to prototype a replacement trainer since the host microcontroller, the Motorola/Freescale HC12 is now considered a legacy product by its manufacturer. For this reason, a student group developed a new teaching platform design based on the S12 processor. This modular platform serves several microcontroller based courses and is adaptable for a beginning microcontroller course through graduate levels courses.

Methods

In this section we detail the development of the new hardware training platform and also the supporting laboratory exercises. For convenience we have subdivided this section into hardware and software.

Hardware

Features

The Motorola/Freescale HC12 teaching platform for the Electrical and Computer Engineering Department's, Microprocessors (EE 4390) course has provided hundreds of students with a teaching aid over its five years of service life. However, the platform has become outdated and needs to be replaced. More so, the HC12 is now considered to be a legacy product by Motorola/Freescale, and a successor is needed to accommodate students.

For these reason, a senior design team developed a new teaching platform design. This platform was designed to provide students in EE 4390 with a smooth transition into the microprocessor realm, letting them learn microcontroller concepts, without having to troubleshoot unintended hardware problems. The platform design also solves the problem with the legacy HC12 processor. The solution is the MC9S12DP256 (a more recent processor) hosted onboard a Minidragon+™ evaluation board. The Minidragon+™ evaluation board will be able to accommodate several courses because it hosts the subsystems required by both the EE 4390 Microprocessor and EE 4590/5590 Real Time Embedded Systems course. Furthermore it will support the processing features required by a stationary teaching platform or a robot based teaching platform.

Maintenance down time is an important factor in the design of the new teaching platform. The platform must be completely available and operational to students during their scheduled laboratory class. We designed the platform for quick and easy maintenance. First, habitual problem circuits were redesigned so the maintainer can quickly replace them in the event they fail. Second, the platform was developed to be modular, providing the service technician the ability to replace parts in a timely manner. Third, the platform was designed to shelter the main processor from the student. Overall these features provide the new teaching/robot platform robustness. A robust design insures this platform will last for no less than five years. The five year requirement is based on the approximate time before the processor is considered to be a legacy component and another teaching platform is needed.

The MC9S12DP256 [8] Teaching/Robot Platform or TRP was developed as a replacement to the previous HC12 teaching platform. The TRP design includes an adapter board which dictates the pins available to the student from the MC9S12DP256 Minidragon+™ [9] evaluation board. The board only provides access to the MC9S12DP256 subsystems required in the EE 4390 Microprocessors course. While this platform is in use in the EE 4590/5590 Real Time Embedded Systems course, the adapter board and enclosure can be removed for complete access to the microprocessor.

The TRP can be supplied with power of two different types. The user of the TRP can use either a 9 VDC wall power supply or the two 7.2 VDC rechargeable batteries. While the wall power supply is available to the platform, the batteries are automatically disconnected. Furthermore, during the time the wall source is active, power is routed to the batteries to charge them. This power system design provides the platform user the ability to run bench top as well as remote activities without having to switch the power supply.

In the Real Time Embedded System's course the platform is used on a robot equipped with servo motors and infrared (IR) sensors. These features have been incorporated into the platform design. This allows the teaching platform to be used as a bench top aid as well as an actual robot platform.

Requirements

The following requirements were established for the TRP design:

1) Full compatibility with the EE 4390 and EE 4590 labs.
    a. Will provide all students in the EE 4390, Microcontrollers course: SCI (serial communication interface) ports, SPI (serial peripheral interface) ports, A/D (analog to digital) converters, timer ports, general purpose ports, LCD (liquid crystal display), eight segment LED displays, keypad and all other instructor necessary systems.
    b. Will provide all students in the EE 4590 course: complete access to the MC9S12DP256 Minidragon+™, as well as platform adjustable devices such as servos, and IR distance sensors.

2) Modular system
    a. Will provide quick and easy maintenance.
    b. Will provide a sophisticated interfacing between auxiliary equipment: IR sensors and servos.

3) Original adapter board design
    a. Exposes only the necessary components for the EE 4390 lab, to reduce misuse of the equipment.
    b. Removable adapter board to allow direct access to the Minidragon+™ for use by the EE 4590 lab.
    c. Interface-able with the HCS12 Minidragon+™ board by means of ribbon cable.

4) Robust design, long lasting.
    a. Quick interchangeable parts to minimize down equipment time.
    b. Protection of the HCS12 Minidragon+™ board by means of an enclosure.
    c. Fully supported and fastened components

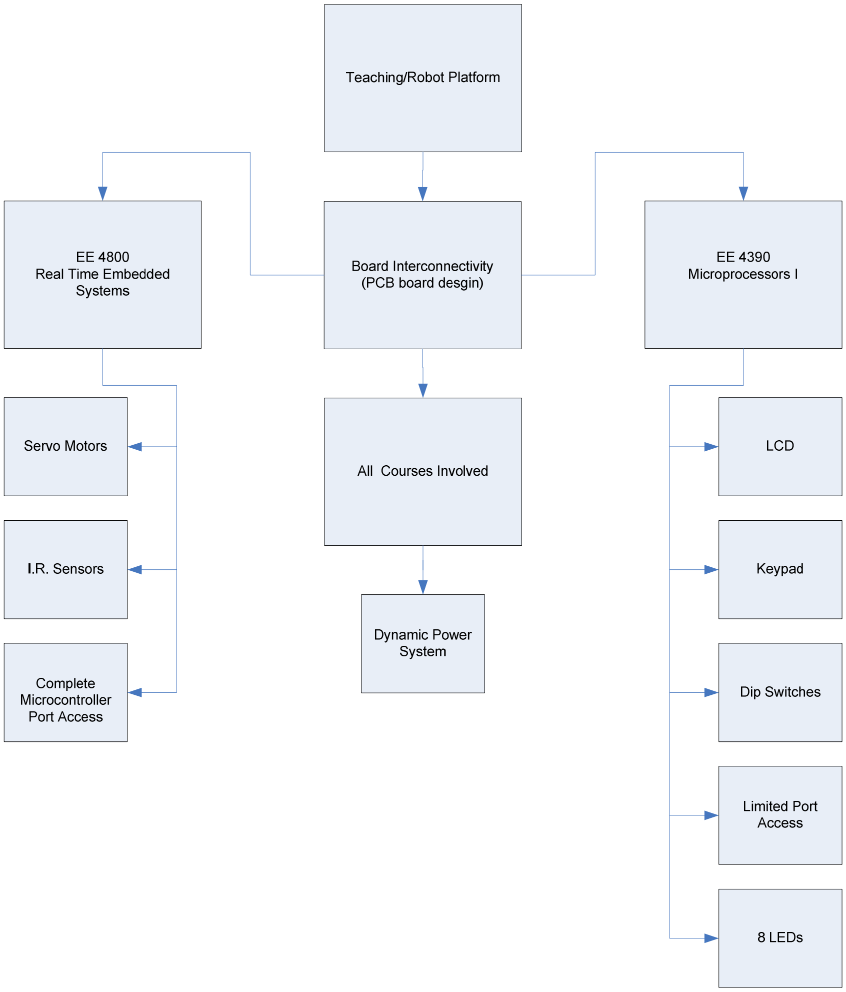

Figure 1: Project block diagram.

5) All inclusive power supply.
   a. Will supply the top-board and Minidragon+.
   b. Will recharge the battery supply when plugged into an external transformer.
   c. Will supply the Minidragon+™ with nine volts of filtered D.C. voltage.
   d. Will supply the top-plate with required voltage to run all components inclusive of the top-plate: The LCD, eight segment LED display, and keypad.

6) Attachable/Detachable servo motors
   a. Allow the motors and wheels required for the EE 4590 lab to be simply attached and detached when necessary. These would be removed for the EE 4390 labs.
   b. Allows the platform to be mobile, which compliments the fully compatible system requirement.

TRP Subsystems

The TRP has been broken up into three subsections as shown in Figure 1. The three subsections are designated EE 4590 Real Time Embedded Systems course, EE 4390 Microprocessors course, and All Courses Involved. The EE 4590 subsection is further subdivided into three simple blocks which make up its characteristics. Servo motors, IR sensors, and complete microcontroller access encompasses all the attributes the EE 4590 course requires in a platform. Next, the EE

4390 course can be subdivided into five different categories: Liquid Crystal Display (LCD), keypad, dip switches, limited port access, and eight LED's. These five categories overview the laboratory features needed in the EE 4390 course. Finally the All Courses Involved section contains only one feature–the Dynamic Power System. The Dynamic Power System focuses on the TRP power system previously described.

Resulting Design

Space does not allow a detailed description of the design. All design details are readily available for use with your course. Please contact the corresponding author for this material. Instead we provide the overall high level design results designated top-plate, center-plate, and bottom-plate.

Top-Plate. The top-plate is only used in the EE 4390 Microprocessors course. On the top-plate there is an LCD, 16-button keypad, two terminal boards, and the accessory board. Figure 2 below shows the top-plate and its components.

Center-Plate. The center-plate is used in all of the courses. On the center-plate there is a section of breadboard, the Minidragon+™ and the power board. When the top-plate is attached to the center-plate most of the key components are shielded from the student user; however, when the top-plate is removed the Minidragon+™ is completely visible and available to the user. Figure 3 shows the center-plate.

Notice in Figure 3 that there are rubber stoppers on the bottom of the platform to raise it off of the bench top. There are also battery connectors and the adapter board which will be removed when in operation during the EE 4590 labs.

Bottom-Plate. The bottom-plate is used strictly for the EE 4590 course. More so, the bottom plate can be removed when students are not programming a mobile robot. In Figure 4 below, there are two aluminum assembly brackets which connect the bottom-plate to the center-plate. The batteries are also located on this plate.

Project Cost

Table 1 (in Appendix) provides the preliminary cost analysis for the TRP. As you can see the estimated parts cost per platform is approximately US$265.00.

Figure 2: Top plate (with center-plate attached).

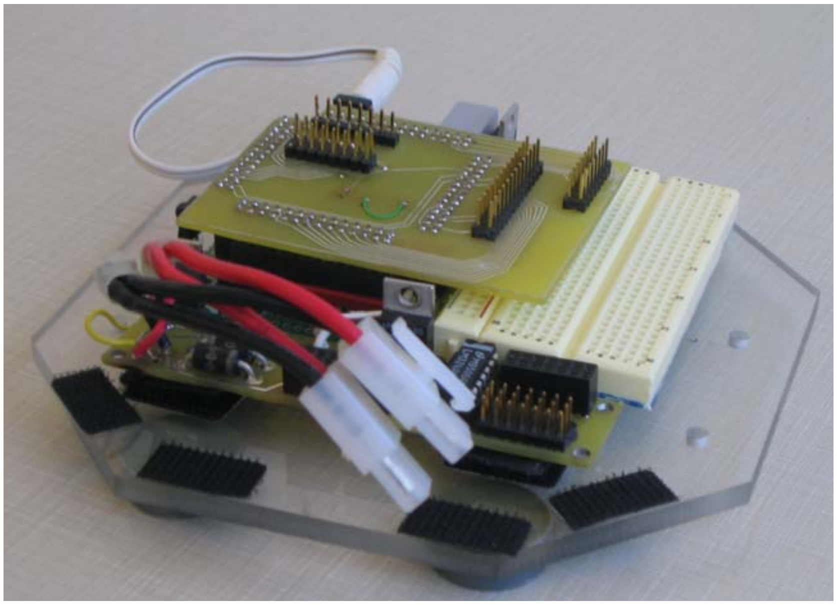

Figure 3: Center-plate.

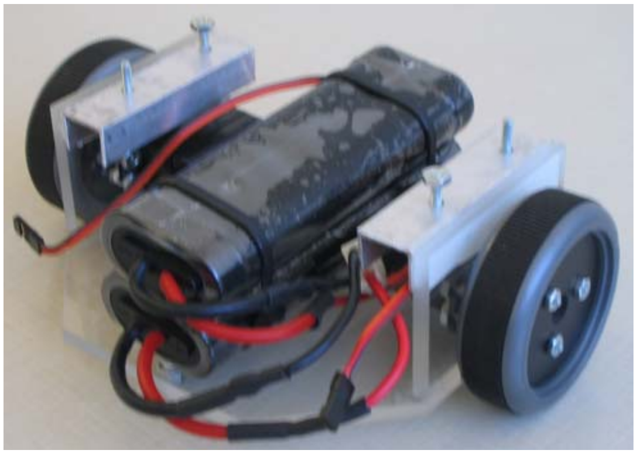

Figure 4: Bottom-plate.

Software

The other major portion of this design exercise was modifying the existing EE4390 Microprocessor laboratory exercises from the HC12 based microcontroller to the S12 based microcontroller. This was not required for the EE4590 Real Time Embedded Systems course since this course already uses the S12 based processor.

The laboratory exercises cover various subsystems of the microprocessor that students learn during the EE4390 course. Labs cover topics such as Serial Communication Interface, Analog to Digital conversion, the Timer Module, and interrupts. Some changes were made to these laboratory exercises to accommodate the interfaced circuits. Furthermore, new laboratory exercises were added for the Real Time Interrupt (RTI), Pulse Width Modulation (PWM), and the Motorola Scalable Controller Area Network (MSCAN) systems of the microcontroller.

Project Overview

This project was designed to adapt current EE4390 Microprocessor laboratory exercises using a training platform based on the 68HC12A4 (HC12) evaluation board into laboratory exercises using the Minidragon+™ evaluation board. The Minidragon+™ evaluation board hosts the MC9S12DP256C (S12) processor. Adapting the laboratory exercises from the HC12 to the S12 processor involves updating laboratory handouts and solutions, and developing new exercises involving the RTI and PWM systems. The goal for this project was to have functional labs using the S12 based Minidragon+™ evaluation board, keeping the same learning objectives currently included in each laboratory.

Laboratory Exercise Overview

Laboratory Exercise 1: Introduction to the HCS12. The first laboratory exercise is an introductory lab into the general use of the HCS12 Minidragon+™ board and associated laboratory equipment. Lab 1 is also used to familiarize the student with D-Bug 12 operating system resident within the microcontroller, and the Image Craft ICC12 assembler/compiler.

Laboratory Exercise 2: The Serial Communication Interface. The purpose of Laboratory Exercise 2 is to examine the operation of the Serial Communication Interface on the HC9S12. This lab uses the various SCI registers. Task 1 for this lab requires inputting the location of various SCI registers. This lab also requires that the student's microcontroller communicate back and forth with another microcontroller. To do this the baud rate and parity must be identical between the two microcontrollers.

Laboratory Exercise 3: Keypad and LCD Interface with the 68HCS12. The purpose of Lab 3 is to connect the LCD and the keypad to the Minidragon+™ and to input data using the keypad and have it display on the LCD.

Laboratory Exercise 4: Logic Analyzer Familiarization and 68HCS12 Serial Communication. Lab 4 revisits the SCI system and introduces the students to the logic analyzer. No additional hardware is required for this lab outside of the Minidragon+™ and the logic analyzer. The lab requires that the "S12" designator be transmitted using the SCI system. The logic analyzer is used to view the transmitted signal. The student must use SCI channel 1, since channel 0 is reserved to communicate between the PC and the S12 board. The students are required to wire from the respective TXD pin to the logic analyzer. The logic analyzer will display a binary representation of the transmitted signal.

Laboratory Exercise 5: Digital Voltmeter and Thermometer Using the Analog-to-Digital Converter. Lab 5 requires that the student again include the "putchar_dp256.c" file. This lab takes a voltage value from a temperature sensor, LM34, and converts it using the built in ATD converter on the S12. The Minidragon+™ has two complements of ATD channels to use, so the student will have to choose one, channel 0 or 1. Also, the LCD is also connected to the board again so that the voltage and temperature can be displayed. This requires that the student develop a software algorithm to convert a floating voltage representation into a digit-by-digit ASCII representation for display on the LCD.

Laboratory Exercise 6: Precision Square Waves with the Timer Module. Lab 6 uses the Timer Module to produce square waves. Task 1 requires that the student program using assembly language. Task 2 requires the code be written in C, same function.

Laboratory Exercise 7: Output Compare with Interrupts. Lab 7 uses interrupts to perform the output compare function.

*Laboratory Exercise 8: Real Time Interrupts. T*he Real Time Interrupt lab was developed from the RTI code that is provided in Barrett and Pack [10]. The RTI is another interrupt lab that can be used to teach students, again, the convenience of using interrupts to perform tasks versus polling. The RTI lab can be adapted to use the LCD as well.

The RTI lab requires the student program the RTI to set after a predetermined amount of milliseconds. This information will be used with a counter to determine elapsed time in seconds and minutes. The second task for this lab will require the student to reset the timer after so many seconds/minutes. This will show the students how tasks may be completed on a schedule without having to continually poll for an event.

Laboratory Exercise 9: Pulse Width Modulated Laboratory. The PWM lab introduces the students to a very useful feature of the HC9S12. The pulse width modulator produces a string of pulses at a given "on" and "off" time. The on time represents the percentage of time relative to the signal period that the pulse is high/active, while the off time represents the amount of time the pulse is low/inactive. The pulse width modulator is used in the EE 4590/5590 Real Time Embedded Systems lab to control the motors that turn the robot wheels. The PWM lab requires students to produce two different square waves at equal frequency but with different duty cycles. These waveforms will have to be verified using the logic analyzer.

Laboratory Exercise 10: Motorola Scalable Controller Area Network (MSCAN) Laboratory. The MSCAN laboratory exposes the students to the fundamental concepts of networking microcontrollers together in a small system to share data and work together on a common problem. Students are required to establish two-way communication between two (or more) microcontrollers equipped with MSCAN features.

Results and Discussion

The prototype TPR and code updates have been used together and all established requirements have been met. The next step in the project will be to fabricate, test, and introduce the TPR to the EE4390 Microprocessor and EE4590 Real Time Embedded Systems course. The fabrication is tentatively scheduled for Summer 2009 pending available funds with a target of putting the updated trainers in the classroom by the Fall 2009 semester.

Summary

We have used student teams to design and implement next generation laboratory equipment for over five years. In this paper we briefly reviewed previous projects completed such as a Motorola HC12 microcontroller based teaching platform, a Freescale S12 microcontroller based teaching robot, and a Verilog HDL based robot. We then focused on the most recent student developed laboratory equipment – a Freescale S12 based laboratory trainer and accompanying laboratory software. This modular platform serves several microcontroller based courses and is adaptable for a beginning microcontroller course through graduate levels courses.

Conclusions

As in previous projects students have once again demonstrated the capability to develop custom, robust, long-lasting educational tools. This provides a lower cost alternative to purchasing off-the-shelf educational tools. More importantly it allows students to participate in real world design challenges that help to satisfy ABET requirements for students to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.

Acknowledgments

All of the hardware and software laboratory material developed in this paper was developed by students for students. Specifically, Chad Hager**,** Mike Yurkoski, and Robert Lewis developed the new Teaching/Robot Platform prototype for the senior capstone design project. Matthew Jespersen developed laboratory exercises 1-9 for his Masters of Science in Electrical Engineering project. Zachary Rubel developed the MSCAN laboratory as an additional senior level project.

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Biographical Information

Steven F. Barrett received the BS in Electronic Engineering Technology from the University of Nebraska at Omaha in 1979, the M.E.E.E. from the University of Idaho at Moscow in 1986, and the Ph.D. from The University of Texas at Austin in 1993. He was formally an active duty faculty member at the United States Air Force Academy, Colorado and is now an Associate Professor of Electrical and Computer Engineering, University of Wyoming. He is a member of IEEE (senior) and Tau Beta Pi (chief faculty advisor). His research interests include digital and analog image processing, computer-assisted laser surgery, and embedded controller systems. He is a registered Professional Engineer in Wyoming and Colorado. He co-wrote with Dr. Daniel Pack five textbooks on microcontrollers and embedded systems. In 2004, Barrett was named "Wyoming Professor of the Year" by the Carnegie Foundation for the Advancement of Teaching and in 2008 was the recipient of the National Society of Professional Engineers (NSPE) Professional Engineers in Higher Education, Engineering Education Excellence Award.

Chad Hager graduated with a Bachelor of Science degree in Electrical Engineering from the University of Wyoming in December 2007. He will complete the Master of Science degree in Electrical Engineering in May 2009.

Mike Yurkoski graduated in May 2008 with a Bachelor of Science degree in Electrical Engineering from the University of Wyoming.

Robert Lewis graduated with a Bachelor of Science degree in Electrical Engineering from the University of Wyoming in December 2007. He will complete the Masters of Science degree in Electrical Engineering in December 2008.

Matthew Jespersen graduated with a Bachelor of Science degree in Electrical Engineering in May 2005 and a Masters of Science degree in August 2007 from the University of Wyoming. He is employed as an engineer in Moorcroft, WY.

Zachary Ruble graduated with a Bachelor of Science in Computer Engineering from the University of Wyoming in December 2007. He began graduate school at the University of Wyoming in January 2008 to pursue a Masters of Science degree in Electrical Engineering.

Appendix

Table 1. Preliminary Cost Analysis of the Teaching/Robot Platform

Design Team Members:		Date Revised:	12/21/2007
Robert Lewis	Estimated Total Spending=		$250.00
Mike Yurkoski	Estimated Cost =		$264.03
Chad Hager	Estimated Spending Left=		($14.03)
Cost Analysis			

Section of Design	On Hand	Description	Unit cost	Qt.	Total Cost
Surface Mount	Yes	L.C.D. display (Optrex, DMC 16204)	Distcont.	1	$15.00
	Yes	Keypad (Grayhill inc. G-04-068-k)	Distcont.	1	$15.00
	No	3M Terminal Bread Boards (3M 923292-I)	$12.80	2	$25.60
	Yes	Tri-state L.E.D.s-Jameco P# 34673	$0.24	8	$1.92
	Yes	10 section-DIP Switches/563-1002-5-ND	$3.30	1	$2.85
Top Board	Yes	LM7805CT 5 volt regulator/Fairchild semi.	$0.71	1	$0.71
	Yes	LM7809 9 volt regulator/Fairchild semi.	$0.71	1	$0.71
	Yes	Ribbon Cable 30	$6.00	1	$6.00
	No	.100" Female Header (2x4) DK - 609-2268-ND	$4.86	2	$9.72
	No	.100" Female Header (2x8) DK - 609-2272-ND	$2.63	1	$2.63
	No	.100" Male Header Shrouded (2x14) DK- A33167-ND	$1.48	2	$2.96
	No	.100" Female Connecter (2x14) DK - ASC26H-ND	$3.24	2	$6.48
	No	.100" Male Header Shrouded (2x8) DK- A33163-ND	$1.32	4	$5.28
	No	.100" Female Connector (2x8) DK-ASC16H-ND	$1.94	4	$7.76
Power Supply	Yes	7.2 Volt 1500 Ni-MH (Piranha) DuraTrax	$14.99	2	$29.98
	No	Battery Connector-Lynxmotion WH-01	$4.95	2	$9.90
	No	AC to DC wall trans.- Jameco Mfg	$10.95	1	$10.95

		#DDU1200050F0981			
	No	Jack,DC, addapter- Jameco P# 151554	$1.49	1	$1.49
	No	35W resistor DK-TCH35P10R0JE-ND	$6.05	1	$6.05
	No	Schottky diode DK- 1N5821/54GICT-ND	$0.74	3	$0.74
Motor Control	Yes	Fairchild Semi. LM324 Rail-to-Rail op. amp.	$0.34	1	$0.34
	No	Hitec HS-55 Micro Servo-Towerhobbies #31055S	$13.99	4	$55.96
IR Sensor	No	GP2D120 IR sensors - Hobby Engineering	$11.50	4	$46.00
Estimated Project Cost Without Safety Factor:					$264.03