2006-2092: MICROPROCESSOR BASED QUASI-AUTONOMOUS ROBOTIC PROJECTS

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Microprocessor Based Quasi-Autonomous Robotic Projects

I Introduction

For a number of years the Department of Electrical and Computer Engineering (ECE) at Texas Tech University (TTU) has supported the BEST (Boosting Engineering Science and Technology) robotics program in area secondary schools. The BEST program is different than many robotics type programs in that the cost to the schools is minimized. The local BEST Hub provides their schools with returnable kits and non-returnable kits to be used to construct the robot for that year's competition. The non-returnable kits, in this case, consist of a relatively large box of materials to be used in construction. These are not robot kits that are assembled. The robots must be built from scratch with the raw materials provided. The game is different every year so the robots also change.

BEST is a volunteer, non-profit organization that must raise the money to support the game and pay for the kits. The robots in the BEST competitions have been remote controlled type robots. The returnable kits are used each year and consist of the remote control system with motors and servos. For some time, the BEST organization has considered moving to a quasi-autonomous robot with microprocessor control. However, no systems have been found to meet the BEST requirements specifically in regard to cost, ease of use, ruggedness and reliability. The ECE Department at TTU has, for a number of years, used robotics projects with embedded microprocessors as an integral part of the project laboratory program. The development of a new system to meet this need for BEST has become a project for the TTU ECE second project Laboratory.

II Project Laboratories

The laboratory structure in the Electrical and Computer Engineering department at Texas Tech University is somewhat different than most university laboratories [1-10]. There are five, 3-hour credit required laboratory classes. Although all of the laboratories have pre-requisites, they are not associated with any one class. All of the laboratories require students to work in teams on long term projects. The student teams each have a project advisor, separate from the lab instructor and teaching assistant associated with each lab class and section. All of the teams report on their progress and answer questions on their projects in a weekly three hour lab meeting with all of the groups. Each group makes a more detailed intermediate and final presentation on the project. In addition, each student writes an individual intermediate and final report covering the whole project.

Although each team member is assigned specific actions by the team with specific deliverables, all team members are considered to be equally responsible for successful completion of the project. During their presentations each team member is expected to be able to answer questions on the whole project. Team members are measured for their contribution to the team by their advisor, lab instructor, lab director's staff and the team itself.

Teams in the first three project labs normally consist of three to four students, chosen randomly. While this helps the student to develop team working skills, it does not expose the students to the large team dynamics that are more prevalent in industry.

The TTU project laboratories also make use of continuing projects. For complex projects that may not be able to be completed in a semester, the projects are carried over into the next semester. Students have access to all previous work in all of the labs including final presentations and reports. For continuing projects the students are expect to learn what had been done in the past and to move the project forward to completion.

III Project Assignment

Students in the second project laboratory (EE 3332) have been directly involved with BEST for a number of years and the lab is considered by the University to have a community service component for this involvement. Other than supporting the BEST effort, there are other group projects in the class related to robotics and embedded microprocessors. Recently, all of the students in the second project laboratory have been assigned to develop a microprocessor based system for possible use in the BEST robotics program or a similar application. The system must work as a simple replacement for the current remote control motor drivers, but with additional capabilities for possible automatic control. This will allow for completely remote control, quasi-autonomous or completely autonomous operation of the robots.

The students were divided into a number of groups, usually 4 to a group. Some of the groups built robotic applications to apply and test the new controller board in its different stages of development. Some groups worked on developing the next versions of the board. Other groups worked on specialized software that is necessary for the BEST application with secondary school students that may not have much programming experience. All of groups in the lab were effectively linked together with a common goal of developing a final product with demonstrable applications. Therefore, the entire laboratory became a super group with a common purpose and important interactions. During laboratory weekly meetings, each group saw what the other groups were doing and how it related to their project and the overall goal linking the projects. Thus, feedback from the robot application groups drove changes in board and software development. The project began in the summer of 2005 and has continued through the spring of 2006.

IV Project Development

A small, very low power RISC type processor, the TI MSP430, was chosen for the project. It is relatively inexpensive and has a C complier available. Small development boards are also available. This processor has been used previously in the second project laboratory. This allows parallel development of applications and new boards.

The first requirement for the new system was that it be interchangeable with the current 4-channel remote control system. The receiver puts out a pulse width modulated (PWM) code to drive servos and motors. The receiver drives the servos directly but goes through a power driver for the motors. Two different size motors are used by BEST. Both operate at 7.2 volts. The large motor has a stall current over 2.5 amps while the small motor's stall current is slightly less than an amp. The servos operate at 5 volts which is obtained from the motor power drivers. Since the MSP430 is a 3.3 volt part, voltage shifting is necessary. There was also concern about isolating the processor from external connections especially since the system is to be used by inexperienced high school students.

Figure 1 shows the existing layout on the left and the proposed system using the MSP430 microprocessor from Texas Instruments on the right. The robot box provides for connection from the receiver to the servos and motor drivers. The new MSP430 system has to, at least, be able to replace the robot box and motor drivers.

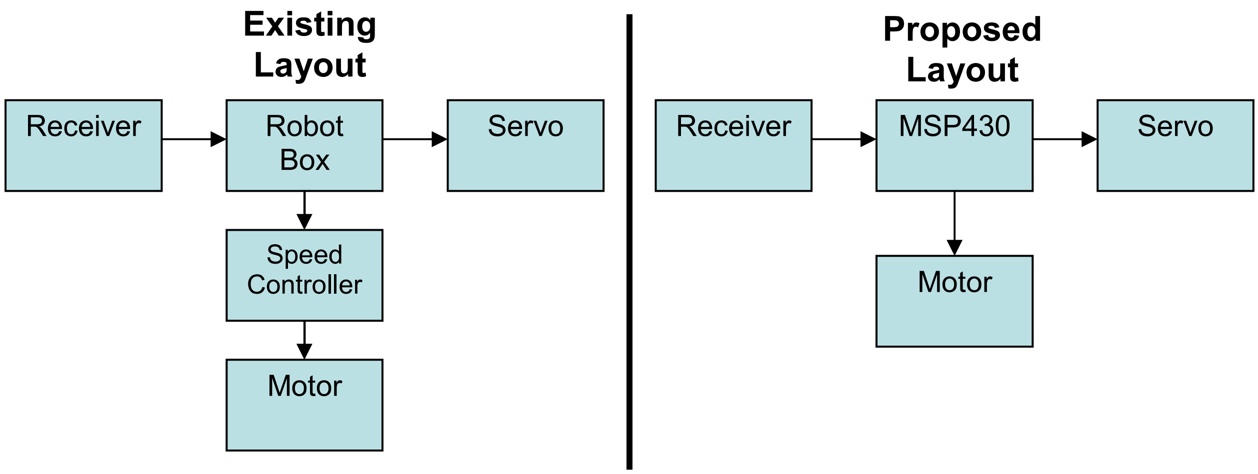

Figure 1: Exisiting and Proposed Layout [11]

A block diagram of the initial design is shown in Figure 2. The 7.2 volt battery is the power source used for the BEST robots. There are two DC to DC converter/regulators in the system to provide 3.3 volts for the MSP430 and 5 volts for the servo and H-bridge motor drivers. The 5 volt source is also connected to the receiver (the connection is not shown in the diagram). This allows the elimination of the receiver battery. Optocouplers are used to provide isolation and level shifting for the MSP430. The optocoupler outputs drive the small servos directly but H-bridges are used to drive the motors.

The receiver has four channels. In the existing system, the receiver can drive servos directly or can drive motors through the speed controllers, as indicated in Figure 1. The user can hard wire each channel to a servo or a speed controller. To allow the use of more motors, in past BEST competitions, one servo was frequently used to activate a switch switching from one motor to another. The new system has 8 independent outputs providing drive for four motors and four servos. This increases the capability of the system. However, for remote control applications, there are still only four channels from the receiver. The hardware switching done previously can now be done through software.

The motor drivers on the new system are TI TPIC0107-B Intelligent H-Bridges. These parts have a number of built-in safety features including current limiting cut-offs. They require direction logic in addition to the PWM signal for speed. The MSP 430 must convert the standard servo drive signal to the appropriate direction and power drive for the motors. [12]

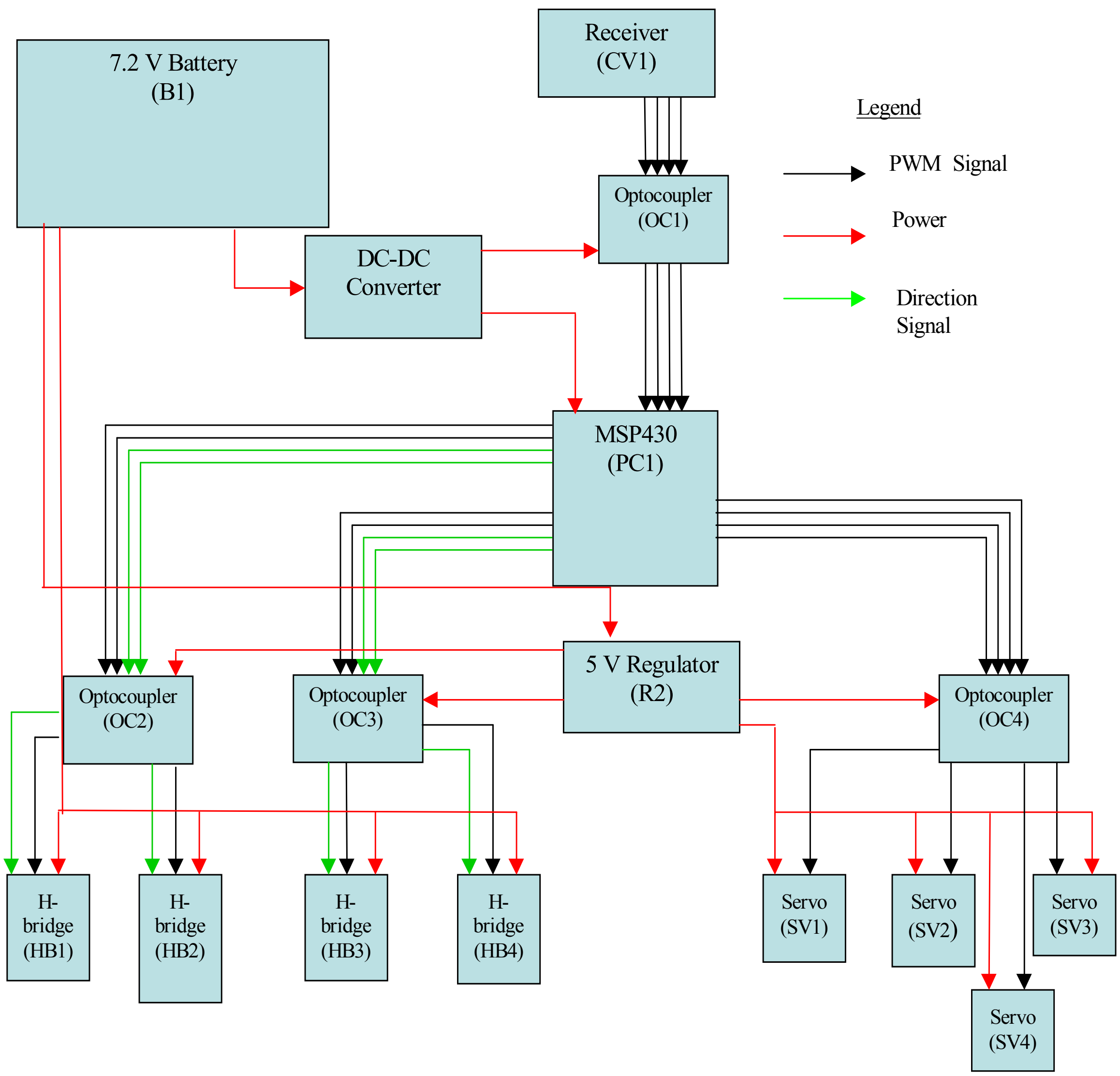

Figure 2. Hardware Interface System [13]

During the fall of 2005, Version 1 of the board was completed. The board is shown in Figure 3 being tested. An excerpt from a student final report, given below, describes the test set up and test performed by the group.

> "In version 1 of the board, the MSP is not integrated on the same board but is instead on its own board with connections coming over to connect its power and I/O pins. The four motor outputs are on the bottom part of the board and are connected to the H-bridges just above. The motor outputs go out to four motors that have been screwed down to a piece of plywood to prevent them from twisting during testing. Two motors of each size were used for testing to get a good idea of how both sizes function." [14]

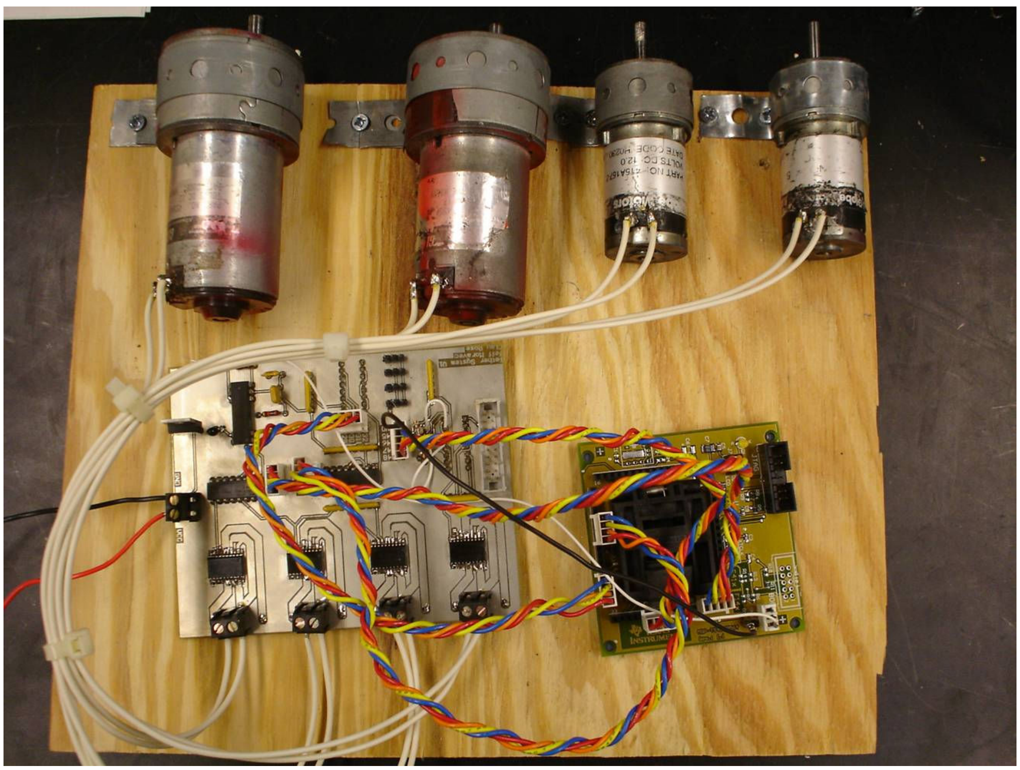

Figure 3: Version 1 Test Setup

> "One of the first tests performed was leaving the MSP on and continuously running the motors for 16 hours and observing its operation. Over that period, everything continued to function correctly and no noticeable change in temperature was observed. The next test run was applying full voltage to the motors and hanging a very large weight from their axels to prevent them from spinning. This increased the current going through the motors and a slight increase in heat was observed on the H-bridges, but everything still continued to function as normal." [14]

Additional tests were run on the board to verify its operation. The Version 1 boards were then made available to other teams developing robots. While this was going on in the lab, another team was developing the next version of the board. Version 2.1 of the board is shown in Figure 4. A close up of the microprocessor is shown in Figure 5. During testing of the board a problem was found and corrected, as described in another student report excerpt.

Assembly

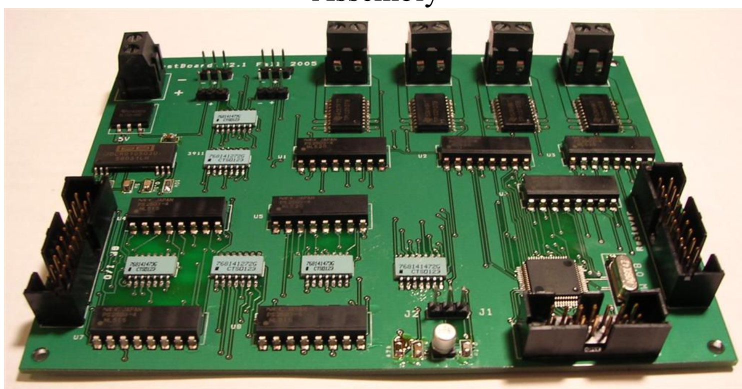

Figure 4: Fully assembled board, Version 2.1

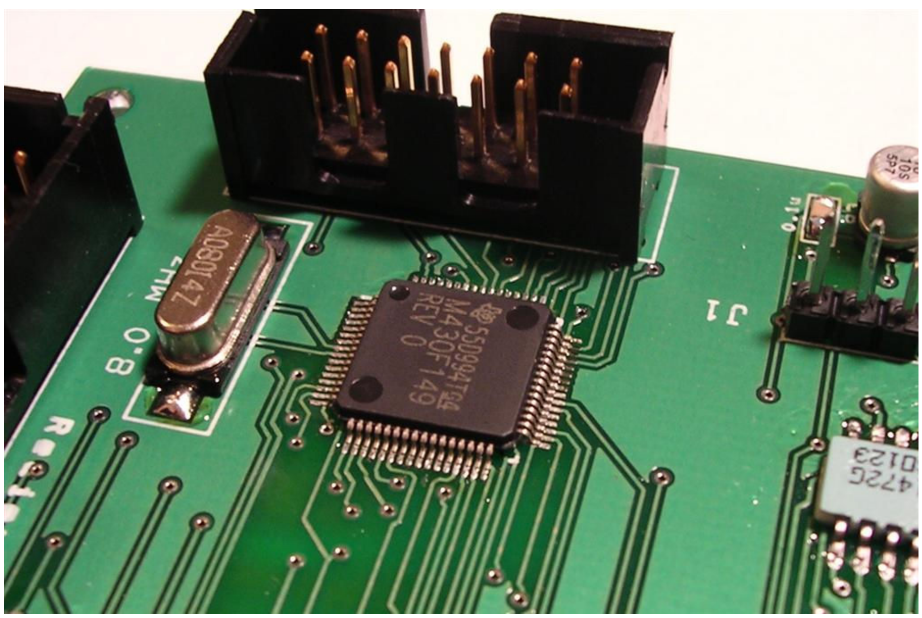

Figure 5: MSP 430

"The first test performed was a basic component voltage test. The board was supplied with an appropriate power supply (7.2V) and, using a voltmeter, each component was tested to see if it was receiving the proper power. Immediately it was determined that the signal was being lost at the optoisolator. This resulted in the board's failure to drive any of the motors. The problem was fixed by adding a jumper to each of the resistor banks." [15]

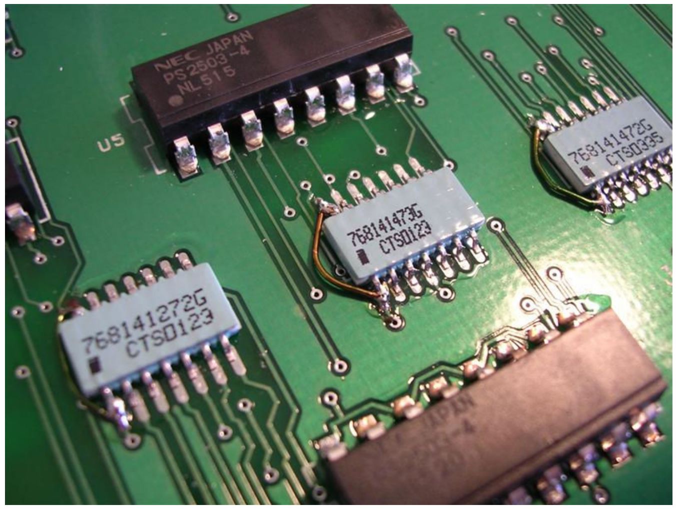

Figure 6: Resistor bank jumper

Further testing verified the operation of the board. The new board was then made available to be used in robotic applications.

The new user software was also being developed by other teams. Two teams together developed the software and wrote a Users Manual for the new software. An excerpt is given below.

> "The Semi Autonomous Language, or SAL, was developed specifically to be used in conjunction with the B.E.S.T. Robotics Competition. The purpose of the language is to allow teams who do not yet possess the necessary programming skills to program a microprocessor.
>
> When working with SAL, the user will be spending most of their time typing out instructions in a text document. After the instruction document is complete, the SAL Translator is used to convert the instructions in the text file into the more common C code. The user then compiles this new C file using a separate compiler designed to be used in conjunction with a microprocessor." [16]

A sample of user code is shown below.

```
While sensor a is high or sensor b is high
{
        Set motor a to 100%.
        Move servo a to the middle.
}
Set motor a to 0%.
```

The sample program indicates the use of sensors. Since BEST robots have always been remote control systems, they did not have sensors. The sensor capability allows the robots to become more autonomous, which is the overall objective. The type of sensor inputs needed on the board and in the software came from the robot application groups and include both digital, as shown in the example code, an analog signals. The MSP430 family of microprocessors has a number of options, most of which include analog-to-digital conversion. Therefore, the change necessary to the board is for additional inputs to the MSP430.

A major part of the overall project is to demonstrate uses of the new hardware and software. Version 1.0 of the board is shown in Figures 7 and 8 being applied to two different BEST type robots. Developing the robots at the same time as the hardware and software allows for rapid feedback and corrections.

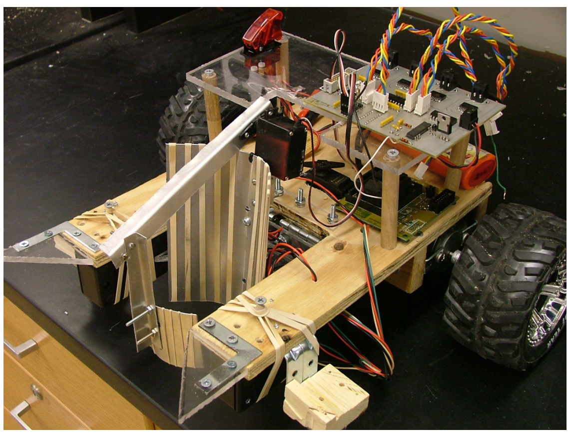
Figure 7. Robot 1

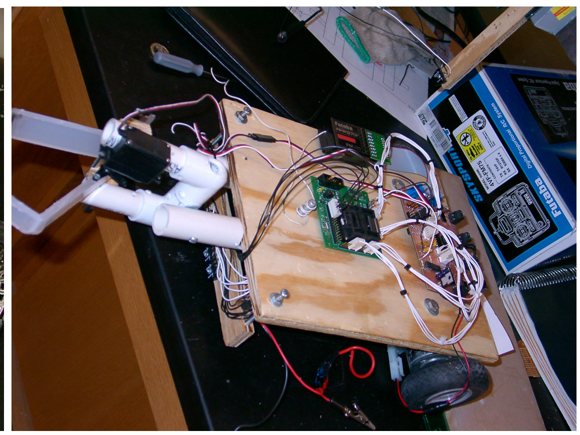
Figure 8. Robot 2

Another major issue for BEST is cost. A student estimate of the piece part cost of version 2.1 of the board is shown in Table 1. The $50 board cost does not include assembly of the board nor the possible discounts possible from vendors. However, the cost is well within the limits for and addition to the BEST returnable kits.

Part	**Quantity**	**Price**	**Total parts**	**1000 Units**
Microcontroller				
MSP430F149	1	$7.47	$7.47	$7,471.75
Isolation				
PS2503-4	8	$1.79	$14.31	$14,306.72
H-Bridges				
TPIC0107B	4	$2.55	$10.20	$10,200.00
Power Regulators				
TL780-05 (5.0v Regulator)	1	$0.25	$0.25	$252.00
DCR010503 (3.3v DC/DC	1	$7.78	$7.78	$7,780.50

Converter)				
Crystal				
8.00 MHz	1	$0.30	$0.30	$300.00
Resistors, Capacitors, and Diodes				
2.2 µF	1	$0.06	$0.06	$61.80
1.0 µF	1	$0.04	$0.04	$44.48
0.1 µF	2	$0.03	$0.06	$60.48
10 kΩ	2	$0.02	$0.03	$31.90
4.7 kΩ 13 Resistor Bus	1	$0.23	$0.23	$227.50
47 kΩ 13 Resistor Bus	3	$0.23	$0.68	$682.50
2.7 kΩ 13 Resistor Bus	2	$0.23	$0.46	$455.00
0.01 µF	1	$0.02	$0.02	$18.88
10 µF / 10 v	1	$0.15	$0.15	$146.00
47 kΩ	1	$0.02	$0.02	$15.95
Connectors				
Terminal Block (Motors and Power)	5	$0.04	$0.20	$198.00
20 Pin Protected Header (Receiver)	1	$0.64	$0.64	$637.00
14 Pin Protected Header (JTAG)	1	$0.55	$0.55	$546.00
Board Manufacturing				
Main Board	1	$6.44	$6.44	$6,440.00
Total			$49.88	$49,876.46

Table 1. Board Cost [15]

V Conclusion

The students in the ECE TTU second project laboratory have made considerable progress toward a final "commercial" product. The students have worked in their individual groups and have continually communicated with the other groups to move the project forward. There are, of course, obstacles. This approach is very new to students. Many students want to do everything themselves and aren't particularly fond of feedback from their peers. However, once the students realize what can be accomplished within a large group, they, for the most part, buy in to concept and move forward. Seeing that their efforts can result in a real, useful product has a definite impact on their attitude and effort.

We feel that this has been an exciting and worthwhile endeavor and will continue it to completion. This also opens up many more interesting projects for future development.

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