

Product Realization of the 2.007 Control Box

by

Wey-Jiun Lin

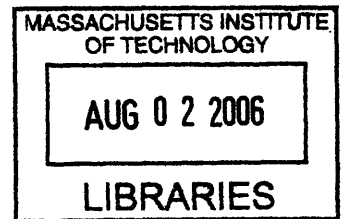
Submitted to the Department of Mechanical Engineering in
Partial Fulfillment of the Requirements for the Degree of

Bachelor of Science

at the

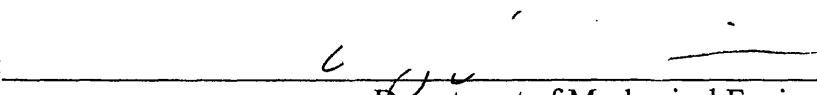
Massachusetts Institute of Technology

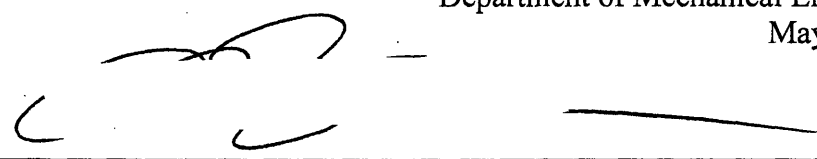
June 2006

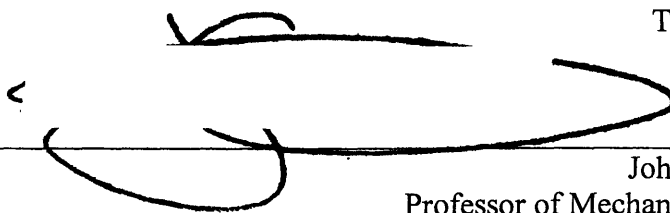


© 2006 Massachusetts Institute of Technology
All rights reserved

The author hereby grants to MIT permission to reproduce and to distribute publicly
paper and electronics copies of this thesis document in whole or in part.

Signature of Author: 
Department of Mechanical Engineering
May 12, 2006

Certified by: 
Alexander H. Slocum
Professor of Mechanical Engineering
Thesis Supervisor

Accepted by: 
John H. Lienhard V
Professor of Mechanical Engineering
Chairman, Undergraduate Thesis Committee

Product Realization of the 2.007 Control Box

by

Wey-Jiun Lin

Submitted to the Department of Mechanical Engineering
on May 12, 2006 in partial fulfillment of the
requirements for the Degree of Bachelor of Science in
Mechanical Engineering

ABSTRACT

A second generation control box using frequency hopping spread spectrum radio was designed and built for use in the Spring 2006 offering of 2.007 Design and Manufacturing I. A third generation control box that could hold up to 6 motors along with all the functional requirements of previous generations was designed and in the process of being built for future 2.007 classes and other engineering design classes around the world.

Thesis Supervisor: Alexander H. Slocum

Title: Professor of Mechanical Engineering

Table of Figures and Tables:

Figure 1: Spring 2006 2.007 Contest Arena	8
Figure 2: Overview of the 2.007 Control System	9
Figure 3: Dolphin Frequency Hopping Spread Spectrum Radio	10
Figure 4: Status Indicator Lights for Debugging and User feedback	11
Figure 5: Overall Dimensions of the 2 nd Generation Control Box	13
Figure 6: Key Features of the 2 nd Generation Control Box	14
Figure 7: 2 nd Generation Control Box	15
Figure 8: Exploded View of the Main Assembly of the 2 nd Generation Control Box	15
Figure 9: Adaptor PCB	16
Figure 10: Adaptor PCB with the Dolphin Radio	16
Figure 11: Modified 1 st Generation Electronics for	16
Figure 12: Exploded View of the 2 nd Generation	16
Figure 13: Remove Bosses and Drill 4 Holes	17
Figure 14: Ventilation Cut-outs	17
Figure 15: Autonomous and Battery Plug Cut-outs	17
Figure 16: On/Off Button and Motor Plug Cut-outs	18
Figure 17: Motor Plug	18
Figure 18: Step in Motor Plug Cut-out	18
Figure 19: Modified Motor Plug	18
Figure 20: Copper Mesh for Ventilation Guards	19
Figure 21: Protel PCB Image of Adaptor PCB	19
Figure 22: Fabricated Adaptor PCB and fully assembled Adaptor PCB	20
Figure 23: Header locations where the adaptor PCB soldered onto the main PCB.	21
Figure 24: Fully Assembled 2 nd Generation Control Box	22
Figure 25: 2 nd Generation Control Box Turned On	22
Figure 26: Overall Dimensions of the 3 rd Generation Control Box	25
Figure 27: Key Features of the Top of the 3 rd Generation Control Box	26
Figure 28: Close up of motor driver fan vent ribs	26
Figure 29: Key Features of the Bottom of the 3 rd Generation Control Box	27
Figure 30: 3 rd Generation Control Box, Lid Removed	28
Figure 31: Exploded View of the 3 rd Generation Control Box	29
Figure 32: 1 st Generation Motor Driver Cooling Solution	30
Figure 33: 3 rd Generation Motor Driver Cooling Solution	31
Figure 34: Exploded View of the 3 rd Generation Motor Driver Cooling Solution	31
Figure 35: Motor Driver Heat Sink	31
Figure 36: Top view of the Motor Driver Heat Sink	31
Figure 37: Traditional Kinematic Coupling Groove	32
Figure 38: Geometry of a Three-Groove Kinematic Coupling	32
Figure 39: Kinematic Coupling Grooves of the 3 rd Generation Control Box	33
Figure 40: Assembly of the SLA of the 3 rd Generation Control Box Enclosure	34
Figure 41: Outside the SLA, top piece	34
Figure 42: Inside the SLA, top piece	34
Figure 43: Outside the SLA, bottom piece	35
Figure 44: Inside the SLA, bottom piece	35
Figure 45: Beam between motor plugs structurally too thin.	35
Figure 46: Bosses to hold up main PCB too thick.	35
Figure 47: Motor Output of the 2 nd Generation Control Box	43
Figure 48: Top Piece of the 3 rd Generation Control Box	43
Figure 49: Bottom Piece of the 3 rd Generation Control Box	44
Table 1: Functional Requirements for the 2 nd Generation Control Box	11
Table 2: Bill of Materials for the 2 nd Generation Control Box	12
Table 3: Functional Requirements for the 3 rd Generation Control Box	24
Table 4: Bill of Materials for the 3 rd Generation Control Box	28

1. Introduction

2.007: Design and Manufacturing I is an MIT engineering design competition that teaches students about the design process. The end-of-the-term robotics competition appeals to MIT students' competitive nature, designing and building their own robot teaches students hands-on skills, and time constraints forces students to learn project management skills. Many engineering programs in the U.S. and around the world have created classes similar to 2.007 to teach their students about the design process.

The machines (robots) students build are radio-controlled and are designed to compete against another classmate's robot in accomplishing specific tasks on a playing field. At the beginning of the term, students are given identical kits of parts and raw materials, and over the semester are led through a deterministic design process to design and build a robot to compete in that year's competition.

To develop and organize a class such as 2.007 is often difficult because of the amount of materials required and resource (people, funds, lab space) constraints. The financial constraints make it difficult to purchase in large quantities components such as motors and batteries with the appropriate specifications for the class. Temporary fixes have been done each year to the control system to make surplus suppliers and corporate donations of components work together, but this consumes a large amount of the instructors' time and energy that could better be used in teaching the students.

In order to facilitate the operation and development of 2.007 at MIT and similar classes are the world, the Precision Engineering Research Group has developed a universal wireless motor control system that accepts a wide range of motors and batteries. While the system has been designed and built previously, the analog radios used were prone to interference caused by bad wiring by the students. The radio communication system can be made much more robust by using spread spectrum digital radios. This led to the redesigning of the 2.007 control system and, the topic of this thesis, the control box.

2. Motivation

The motivation for designing and building the second generation control box was to implement a low-cost frequency hopping spread spectrum wireless communications infrastructure. "Frequency hopping spread spectrum radios drastically improves the robustness and ease-of-use of wireless communications by eliminating interference problems caused by conflicting devices communicating on the same frequency." [2] The first generation control boxes used hobby radios that are susceptible to interference. The old boxes also are not electrically capable to handle a new radio nor did they have the room because it had big motor and battery plugs. The control box therefore needed to be quickly redesigned and built for the Spring 2006 2.007 offering.

In designing the 2.007 second generation control box it became apparent that there were many design restriction in using a commercial plastic box and modifying it. All the innovation in the 2.007 control system such as wireless communication, the ability to accept a wide range of battery sources and then be reconfigured to drive motors at different voltage ratings, and now a frequency hoping spread spectrum radio that could no longer be confined to an off the shelf plastic box required that a new custom box be created. Thus this project proposes to solve this

problem by developing a control box specifically designed for classes like 2.007 in which anyone who wanted to implement a class like 2.007 could use. The third generation of 2.007 control box would be this box that all engineering design classes could use.

Depending on the success of the third generation control box in 2.007, there are possibilities to use this box for wireless communications in other engineering design competitions. These engineering competitions include FIRST Robotics, FIRST Vex Challenge, and RoboCup.

3. Background

A. MIT 2.007: Design and Manufacturing I

2.007: Design and Manufacturing I is a second year MIT Mechanical Engineering class that not only teaches student the creative design process but exposes them often for the first time to how the fundamental engineering principles they've learned in previous classes apply in real life situations. Students learn how to take all those theoretical equations, analysis tools, and experimental methods and apply them in designing and manufacturing a remote-controlled machine to compete in a competition at the end of the term.

The objectives of the competition changes year to year and are designed by students who took the class the previous year. Some examples of what has been required of past 2.007 robots include depositing weights into bins, climbing ramps, climbing poles, jumping over chasms, and spinning ball-laden Lazy Susans. The name of this year's contest is called "MIT - IHTFP (I Have To... Fantastically Pass)", in honor of an MIT acronym often used to describe the academic workload at MIT. A solid model of the contest arena is shown in Figure 1. The robots start on opposite sides of the table and run head-to-head in 45-second-long rounds. The robot arena consists of a number of major elements such as starting zones, scoring bins, and balls. The students can score by moving balls from locations across the board into the scoring bins at the bottom of the arena.

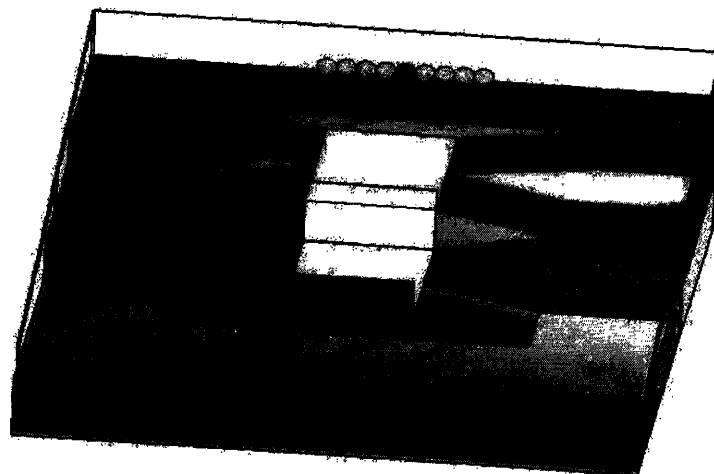


Figure 1: Spring 2006 2.007 Contest Arena

B. Current Control System

At the start of 2.007, students are supplied with a kit which includes a Milwaukee 14.4V cordless drill, four motors with gear boxes, and two types of connectors. The drill includes two 1.4 amp-hour, rechargeable, nickel-cadmium batteries and a charger. The motors used are brushed DC motors from Tamiya Motors (P/N: RC-260RA-18130) commonly found in toy cars. These motors are specified for a maximum 6V input with a 2A stall current. The gear boxes, with up to 4 stages of planetary gears, were also purchased from Tamiya.

As long as they have assembled their motors correctly and wired the connectors properly, students should be able to plug their machines into the control box, turn on the control system, and drive it around. Without having to worry about the details of powering their machines, students can focus on the mechanical design.

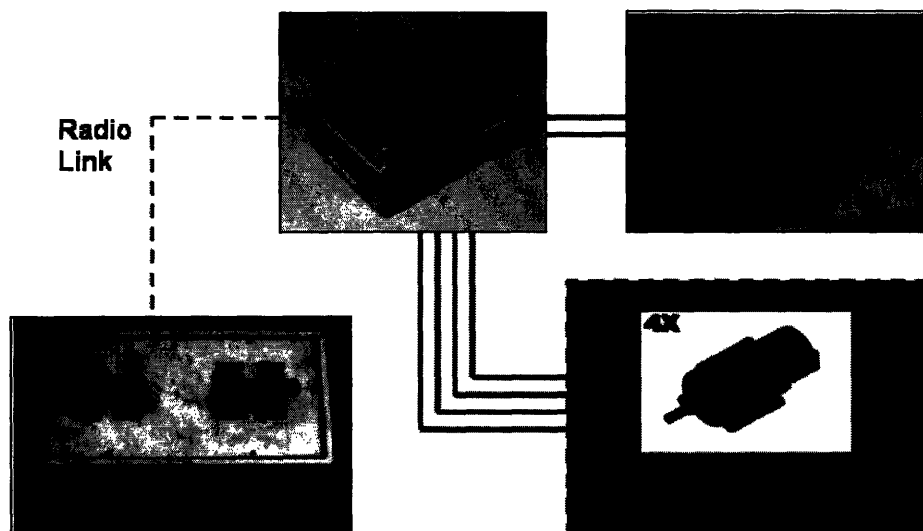


Figure 2: Overview of the 2.007 Control System

The control system consists of control podiums located near each side of the contest table that has corresponding color control boxes per podium. An overview of the control system schematic is shown in Figure 2. Currently, each robot is allowed a maximum of four motors which are controlled by signals from the podium. Each podium displays four, one-dimensional, video-game joysticks that when pushed, determine the direction of spin on each of the motors on the robots.

4. 2nd Generation Control Box

A. Functional Requirements

Defining the functional requirements for the second generation control box included adding additional electronic components to accommodate the new frequency hopping spread

spectrum radios while keeping the same functionalities the first generation control box had. An image of the new frequency hopping spread spectrum radio is shown in Figure 3.

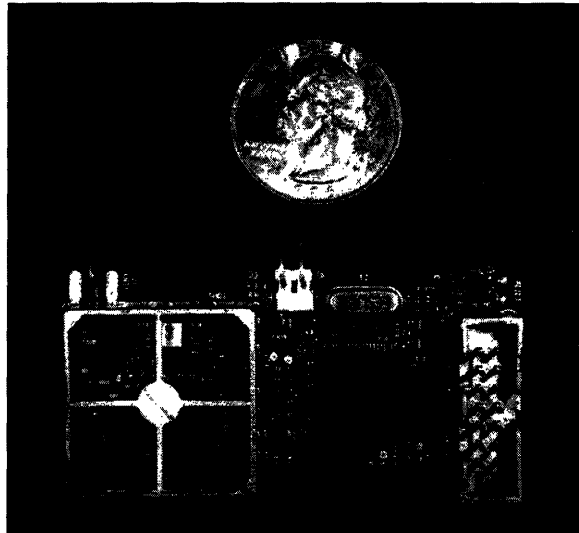


Figure 3: Dolphin Frequency Hopping Spread Spectrum Radio

What more, the Spring 2006 is to be the first year 2.007 did a trial autonomous robot section and thus the control box needed a 4-pin port where students working on autonomous robots could connect their sensor output to.

The functional requirements from the first generation control box that needed to be maintained in the second generation control box included the ability to connect up to 4 motors and the use of a 14.4 V cordless drill battery as the power source. The box would continue to provide user feedback in the form of lights that tell students if their robot is receiving the signal to go forward, backwards, or stay idle. Other user feedback included a power light to signal that the box was on, a thermal warning light if the box was overheating, and a low battery light to indicate that the battery needed to be recharged. Figure 4 shows the status indicator light for debugging on the first generation control box.

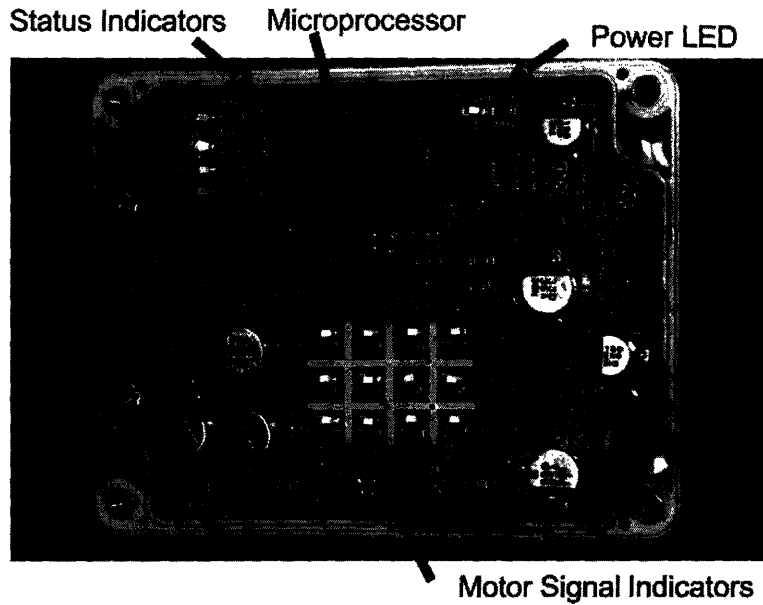


Figure 4: Status Indicator Lights for Debugging and User feedback

Mechanically, the control box need to stay cool while being rigorously used in 45 second rounds, robust to student abuse, and light in weight so it does not affect the center of mass of the students' robot when mounted on. In all, the second generation control box functional requirements and design parameters are summarized in Table 1. The design parameters will be discussed in more detail in the later sections.

Functional Requirements	Mechanical Design Parameters
1. Incorporates frequency hopping spread spectrum radios.	- additional electronics added via adaptor PCB attached to existing main PCB to supply required voltage and establish communication between main PCB and radio - remove generation 1 motor and battery plugs to provide room
2. Autonomous mode: take in sensor outputs.	- 4-pin autonomous plug - "hacks" to main PCB to accept autonomous signals
3. The ability to connect up to 4 motors.	- motor plugs that total up to 4 sets (+/-) of motor pins
4. The ability to use a 14.4V cordless drill battery as the power source.	- 2-pin (+/-) battery plug
5. Provide user feedback for debugging (forward, stop, reverse, thermal warning, low battery, and power).	- green illuminated on/off button - motor plug and on/off button on the same side as LEDs

Table 1: Fucntional Requirement for the 2nd Generation Control Box

B. The Design

a. Mechanical

Overall, the design of the second generation 2.007 control box was a modification of the first generation control box. This was partly due to time constraints as these boxes needed to be ready for the Spring 2006 2.007 class offering. The same commercial enclosure and main PCB board from the first generation control boxes were used. Mechanically, the location and the plugs for the motors and battery changed along with an additional connector for autonomous machines. Electrically, an additional adaptor PBC board was added to accommodate for the new radio and autonomous plug. Table 2 lists all the higher level parts in the second generation control box.

Qty.	Description:	Item:	Part Number:	Vendor:
1	Control Box enclosure	BOX NEMA4X POLY 4.53X3.54X2.17IN	377-1120-ND	Digi-Key
4	Main PCB mounts	STANDOFF HEX 6-32THR 1.25"L ALUM	1818K-ND	Digi-Key
4	Fastener to fasten PCB mounts (standoff) to enclosure	Zinc-Plated Stl Flat Head Phil Machine Screw 6-32 Thread, 1/2" Length	90273A148	McMaster Carr
3	Fastener to fasten Main PCB to mounts	Round Head Combination Drive Machine Screw Zinc-Plated Steel, 6-32 Thread, 1/2" Length	91440A148	McMaster Carr
2	Motor Plug	CONN PLUG 4POS .093	WM1326-ND	Digi-Key
8	Motor Plug terminals	CONN TERM MALE SOLDER-TAIL TIN	WM1104-ND	Digi-Key
1	Autonomous Plug	CONN HEADER 4POS .100 R/A GOLD	WM4902-ND	Digi-Key
1	Battery Plug	CONN HEADER 2POS 7.92MM R/A TIN	H2776-ND	Digi-Key
1	Electronics – main board	Main Board from G1 Control Box		
1	Electronics – for new radio	Adaptor Board (assembled)		Digi-Key/Advanced Circuits
1	Receiver	Frequency Hopping Spread Spectrum Radio	DOLPHIN-LP- ADDER	TI

Table 2: Bill of Materials for the 2nd Generation Control Box

The overall size of the second generation control box remained similar to those of the first generation. A drawing with the key dimensions for the second generation control box is shown in Figure 5.

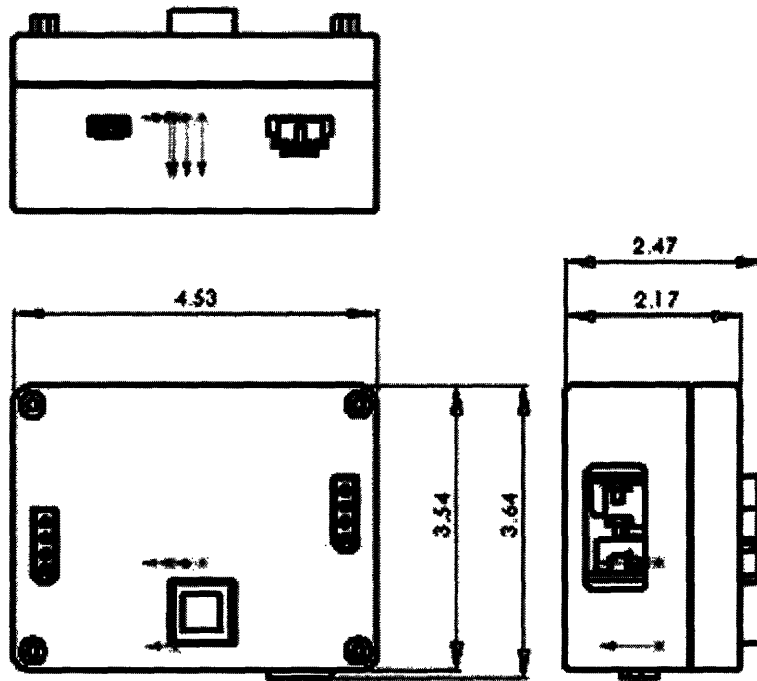


Figure 5: Overall Dimensions of the 2nd Generation Control Box

By using the basic packaging of the first generation control box, several specifications were predetermined. For example the motor plug. The spacing of the holes on the main PCB board limited the connector to have a pitch of 0.093". The location of certain electrical components such as the motor driver limited where the adaptor board and thus the new radio could be attached.

In the second generation control box, the motor plugs and on/off button were moved to the same side as the user feedback lights so the lights could be utilized for debugging students' robots when connected to the control system. On the adjacent face is the new location for the battery and autonomous plugs. There was also space on this face to put the appropriate color label for the box. An additional vent was opened up on the long face of the box opposite to the battery and autonomous plug to provide additional cooling to the motor drivers which were located next to this new vent. In all, the new design had one less button than the first generation control box and one additional plug for the autonomous feature. A labeled diagram of the key features of the second generation control box is shown in Figure 6.

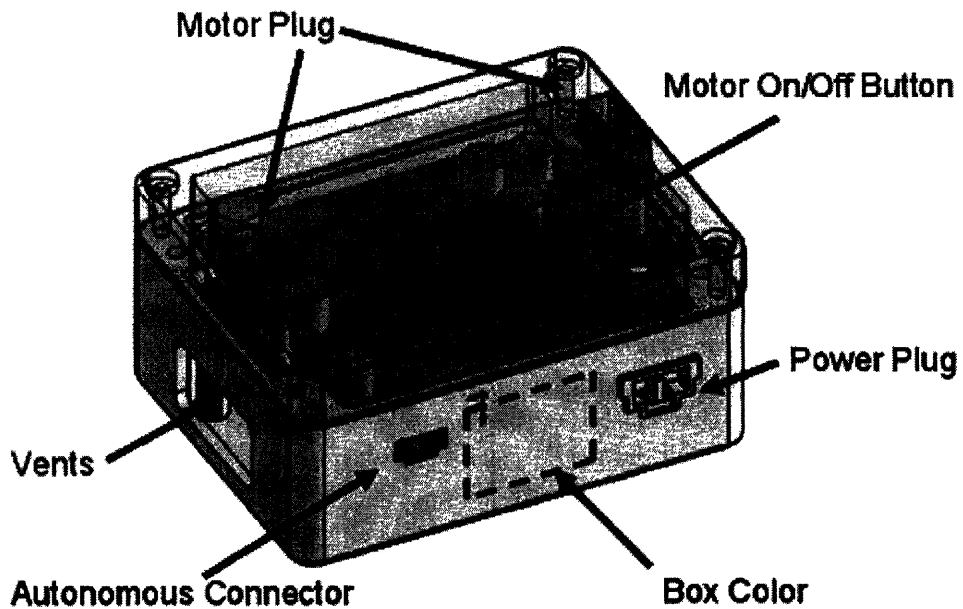


Figure 6: Key Features of the 2nd Generation Control Box

The box had a flat bottom side so the students could place on their robot to strap the control box in.

The higher level assembly of the second generation control box included the ABS box, 4 aluminum standoffs, a main board assembly which included both the main PCB, adaptor PBC, and plugs assembled together, a frequency hopping spread spectrum radio, a clear polycarbonate lid, and an illuminated green on/off button. A complete assembly of the second generation control box is shown in Figure 7 along with an exploded view of all the higher level assembly parts in Figure 8.

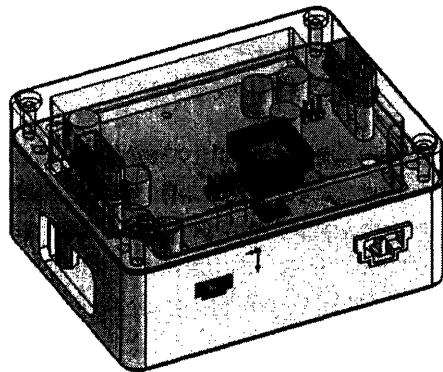


Figure 7: 2nd Generation Control Box

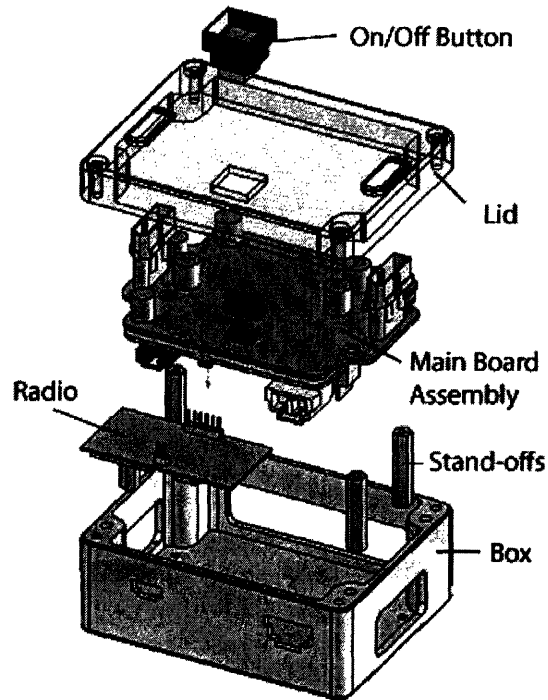


Figure 8: Exploded View of the Main Assembly of the 2nd Generation Control Box

b. Electrical

Electrically, the first generation control box was not adequate to support the power requirements of the new frequency hopping spread spectrum radios. In order to continue using the main PCB from the first generation box, an adaptor PCB needed to be designed and fabricated. This board not only had to support the new radio, it also had to connect and fit with the current existing main PCB and provides connection point for an autonomous plug.

The only space available was next to the motor drivers cooling system where the old hobby radios mounted and where the back of the old motor and battery plugs took up. To keep the two plugs located near each other the decision was made to have the battery plug also located on the adaptor PCB. This meant the adaptor PCB, which would be located on the lower half of the main PCB, had to connect to the two power holes on the main PCB, and located on the upper left corner of the main PCB, where the battery plug was previously connected. These design constraints dictated the final L-shape of the adaptor PCB shown in Figure 9. Figure 10 shows how the new frequency hopping spread spectrum radio is mounted onto the adaptor PCB.

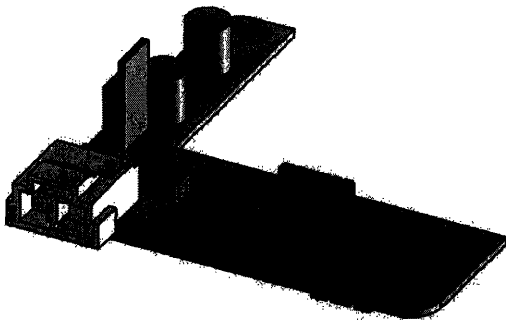


Figure 9: Adaptor PCB

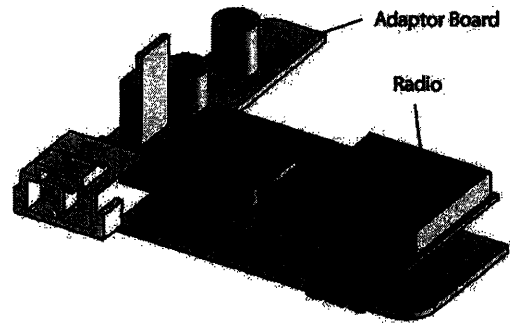


Figure 10: Adaptor PCB with the Dolphin Radio

Figure 11 shows an exploded view of the adaptor PCB to main PCB assembly which also shows the space available on the main PCB for the adaptor PCB. Figure 11 shows the complete PCB assembly of the main PCB, adaptor PCB, and the new radio which make up the main board assembly.

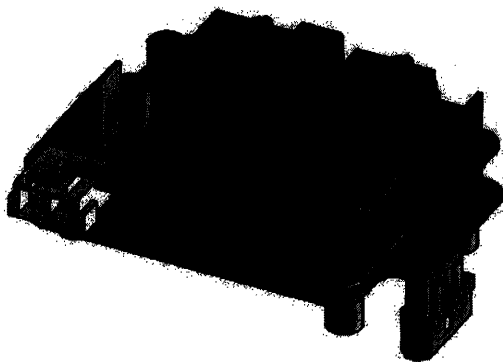


Figure 11: Modified 1st Generation Electronics for 2nd Generation Control Box

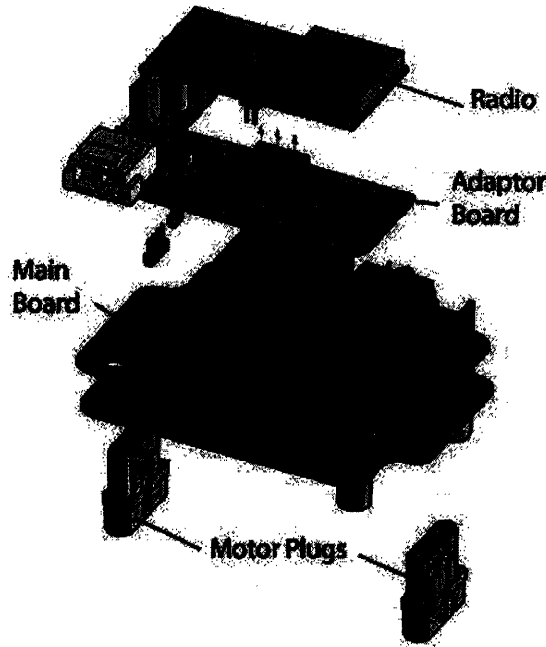


Figure 12: Exploded View of the 2nd Generation Electronics Stack-up

In the first generation control box, both the motor and battery plugs were connected to the main PCB by heavy gauge wires which created a nest of wires in the box. In the second generation control box, motor and battery plugs are mounted directly to the PCBs in the box which created a cleaner electrical package as shown in Figure 11.

C. Fabrication of Design

The first step in fabricating the second generation control box was to modify the polycarbonate lid and ABS base of a Nema 4x Enclosure (P/N: 377-1120-ND). Looking into the ABS base, 4 bosses needed to be removed as shown in Figure 13. 4 additional holes needed to be drilled to mount the standoffs for the main board assembly to mount to the box.



Figure 13: Remove Bosses and Drill 4 Holes

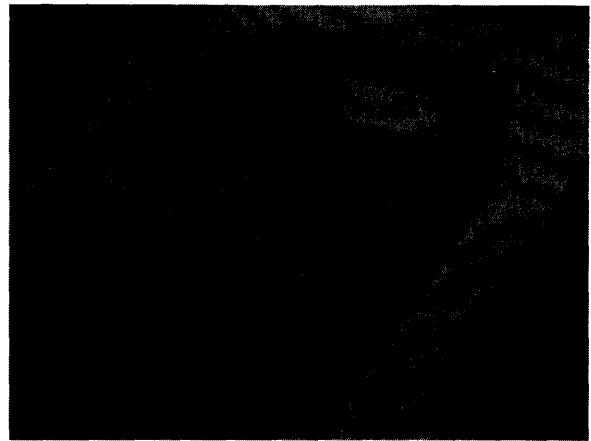


Figure 14: Ventilation Cut-outs

Next, three ventilation slots were cut out of three of the four faces on the ABS base. Exactly which faces is not important since the box is symmetrical; the important thing is that two short faces and only one long face have ventilation slots cut into them. The ventilation slots are shown in Figure 14.

On the remaining face, the plug profiles of the autonomous and battery plugs were cut out shown in Figure 15. This was done using a CNC mill programmed with the paths of these profiles. A little filing was needed since end mills are round and the plug profiles required sharp corners.

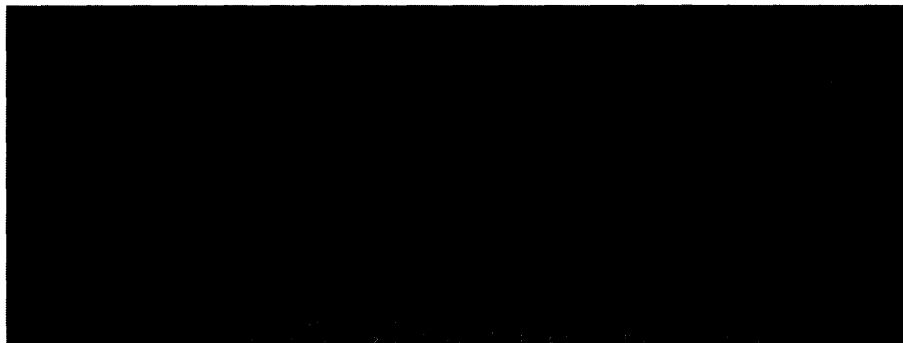


Figure 15: Autonomous and Battery Plug Cut-outs

The next piece that needed to be modified is the polycarbonate lid. Three holes needed to be cut: one for the on/off button and two for the motor plugs shown in Figure 16.

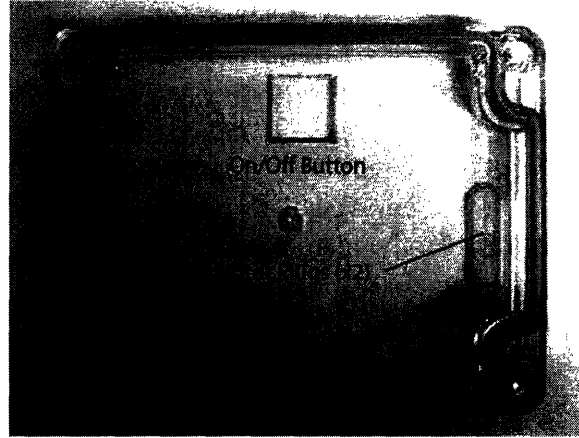


Figure 16: On/Off Button and Motor Plug Cut-outs

The cutout for the on/off button is a square shaped hole. The cutouts for the motor plugs were a little more intricate. If these plugs were pushed inwards, the main PCB would be there to support it. However, if the motor plugs were pulled on, eventually, over time, they might come out of their solder joint to the main PCB. To add strain relief for the plug against pulling, a small step was added to the motor plug shown in Figure 19 along with a corresponding step in its cutout on the polycarbonate lid shown in Figure 18.

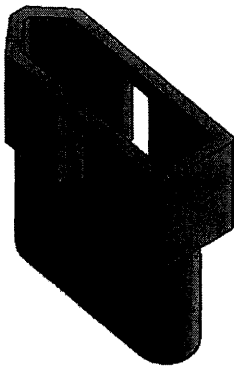


Figure 17: Motor Plug



Figure 18: Step in Motor Plug Cut-out

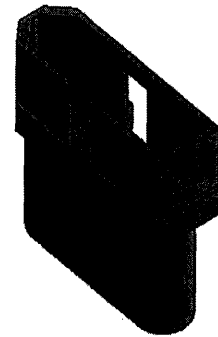


Figure 19: Modified Motor Plug

Lastly, three strips of copper mesh corresponding to each ventilation slot was cut and glued over the slots from the inside of the box shown in Figure 20. These were to allow air to flow in and out of the control box, but prevented debris such as small fasteners from falling into the control box and possibly short-circuiting internal electrical components.

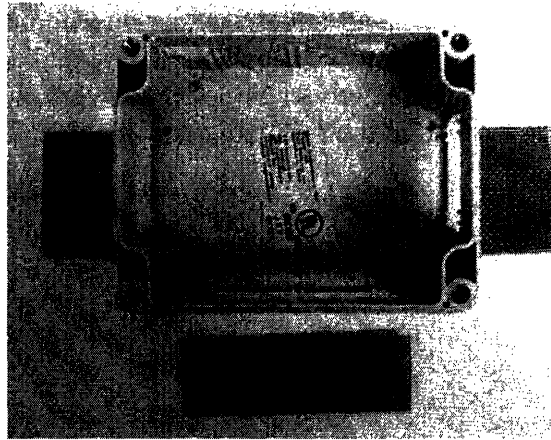


Figure 20: Copper Mesh for Ventilation Guards

The schematic of the adaptor PCB was designed by Hongshen Ma, an Electrical Engineering PhD candidate at MIT. A copy of the schematic diagram can be found in the Appendix A. Mechanically, the dimensions of the adaptor PCB were determined by remaining space available in the box and the connection points it needed to make with the main PCB. Given the L-shape and schematic diagram, the PCB was laid out using Protel, a PCB layout program. A screenshot of the PCB layout is shown in Figure 21. Since the solder mask layer on PCBs is not ideal for gluing components the darken rectangles indicate regions on the PCB to be left uncoated so that the battery and autonomous plugs can be epoxyed to the board. Once the board layout was complete it was sent to Advanced Circuits for printing.

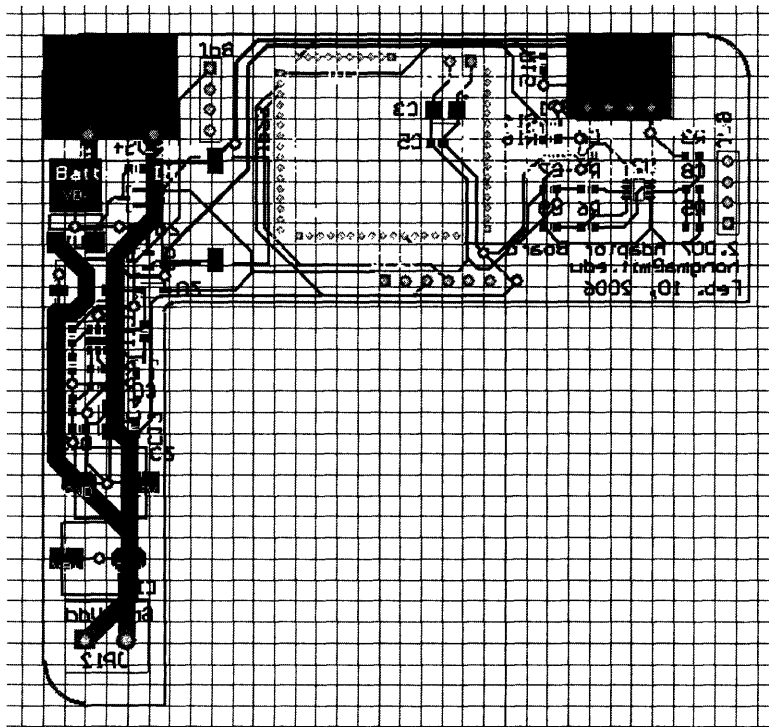


Figure 21: Protel PCB Image of Adaptor PCB

The adaptor PCBs were then hand soldered since the number of components did not justify it being sent out and stuffed. Figure 22 shows the fabricated adaptor PCB and an adaptor PCB stuffed with its components. The electrical components were ordered from Digi-Key and a detailed Bill of Materials can be found in the Appendix A.



Figure 22: Fabricated Adaptor PCB and fully assembled Adaptor PCB

Several “hacks” had to be performed on the main PCB before the adaptor board could be mounted to it:

1. A connection between JP6-5 on the main PCB to resistor R35 needed to be made with a 10K Ω resistor in between.
2. A connection between JP6-6 on the main PCB to resistor R32 needed to be made with a 10 K Ω resistor in between.
3. A connection between JP5-11 on the adaptor PCB to JP3-4 on the main PCB needed to be made. This can be done by going through JP3-4 on the adaptor PCB.
4. The trace connecting JP3-4 on the main board to its closes via needed to be cut. The via then needs to be wired to JP6-8 on the main PCB.
5. The following holes on the adaptor PCB needed to be connected to their corresponding hole of the same designator on the main PCB: JP4-16, JP6-1, JP6-2, JP6-3.

These “hacks” were performed to enable the autonomous feature to work on the main PCB and communication between the adaptor PCB and the main PCB.

An additional “hack” was performed to enable current readings on the control box. This hack involved putting a 0.10 μ F and 1.0K Ω in parallel at the end of capacitors C12, C14, C15, and C23.

Once these “hacks” were complete, the adaptor PCB was soldered via three sets of headers onto the main PCB shown in Figure 23.

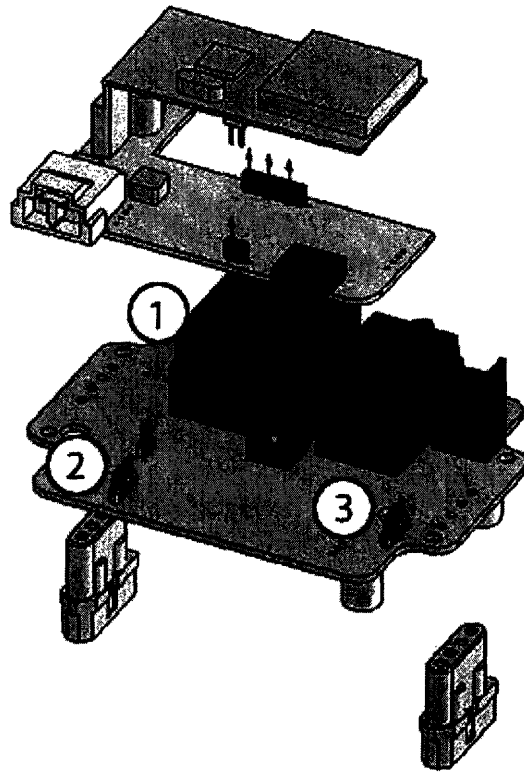


Figure 23: Header locations where the adaptor PCB soldered onto the main PCB.

The main board assembly was then installed into the base of the box mounting on four aluminum standoffs. The assembly is first placed into the box with the four holes not aligned to the standoffs. The board is then slid over a couple of millimeters allowing the autonomous plug and battery plug to fit into their respective cutouts on the box base. The main board assembly is then fastened into place. The on/off button was then pressed fitted into its cutout on the polycarbonate lid and plugged into the main board assembly. Finally the polycarbonate lid is place over the box and fastened into place. The assembly of the box is complete as shown in Figure 24. Overall, the second generation control box was lighter in comparison to the first generation control box.

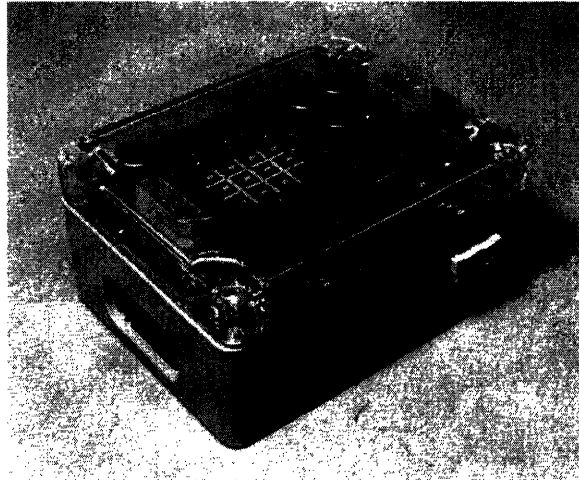


Figure 24: Fully Assembled 2nd Generation Control Box

D. Implementation of the 2nd Generation 2.007 Control Box



Figure 25: 2nd Generation Control Box Turned On

To incorporate the second generation control box into the 2.007 curriculum, a control system lecture was given. In this lecture, a brief overview of the control system was presented along with step-by-step instructions on how to make the wires necessary to connect their machines to the control box. The control system lecture notes can be found in the Appendix B.

The wiring students needed to make consisted of three connector wires: one between their battery and the control box and two between their motors and the control box. To provide a quick reference in how to make these connector wires two “How To...” handouts were developed, one for the motor connectors another for the battery connector. Copies of these handouts can be found in Appendix B.

The final step in the transition between the first and second generation control boxes was the control system section in the 2.007 website (<http://pergatory.mit.edu/2.007>). These pages were updated to reflect the second generation control box. The handy debug sheet for using the connectors was also updated and posted on the website for students to print out and use. A copy of this handout can be found in Appendix B.

E. Design Feedback

The second generation control box is currently being used in the Spring 2006 2.007 course offering. As students began wiring up their robots for testing, design flaws started to emerge. Just plugging in the headers on the new frequency hopping spread spectrum radios into female sockets on the adaptor PCB was not sufficient to hold them in. Students, despite countless warnings, rarely mounted the control box properly while testing and often sent the box flying off their robot hitting the ground shaking the radio loose. This problem was resolved by soldering the radios in place.

Another design flaw was the fan used in the motor driver cooling system of the four motor drivers. In the first generation control box, there were wires connecting the old motor and battery plugs to the main PCB which acted as a nest to hold the fan in place. The second generation control box does not have the same wire nest. What more, the fans were hot glued onto the coated PCB which is not a good surface for gluing things to. The fan was often the other thing that came loose in the box. This problem was resolved by using epoxy to glue the fans on place.

The space in the Nemax 4x Enclosure was tight and slipping in the main board assembly was sometimes difficult if the right technique was not used. Instead of dropping in the main board assembly and sliding it into place as it was designed, the main board assembly had to be put in at an angle with the battery and autonomous plugs partially into their respective cutouts on the box and rotated into place. The tight tolerances required to make the design work were hard to hold making the design not viable for mass production. The main board assembly had to come out often to solder the radio in place and reattached the fan when they came loose.

How to mount the control box was left open for the students to figure out and design the proper hardware. They were given the following functional requirements for mounting the control box:

1. The green buttons must be easily accessible by a staff member.
2. The status LEDs should be visible for debugging (optional but recommended!).
3. ALL connectors must be easily accessible by a staff member.
4. ALL connectors must be protected against impact.
5. The cooling vents on the control box must be unobstructed.
6. It should take about 5 seconds to remove the control box from your machine.

Mounting the control box was the last thing on many students' minds as they hurried to complete their robot by the deadline. With no preferred method for mounting many students neglected to mount their control boxes during the testing phase of their robot. This revealed the design flaws mentioned.

5. 3rd Generation Control Box

A. Functional Requirements

The functional requirements in designing the third generation control box involved increasing the number of motors that could be connected to six while keeping the same functionalities as

previous generation control boxes. Additionally, a suggested control box mounting method would be designed into the box for the student to use. The design would be from scratch with no restrictions from any reused PCBs as was with the second generation box. In all, the third generation control box functional requirements and design parameters are summarized in Table 3. The design parameters will be discussed in more detail in the later sections.

1. The ability to connect up to 6 motors.	- 2 additional sets (+/-) of motor pins in motor plugs - 2 additional motor drivers
2. Have a suggested mounting method that which students can use.	- Velcro™ strap slots - kinematic coupling grooves under box
3. Mechanically change the setting so that any given battery voltage (e.g. 14.4V) can be converted to the appropriate motor specified voltage (e.g. 6 V) and provide a constant voltage output.	- 16-position switch setting motor-to-battery ratio - accessible by removing bottom half of box
4. Set the ID of the control box mechanically.	- 16-position switch
5. One PCB board.	- layout and solder all electrical components on one 4-layer PCB
6. Incorporates frequency hopping spread spectrum radios.	- place on PCB to plug into
7. Autonomous mode: take in sensor outputs.	- 4-pin autonomous plug
8. Provide user feedback for debugging (forward, stop, reverse, thermal warning, low battery, and power).	- viewable LED lights on the top surface of the box near motor connectors
9. Does not affect the center of mass of students' robots.	- light in weight
10. Robust to student abuse.	- round corners - PCB securely mounted in 4 places

Table 3: Functional Requirement for the 3rd Generation Control Box

The ability to mechanically change the setting so that any given battery voltage (e.g. 14.4V) can be converted to the appropriate motor specified voltage (e.g. 6 V) allows instructors of engineering design classes like 2.007 to use whatever surplus batteries or motors available to them for their class without needing to reprogram the box. To set the control box ID mechanically gives more flexibility to the boxes so in the case that one fails, another can be used without the need to connect it to a computer and reset its ID through software.

B. The Design

a. Mechanical

Overall, the proposed design for the third generation control box is bigger length and width-wise but slightly smaller in depth as shown in Figure 26.

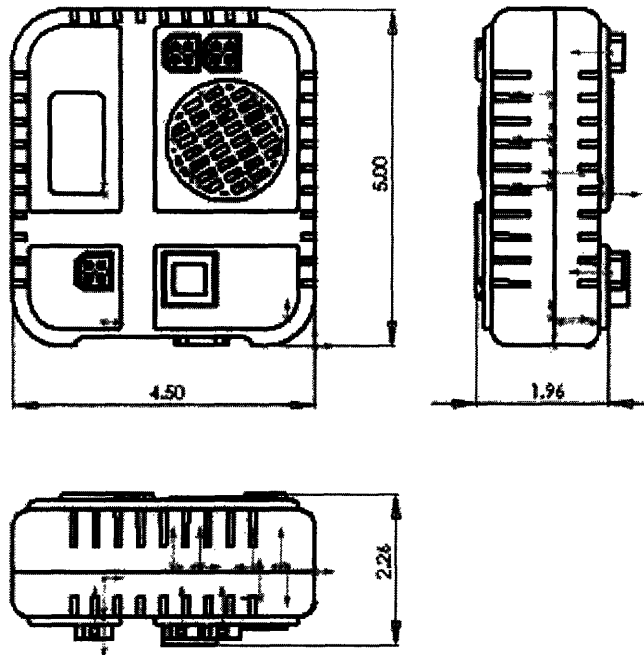


Figure 26: Overall Dimensions of the 3rd Generation Control Box

The size difference makes sense because of the two extra motor drivers needed to increase the number of motors connected to the control box.

On the top face of the box are three motor plugs, with the ability to plug up to two motors each totaling to six motors. There is a clear polycarbonate window that displays user feedback in the form of lights similar to those shown in Figure 4. Like the previous generation control box, the one illuminated green on/off button was used as the power button. There is also a round motor driver fan vent on the top face of the box. Lastly, Velcro™ strap slots have been introduced for students to use in mounting the control box. The key features on the top face of the third generation control box are shown in Figure 27.

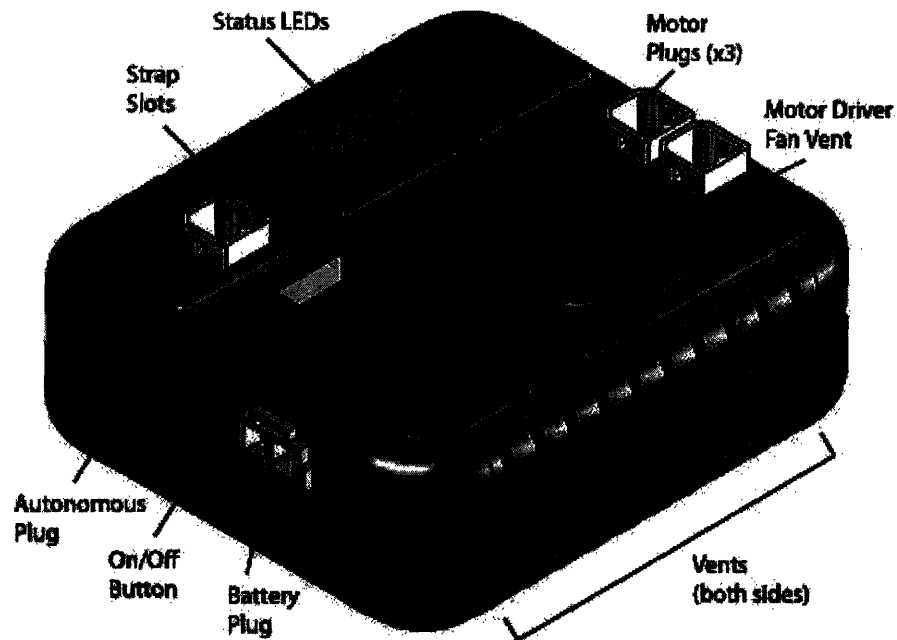


Figure 27: Key Features of the Top of the 3rd Generation Control Box

The bottom side of the third generation control box has several features. Traditional kinematic coupling grooves have been introduced to go along with the strap slots on the top face of the control box. It was chosen because it is a dependable method for continuously mounting rigidly in the same place. There is also another motor driver fan vent directly under the motor driver fan vent from the top of the control box. Ribs were used to reinforce the motor drive fan vents on the bottom side of the enclosure. These vents also served as “guards” to preserve air flow into and out of the box even if a student chooses to place the box flat on the bottom surface. A close-up of the ribs is shown in Figure 28.

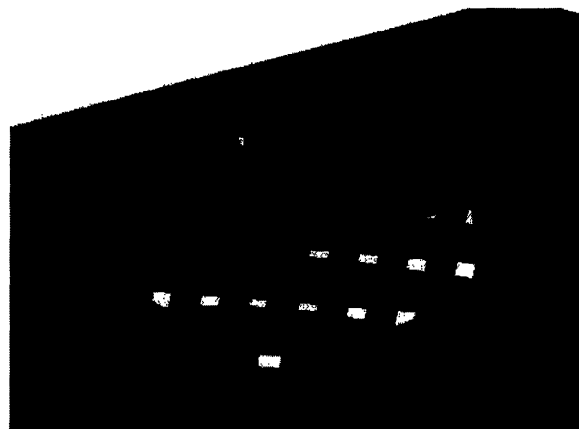


Figure 28: Close up of motor driver fan vent ribs

The key features on the bottom face of the third generation control box are shown in Figure 29.

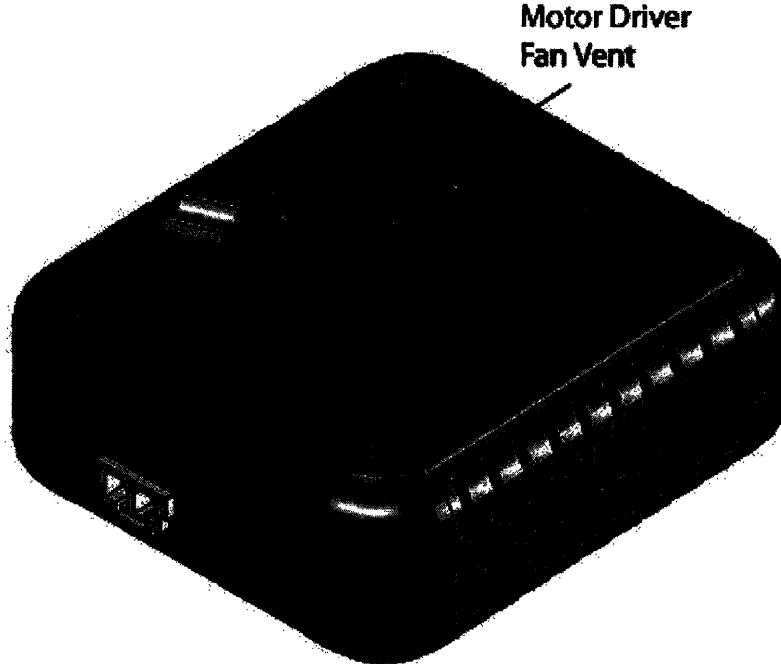


Figure 29: Key Features of the Bottom of the 3rd Generation Control Box

Both the top and bottom pieces of the enclosure have vents along the edges that were designed in to them to eliminate the extra copper mesh pieces used in previous generation control boxes and to provide cooling.

The third generation control box was designed so that it would be easy to mechanically set the motor-battery ratio along with the ID of the box. Currently, the adjustment between different battery and motor specified voltages has been accounted for through motor driver chips that can tolerate a wide power supply range, applying a Pulse Width Modulation (PWM) to limit the output range, and by scaling it down by the ratio of motor to battery voltages. [1] This allows the control box to accept a wide range of battery sources to accommodate for the motor available to the class. In previous generation control boxes, the scaling down by the motor-to-battery ratio has been done by two methods: through a 16-position switch in the first generation control box and by software in the second generation control box. By design, the 16-position switch used in the first generation control box was not very accessible since the main PCB had to be removed from the enclosure in order to change the switch settings. In the third generation box, to change the motor-to-battery ratio the user only needs to remove the bottom of the box and rotate the switch to the right position.

In order to set the ID of the box, a similar 16-position switch was incorporated giving the control box up to 16 possible IDs. Figure 30 illustrates the position of the two switches, one for setting the motor-to-battery ratio, the other for setting the control box ID.

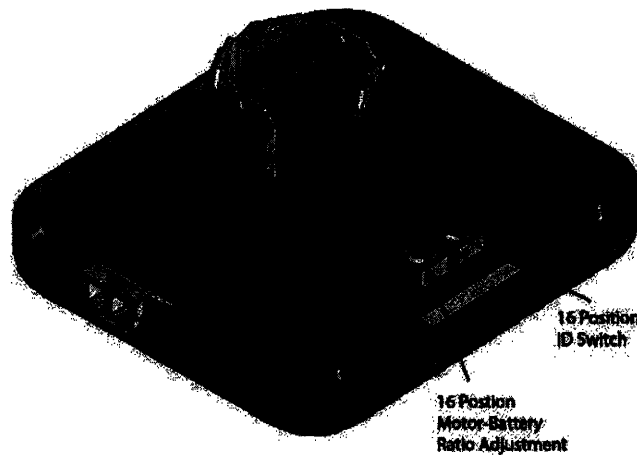


Figure 30: 3rd Generation Control Box, Lid Removed

The higher level assembly of the third generation control box includes a polycarbonate injection molded enclosure, a main board assembly, a frequency hopping spread spectrum radio, an illuminated green on/off button, and a clear polycarbonate window piece. Table 4 lists all the higher level parts in the third generation control box.

Qty.	Description	Item	Part Number	Vendor
1	Control Box Enclosure - Top	Injection Molded Polycarbonate Enclosure - Top		TBD
1	Control Box Enclosure - Bottom	Injection Molded Polycarbonate Enclosure - Bottom		TBD
4	Fasten two halves of enclosure together	Sharp Point Thread-Form Screw for Plastic 410 Ss, Pan Head Phillips, 8-11 Thread, 1/2" Length	92325A311	McMaster Carr
3	Motor Plug	CONN PLUG 4POS .093	WM1327-ND	Digi-Key
12	Motor Plug terminals	CONN TERM MALE SOLDER-TAIL TIN	WM1104-ND	Digi-Key
1	Autonomous Plug	CONN HEADER 4POS .100 R/A GOLD	WM4902-ND	Digi-Key
1	Battery Plug	CONN HEADER 2POS 7.92MM R/A TIN	H2776-ND	Digi-Key
1	Electronics	Main Board		Digi-Key/Advanced Circuits
1	Receiver	Frequency Hopping Spread Spectrum Radio		TBD

Table 4: Bill of Materials for the 3rd Generation Control Box

An exploded view of the higher level assembly is shown in Figure 31.

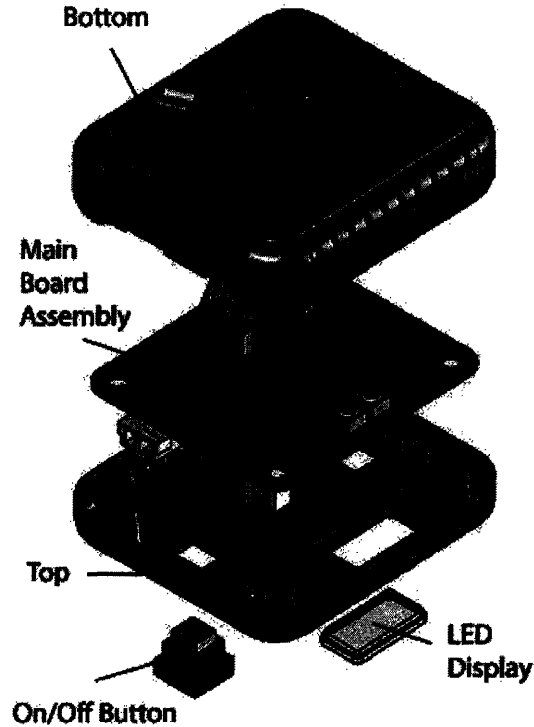


Figure 31: Exploded View of the 3rd Generation Control Box

Overall, the new design uses fewer parts than previous years. The third generation control box enclosure incorporates into its' design standoffs for the PCB and vents for air circulation to cool the electrical components within the box.

1. Motor Driver Heat Sink Configuration

For every motor that could be plugged into the control box, there needed to be a corresponding motor driver. The first and second generation control boxes use H-bridge motor driver which comes pre-packaged from National Semiconductor (P/N: LMD18200). The LMD18200 is a good choice because it can be supplied a range of 11 to 55V which allows for different battery sources to be used. At maximum operating current, 3A per motor, each LMD18200 H-bridge can produce up to 0.5 watts of waste heat energy. [1] In the first and second generation control boxes, heat sinks have been mounted to the back of the motor drivers to dissipate the commercial heat and limit the temperature rise of the motor drivers. A central fan was introduced between the heat sinks to help circulate the air within the box to the cooling vents. Figure 32 shows the cooling solution implemented in the first two generation control boxes.

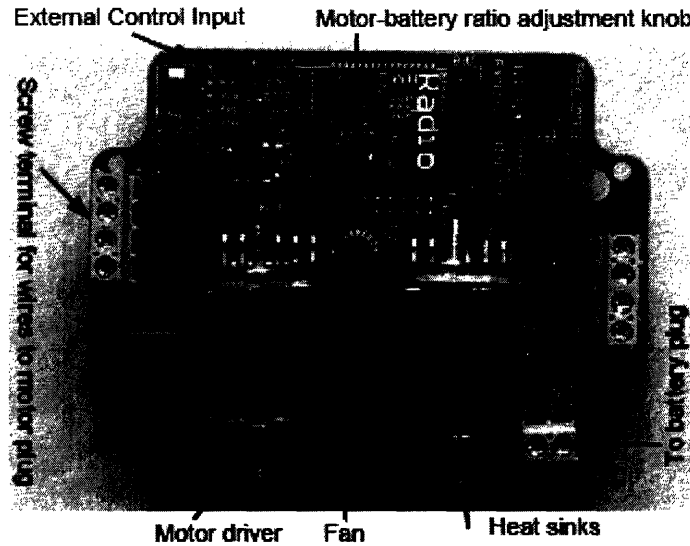


Figure 32: 1st Generation Motor Driver Cooling Solution

By introducing two more motor drivers, a new cooling solution needed to be designed and implemented to keep them all cool. The proposed solution in the third generation control box arranges the six motor drivers into a hexagon configuration with heat sinks mounted on the back of each driver. A CAD model of this configuration is show in Figure 33 with an exploded view in Figure 34. At the base of the hexagon is mounted a fan. This design is analogous to active cooling in heat pipes: the walls are the back of the six motor drivers, the heat sinks provide the wick structure, and the fan provides air, the “coolant” of the system. The difference is that this configuration is only a small section of the heat pipe. To complete the cooling system, motor driver fan vents were introduced on the top and bottom pieces of the enclosure shown in Figure 27 and Figure 29.

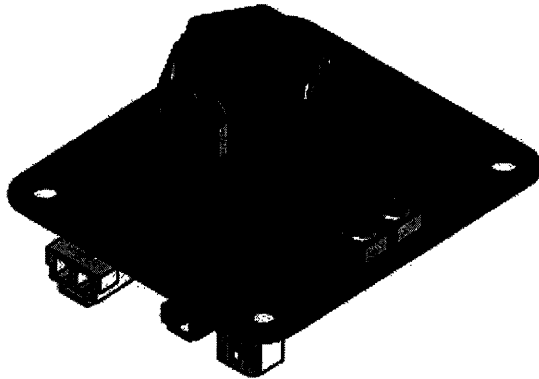


Figure 33: 3rd Generation Motor Driver Cooling Solution

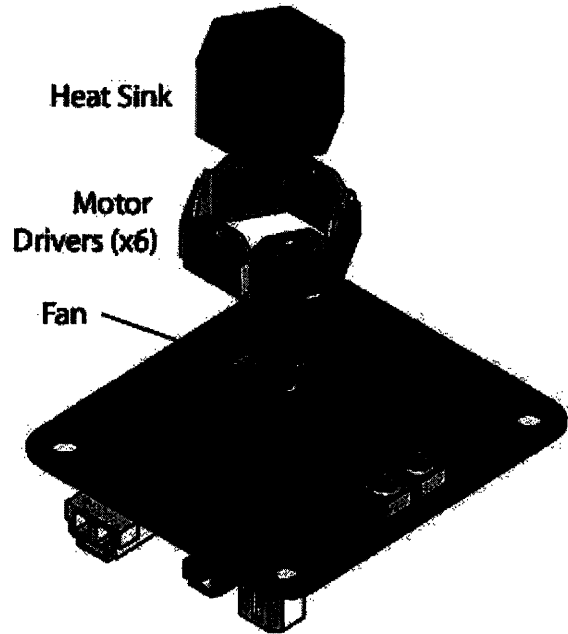


Figure 34: Exploded View of the 3rd Generation Motor Driver Cooling Solution

The heat sink design is an array of fins, similar to those found in computer towers. The fin arrays are arranged in the shape of a hexagon. Figure 35 shows a CAD model of the heat sink design. There are three holes on the heat sink to mount the heat sink to the motor drivers. A top view of the heat sink can be seen in Figure 36. The heat sink was made as one piece to lower the number of parts and complexity in the motor driver cooling system assembly.

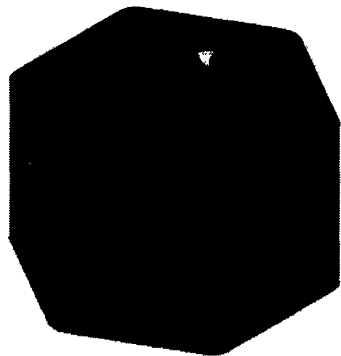


Figure 35: Motor Driver Heat Sink

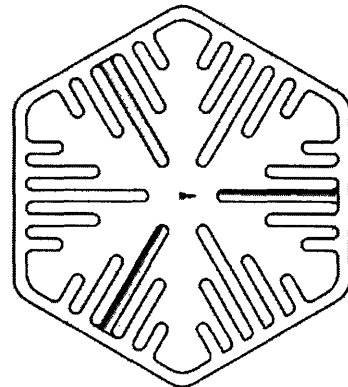


Figure 36: Top view of the Motor Driver Heat Sink

2. Kinematic Couplings

“Kinematic couplings have long been known to provide an economical and dependable method for attaining high repeatability in fixtures.” [5] The design chosen to be implemented for the third generation control box is a three-groove type illustrated in Figure 37.

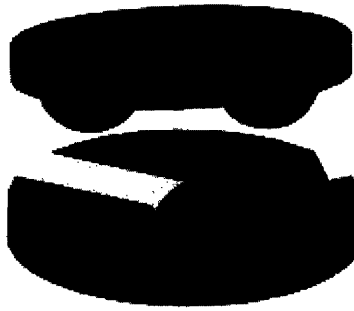


Figure 37: Traditional Kinematic Coupling Groove

If designed properly, kinematic couplings only need to “make contact at a number of points equal to the number of degrees of freedom that are to be restrained,” in this case, six. [5] For good stability in a three-groove kinematic coupling, the normals to the planes containing the contact force vectors should bisect the angles between the balls, as shown in Figure 38. For more information regarding the design and application of kinematic couplings, refer to the MIT Precision Engineering Research Group’s kinematic coupling website (<http://www.kinematiccouplings.com>).

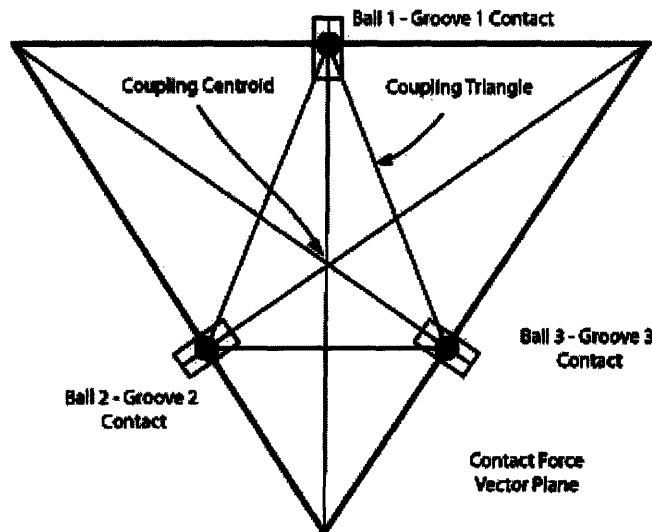


Figure 38: Geometry of a Three-Groove Kinematic Coupling

Taking in account the strap slots on the top piece of the enclosure, the kinematic coupling grooves were designed and placed where the forces would be applied when the control box is strapped in. Figure 39 illustrates the geometry used to determine the location of the three-groove kinematic coupling.

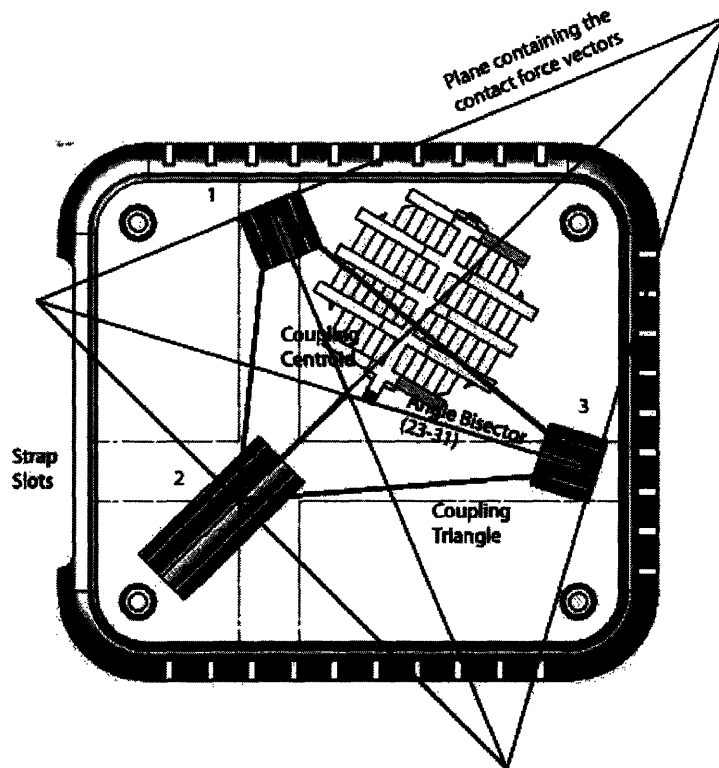


Figure 39: Kinematic Coupling Grooves of the 3rd Generation Control Box

Originally, the grooves were to be below the surface of the bottom face of the control box. However, if the student chooses not to use the grooves and places the box flat on the bottom face this would block the motor driver fan vent. The kinematic coupling grooves were thus designed raised off the surface of the bottom of the control box to serve also as “feet” to maintain a gap between the motor driver fan vent and the surface the box is mounted to.

b. Electrical

The schematic for a new main PCB was designed by Hongshen Ma. A copy of the schematic diagram can be found in the Appendix C. The physical layout of the board is still being worked on at the time of the writing of this thesis.

Mechanically, the board has four mounting holes that get mounted and sandwiched between the top and bottom enclosure pieces as shown in Figure 30. There is a hole where the center of the motor driver hexagon configuration is located to provide an opening for the fan to blow through shown in Figure 33. It is to be a four layer PCB board to accommodate for the size of the board which limits the space to route all the electrical components.

The frequency hopping spread spectrum radios from Texas Instruments used in the second generation control box has started showing malfunctions during this year’s 2.007 offering. New frequency hopping spread spectrum radios are currently being investigated to find a smaller, more robust and dependable radio. One radio currently being looked at is the XBee 2.4 ZigBee GHz RF module (<http://www.maxstream.net/products/xbee/xbee-oem-rf-module-zigbee.php>).

C. Current Stage of the Project

The third generation control box is currently in the prototype stage. The first iteration of the enclosure design has been rapidly prototyped through SLA shown in Figure 40 through Figure 44 and is currently being evaluated.

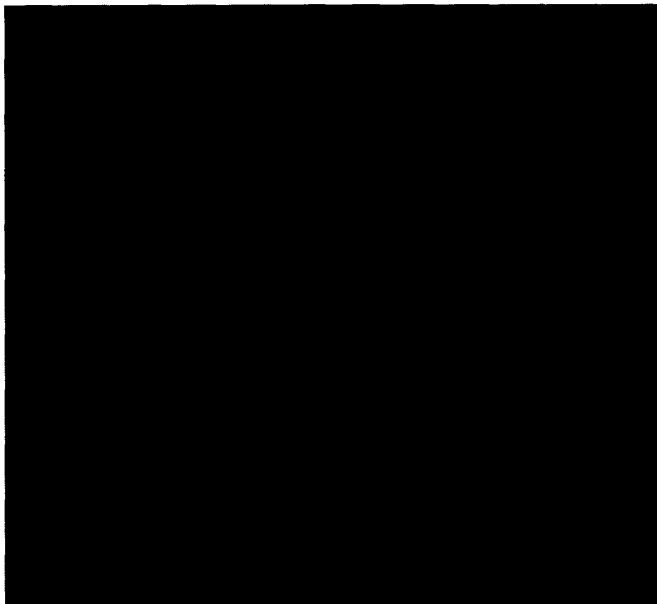


Figure 40: Assembly of the SLA of the 3rd Generation Control Box Enclosure

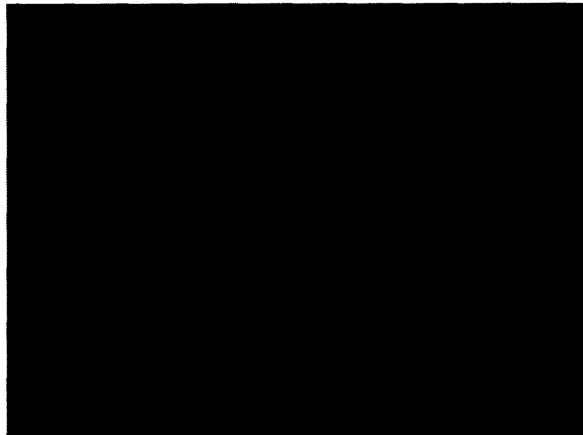


Figure 41: Outside the SLA, top piece

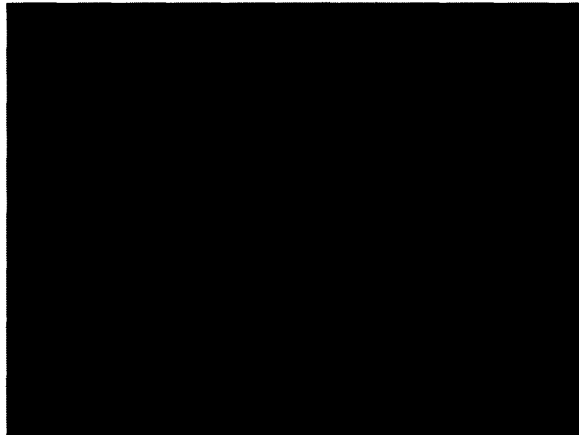


Figure 42: Inside the SLA, top piece



Figure 43: Outside the SLA, bottom piece

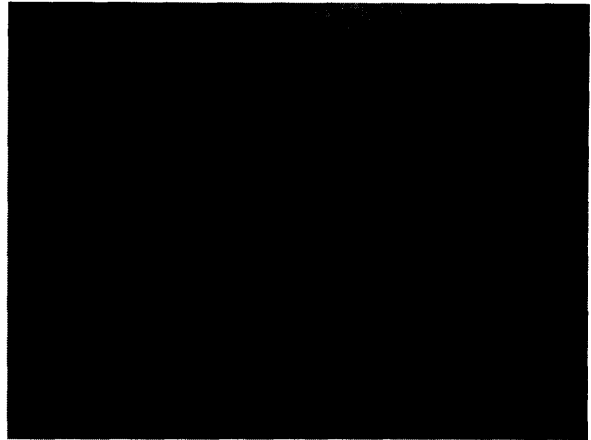


Figure 44: Inside the SLA, bottom piece

In order for the part to be injection molded, the part needs to be approximately the same thickness all around with appropriate draft angles. The main body of the top and bottom enclosure currently has a one degree draft. The vents have a five degree draft to ensure that none of the intricacies get stuck in the mold.

D. Design Feedback

Two design flaws have been spotted in this first enclosure iteration. The spacing between the two closest motor plugs shown in Figure 45 is too thin currently and could easily break. The motor plugs' openings will need to be shifted apart to provide more material to reinforce this spot. The boss on the top enclosure pieces where the main PCB mounts to is currently too thick shown in Figure 46. These features are hard to mold and would create sink marks on the cosmetic top surface of the control box. The walls of the bosses will need to be made thinner while providing the same functionalities of supporting the main PCB.

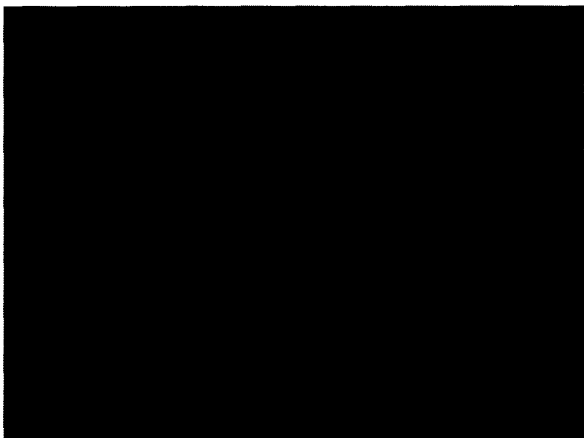


Figure 45: Beam between motor plugs structurally too thin.

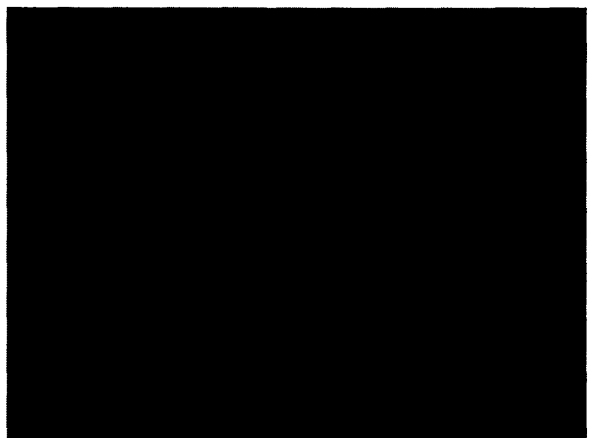


Figure 46: Bosses to hold up main PCB too thick.

An aspect of the design that still needs to be worked on is finding a cheap, high life cycle, high power load connector for the motor plug and connector. The current plug and connector assembly chosen will last for the duration of the class and competition but will need to be

replaced each year. This is not ideal for a product because this is like sending it back to the manufacture each year for repairs. The ideal connector has yet to be found at the writing of this thesis.

6. Conclusion & Future Goals

A. 2nd Generation Control Box

The second generation control box has been built and is currently being used in the Spring 2006 offering of 2.007. So far the new boxes have been well-received. It is too early to evaluate the effectiveness of the boxes until after the end-of-the term competition. A survey will be distributed to this year's students asking them to evaluate the 2.007 control system. A copy of this survey can be found in Appendix B.

B. Future Plans for 3rd Generation Control Box

The plan for the third generation control box is to build-up the first design iteration, evaluate, and make changes towards a final design. Once the third generation control box design has been finalized, molds will be made to injection mold in clear plastic the enclosure. The boxes would be mass produced and introduced first to the 2.007 curriculum and then to the rest of the world.

Acknowledgements

The author would like to thank the Cambridge/MIT Institute for funding this project. The author would like to thank Edward Summers for his help with testing the control system. The author would also like to thank Professor Alexander H. Slocum for his guidance on this project. The author would like to specially acknowledge Hongshen Ma for his guidance and electronics expertise in this entire project. The author would also like to thank the countless students and staff who have made 2.007 a success over the years.

References

- [1] Ma, Hongshen, and A. H. Slocum. "A flexible-input, desired-output motor controller for engineering design classes." IEEE Transactions on Education February 2006: 113-121.
- [2] Ma, Hongshen, Wey-Jiun Lin, and A. H. Slocum. "A Reconfigurable Spread Spectrum Wireless Control System for Engineering Design Classes and Competitions." In Preparation for: IEEE Transactions on Education. March 2006.
- [3] MIT Precision Engineering Research Group. "2.007 - Design and Manufacturing I." <<http://pergatory.mit.edu/2.007/contests/2006/html/table.html>> (May 2006)

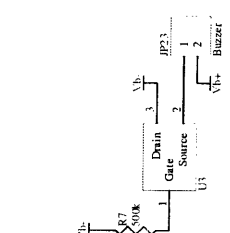
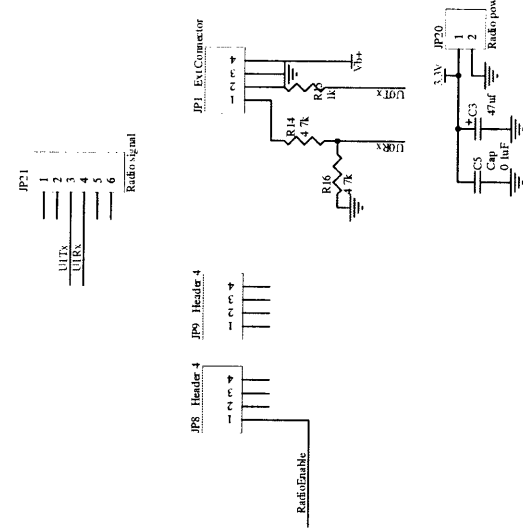
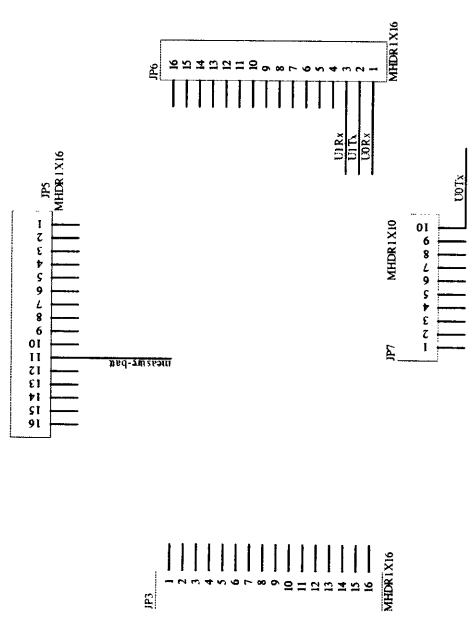
- [4] MIT Precision Engineering Research Group. "MIT Precision Engineering Research Group's kinematic coupling website." <<http://www.kinematiccouplings.com>> (April 2006)
- [5] Slocum, A. H. "Kinematic Couplings for Precision Fixturing - Part I - Formulation of Design Parameters." Precision Engineering April 1988: 85-91.

Appendix

A. 2nd Generation Control Box

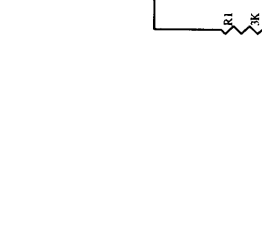
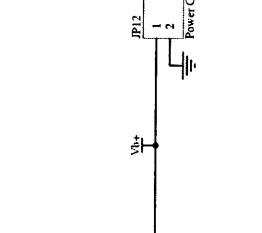
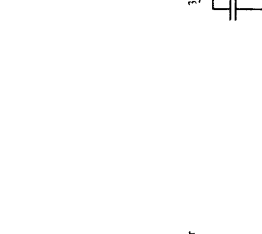
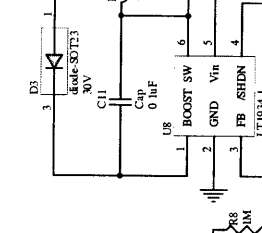
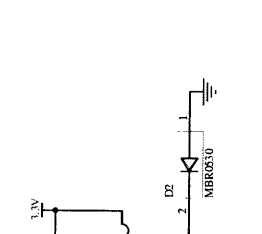
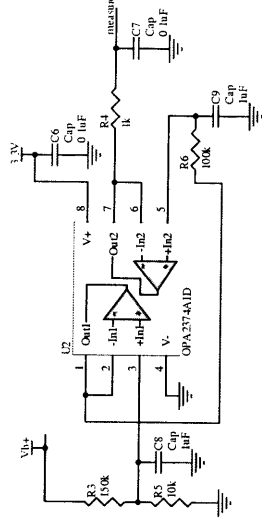
The following is more detailed information on the design of the 2nd Generation Control Box.

Schematic of 2nd Generation Control Box Adaptor Board



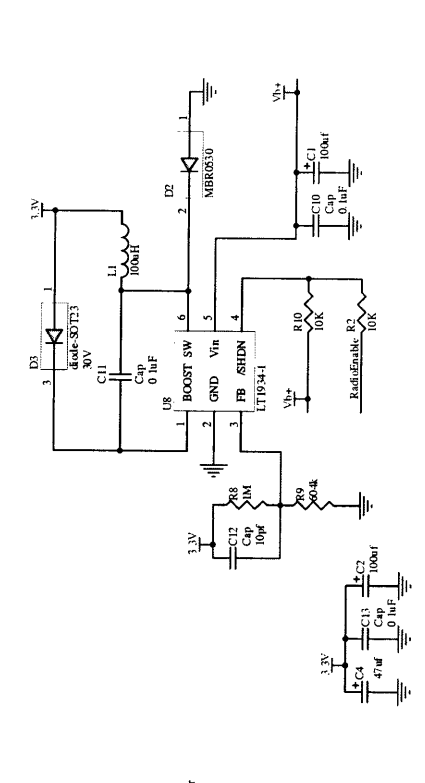
A

B



C

D



Put these caps close to the radio power plug.

Put these two caps to the LT1934

E

2nd Generation Control Box - Adaptive PCB Schematic			
Size	Number	Sheet of	Revision
B		5/12/2006	3
File	E:\Thesis\Adaptive3.2_SCHDOC		Drawn By
		Hongshen Ma, MIT	

F

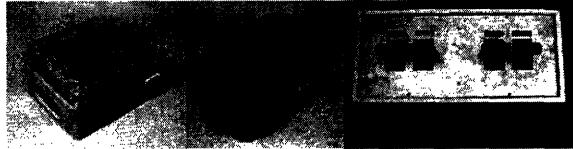
Bill of Material for Adaptor PCB Assembly

Qty	Description	Designator	Part Number	Vendor
2	CAP 100UF 25V ELECT HD SMD	C1, C2	PCE3370TR-ND	Digi-Key
2	CAP TANT 47UF 6.3V 20% POLY SMD	C3, C4	478-3139-1-ND	Digi-Key
6	CAP CER .10UF 25V Y5V 0603	C5, C6, C7, C10, C11, C13	445-1325-1-ND	Digi-Key
2	CAP CER 1.0UF 16V Y5V 0603	C8, C9	445-1327-1-ND	Digi-Key
1	CAP CERAMIC 10PF 50V NP0 0603	C12	BC1225CT-ND	Digi-Key
1	DIODE ZENER 225MW 15V SOT23	D1	BZX84C15LT1OSCT-ND	Digi-Key
1	DIODE SCHOTTKY 30V 500MA SOD123	D2	MBR0530-TP	Digi-Key
1	DIODE SCHOTTKY 30V 200MA SOT- 23	D3	BAT54FSCT-ND	Digi-Key
1	POWER INDUCTOR 100UH 0.60A SMD	L1	CDRH74-101MC	Digi-Key
1	RES 3.30K OHM 1/10W 1% 0603 SMD	R1	RHM3.30KHCT-ND	Digi-Key
3	RES 10.0K OHM 1/10W 1% 0603 SMD	R2, R5, R10	RHM10.0KHCT-ND	Digi-Key
1	RES 150K OHM 1/10W 1% 0603 SMD	R3	RHM150KHCT-ND	Digi-Key
2	RES 1.00K OHM 1/10W 1% 0603 SMD	R4, R15	RHM1.00KHCT-ND	Digi-Key
1	RES 100K OHM 1/10W 1% 0603 SMD	R6	311-100KHCT-ND	Digi-Key
1	RES 499K OHM 1/10W 1% 0603 SMD	R7	RHM499KHCT-ND	Digi-Key
1	RES 604K OHM 1/10W 1% 0603 SMD	R9	RHM604KHCT-ND	Digi-Key
1	RES 1.00M OHM 1/10W 1% 0603 SMD	R8	RHM1.00MHCT-ND	Digi-Key
1	RES 4.75K OHM 1/10W 1% 0603 SMD	R14	RHM4.75KHCT-ND	Digi-Key
1	MOSFET N-CH 55V 56A DPAK	U1	IRFR2405-ND	Digi-Key
1	IC OPAMP DUAL R-R I/O SOT23-8	U2	OPA2374AIDCN	Digi-Key
1	TRANS SS GP NPN 60V SOT23	U3	MMBT2484LT1OSCT-ND	Digi-Key
1	IC REG SW STEP-DWN 300MA SOT23-6	U4	LT1934IS6-ND	Digi-Key

B. Implementation of 2nd Generation Control Box

The following are figures and educational documents used in implementing the 2nd Generation Control Box into the Spring 2006 offering of 2.007.

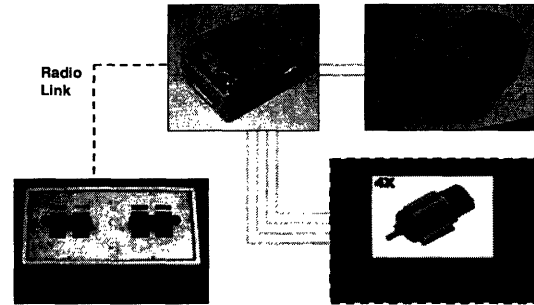
Control System Lecture Notes



2.007 Control System

Hong Ma
Wey Jun Lin
Spring 2006

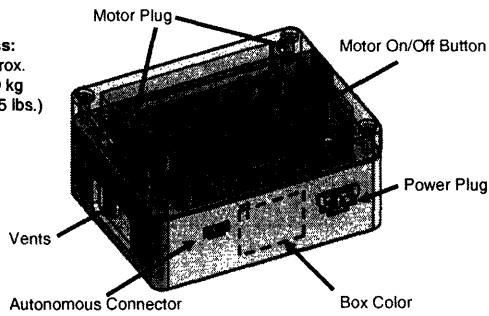
Control System Overview



Control Box

Key Features

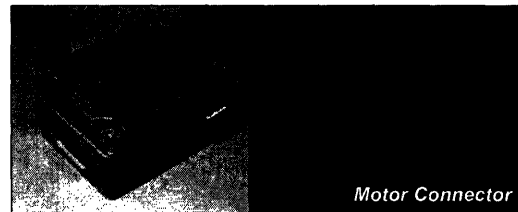
Mass:
Approx.
0.39 kg
(0.85 lbs.)



Control Box Feature

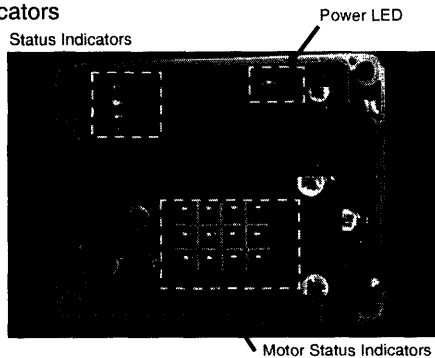
Electrical Characteristics

- 4 channel output
- Up to 3A maximum on each channel



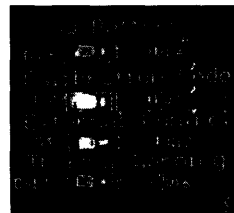
Control Box Feature

Indicators



Control Box Feature:

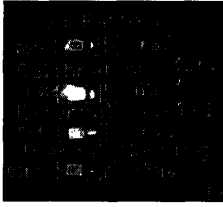
Battery Low Voltage Protection



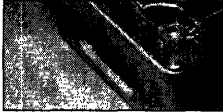
- Red LED turns on when the battery is low.
- Motor controllers will turn off automatically soon after that.

Control Box Feature:

Thermal Protection

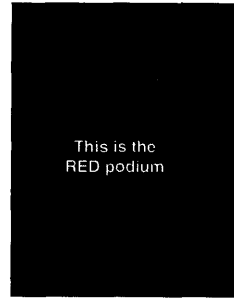


- **Amber Thermal Warning LED** turns on when the internal temperature of the motor controller is too high.
- **Thermal Warning** usually means that your motor has been stalled for >35s. Beware of damage to your motor!
- Turn off motors, but leave the control box plugged in for cooling.
- Continued heating will cause automatic shutoff.

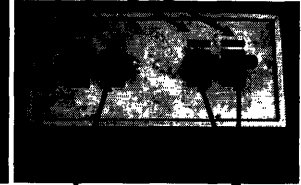


Control System

Podium



Green=Forward
Red=Stop
Blue=Reverse



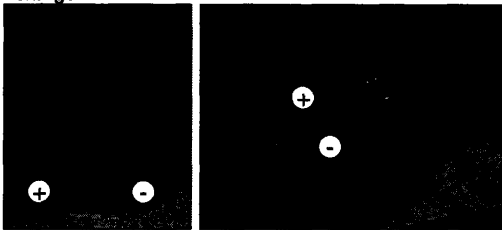
Inactive
Button

Throttles

The Battery

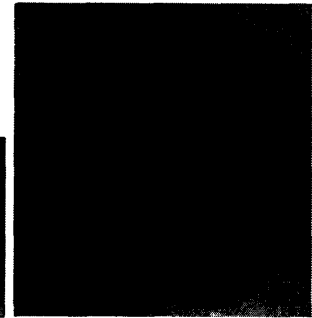
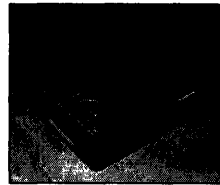
Your Robot's Power Source

- Beefy NiCd battery
- 14.4V nominal, but actually 12-17V depending on charge L L



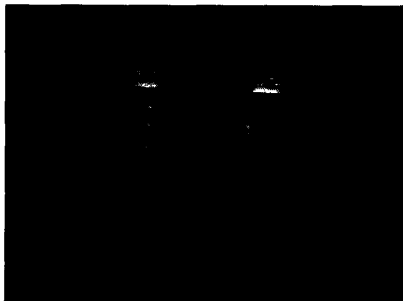
Mounting the Control Box and Battery

- Control box and battery is a large % of your total mass
- Need a robust mount for predictable robot performance



"Good" Battery Mounting

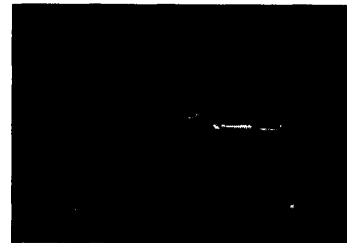
Example



The Motor

Your Robot's "Engines"

- 6V motor designed for remote control cars
- Torque-Speed characteristics available

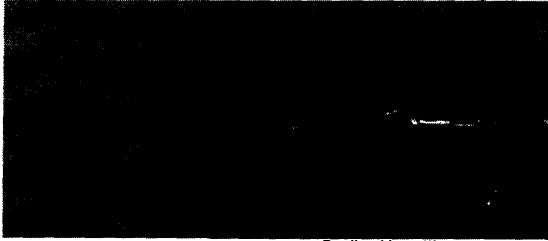


Wiring Your Motor

EE for MechE

- Motor electrical contacts are extremely fragile. They must be strain-relieved.

Make a Loop with the Wire. Hold in place with a thin strip of electrical



Cooling Vents!!!

How to Make a Battery Plug

What You'll Need



2 x 1/4" Tab Connectors



1 x 2 Pos. Connector



2 x Connector Terminals



4 x 3/16" Heat Shrink



2 x 18 AWG Wire

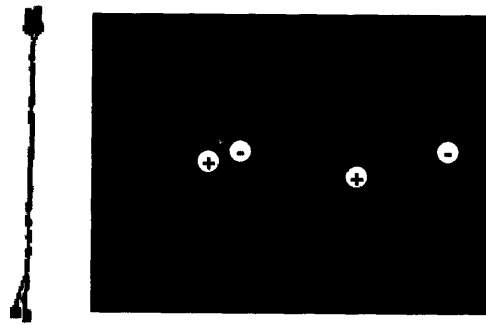
How to Make a Battery Plug

Key Steps



Using Your Connectors

Battery to Control Box



How to Make the Motor Plugs

What You'll Need



4 x female Terminals



2 x 4 Pos. Connectors



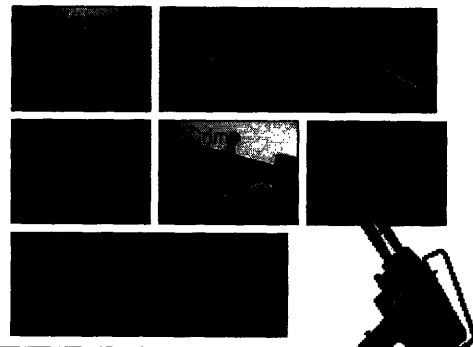
8 x 18 awg Wire



8 x 3/16" Heat Shrink

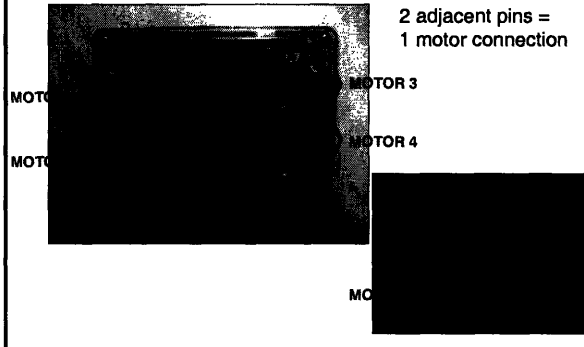
How to Make the Motor Plugs

Key Steps



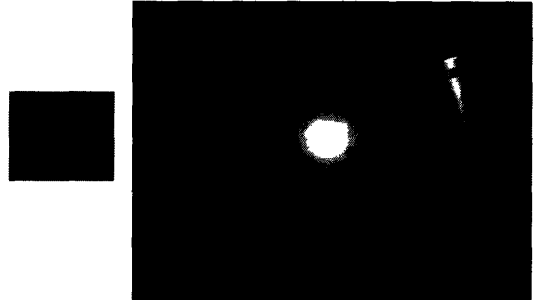
Using Your Connectors

Motors to Control Box



Using Your Connectors

Motors to Control Box



More Wiring Tips

EE for MechE

Do:

- Wrap all connections with heat-shrink or electrical tape
- Strain relieve all connections. Zip ties, etc. are in the cabinet
- Keep your wires as short as possible
- If you need longer wires, twist/braid them together to reduce interference

Don't:

- Make connections solely with electrical tape. Solder them or use a connector
- Wire your machine like a rat's nest
- Allow your motor leads to short against each other
- Use wires as string
- Wait until impending day to wire your machine

Tips and FAQ

- Control box is on, but my motors doesn't work – Check the on button, check for stop from all 4 channels.
- I can't get over obstacles – Rock back and forth, don't stall your motors!
- I get spurious radio signals when I'm driving – Your motor wires are causing interference. Shorten your wires, twist/braid them together, and don't encase your control box in metal

Appendix: How to Solder Wires Together

1. Strip insulation
2. Put on heat-shrink



How To Motor Connector

WHAT YOU WILL NEED

2 Motor Connectors

8 Connector Crimp Terminals

8 pieces of wire approx. X* long

8 strips of 3/16" Heat Shrink Tubing

Access to...

- Wire Strippers
- Crimpers
- Heat Gun
- Soldering Iron

*X > distance from your motors to your control box mount.

2.007 HOW TO

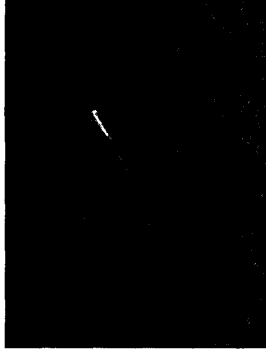
MOTOR CONNECTORS



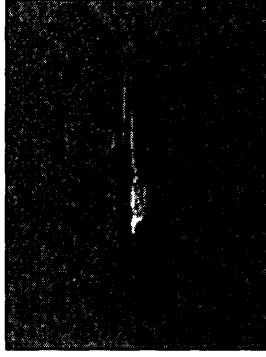
1 Strip approx. 1cm of wire insulation off both ends of the wire using 20 setting on stripper.



2 Tin both ends of the wires as shown.



3 A tinned piece of wire looks like this. Put 1 piece of heat shrink onto each wire.



4 Tin the insides of the connector terminals where indicated.



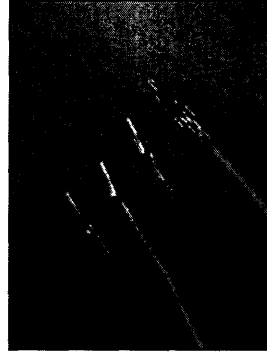
5 Solder by pressing the wire and terminal together with soldering iron. One terminal per wire. Add solder if necessary.



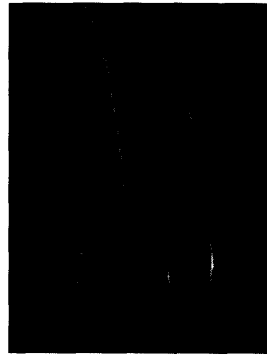
6 Crimp lower tabs of terminal over insulation part of wire using 2.8 setting on crimper.



7 Crimp upper tabs of terminal over stripped part of wire using 2.8 setting on crimper.



8 Crimped terminals should look like this.



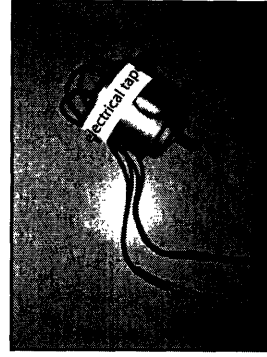
9 Using a heat gun, "shrink" heat shrink around area where wire is soldered onto terminal.



10 "Plug" connector crimp terminals into connector. Adjacent hole pairs - 1 motor



11 Tape connector leads to motor leads and test with control system. Swap leads if necessary.



12 Solder connector lead with corresponding motor lead. Heat shrink over solder joint.

How To Battery Connector

WHAT YOU WILL NEED

1 Battery Connector



2 Connector Crimp Terminals



2 pieces of wire approx. X* long



2 Battery Tab Crimp Terminals



4 strips of 3/16" Heat Shrink Tubing



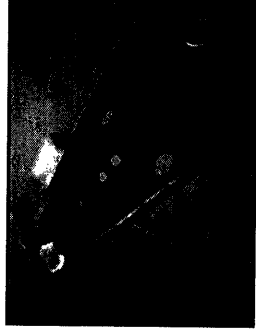
Access to...

- Wire Strippers
- Crimpers
- Heat Gun
- Soldering Iron

*X > distance from your battery mount to your control box mount.

2.007 HOW TO

BATTERY CONNECTOR



1 Strip approx. 1cm of wire insulation off both ends of the wire using 20 setting on stripper.



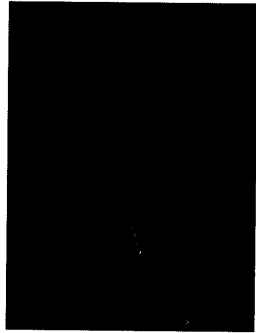
2 Put 2x heat shrink onto each wire. Tin both ends of the wires as shown.



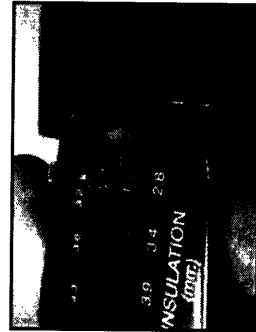
3 A tined piece of wire looks like this.



4 Tin the insides of the battery tab connectors and connector terminals where indicated.



5 Solder by pressing the wire and terminal together with soldering iron. One of each terminal type per wire.



6 Crimp lower tabs of terminal over insulation part of wire using 2.8 setting on crimper.



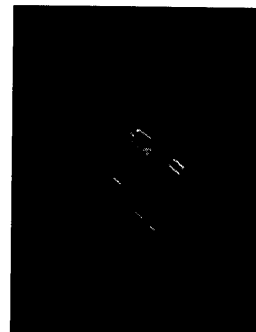
7 Crimp upper tabs of terminal over stripped part of wire using 2.8 setting on crimper.



8 Crimp lower tabs of terminal over insulation part of wire using 3.4 setting on crimper.



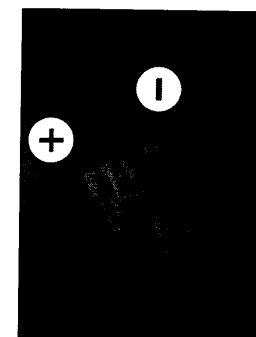
9 Crimp upper tabs of terminal over stripped part of wire using 2.3 setting on crimper.



10 Crimped terminals should look like this.

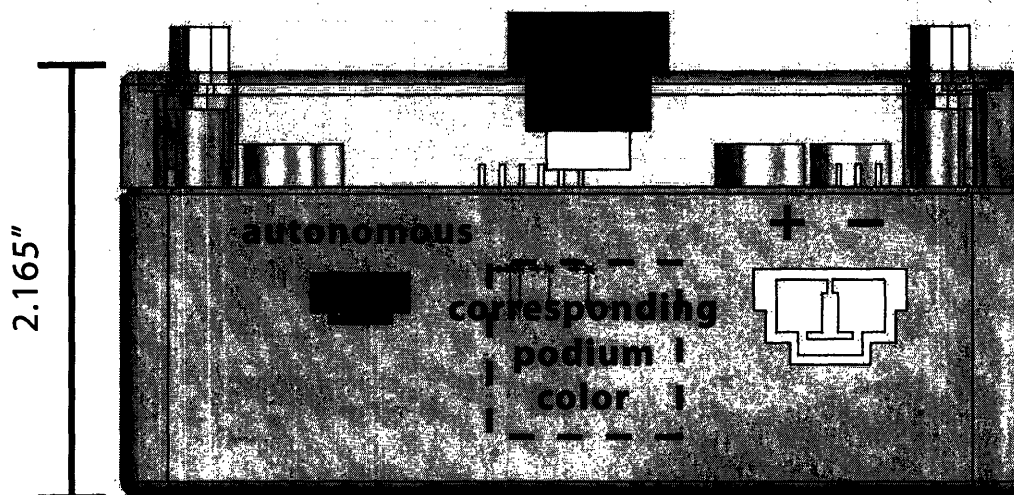
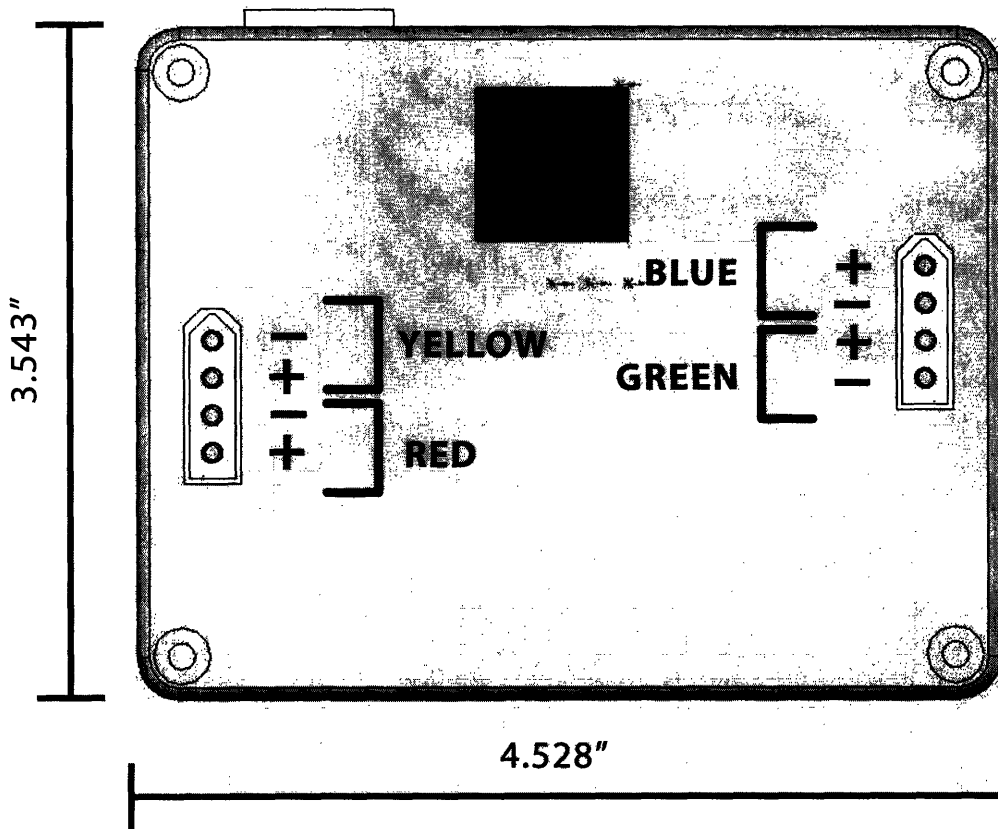


11 Using a heat gun, "shrink" heat shrink around area where wire is soldered onto terminal.



12 "Plug" connector crimp terminals into connector.

2.007 Control System: Debug Sheet



Helpful Hints

1. If the control box is beeping, you've plugged the batteries in backwards.
2. If the motors go the "wrong way," reverse the wires. Remember to "Tape-Test-Solder."
3. All electrical connections (including those on the batteries and the motors) must be properly insulated with heat shrink. Not doing so is a disqualifying offense.
4. The plugs and buttons on the control box must be accessible by the staff during the contest.
5. Check all power cords (including the podium one) if the control box isn't working.

2.007 Control System End-of-the-Year Survey

2.007 Control System Survey

May 16, 2006

- | | | |
|----|--|--|
| 1 | Would you prefer to control your robot via radio control or tether? | radio
control / tether
(circle one) |
| 2 | How would you rate the reliability of the radio system?
Comments on reliability... | Bad Good
1 2 3 4 5 |
| 3 | If the reliability of the current radio system could be improved (i.e. using spread-spectrum radios such as IEEE 802.15.4 – Zigbee radios), how would you rate the reliability of the control boxes? | Bad Good
1 2 3 4 5 |
| 4 | Was the control latency (i.e. the delay time between the joystick and the control box receiving the signal) sufficiently low? | Yes / No |
| 5 | Are the indicator lights on the control box useful? | Yes / No |
| 6 | Would a bar graph indicator on the podium for each joystick be useful? | Yes / No |
| 7 | Would it be helpful to know the current delivered to each of your 4 motors to help you monitor their torque output? | Yes / No |
| 8 | Are the connectors easy to use? | Yes / No |
| 9 | Are the connectors easy to make? | Yes / No |
| 10 | How sensitive was the podium joystick? (Not sensitive enough/Too sensitive 1...5) | low high
1 2 3 4 5 |
| 11 | Was the control box easy to mount? | Yes / No |
| 12 | Assuming that your motors were properly constrained, did the control box and motor provide enough power for your robot? | Yes / No |
| 13 | Was 4 motors enough?
If not, how many more motors would you like to have? (1, 2, 3, ...) | Yes / No |

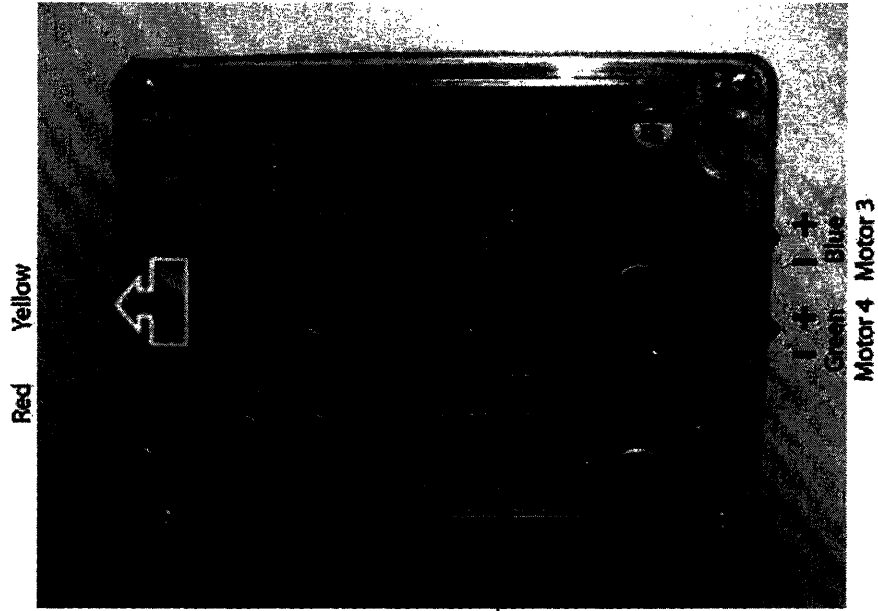


Figure 47: Motor Output of the 2nd Generation Control Box

C. 3rd Generation Control Box

The following are more detailed figures and information on to design the 3rd Generation Control Box.

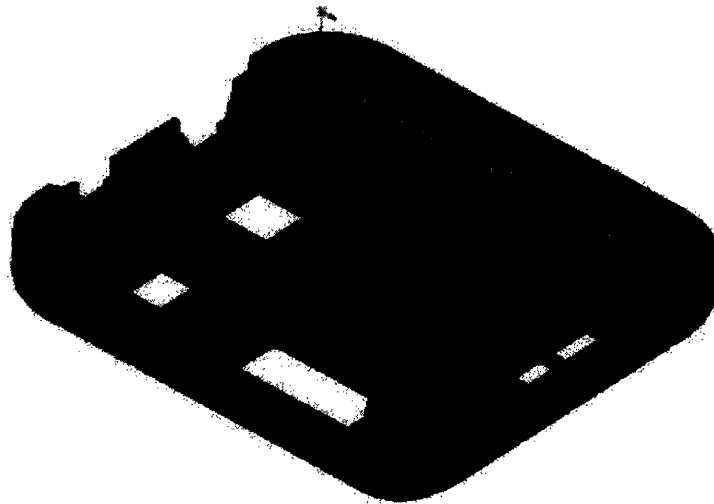


Figure 48: Top Piece of the 3rd Generation Control Box

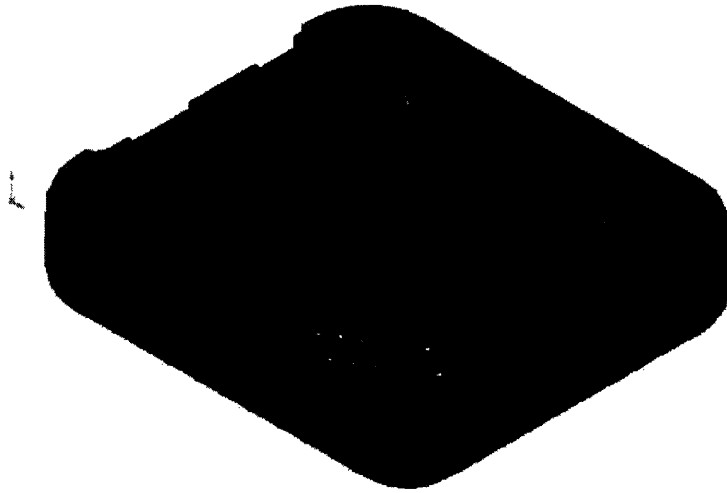
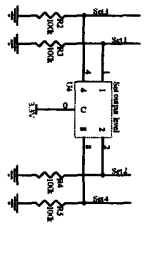


Figure 49: Bottom Piece of the 3rd Generation Control Box

Schematic of 3rd Generation Control Box PCB

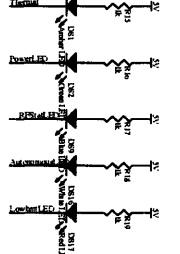
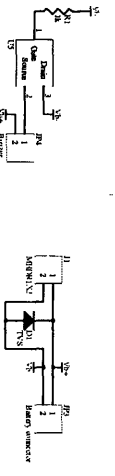


3.3V Microprocessor Power Supply

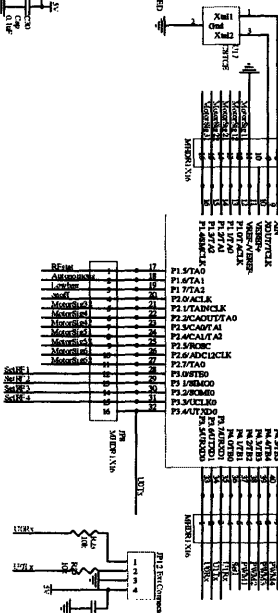
Power Bulbs with LED?
 Determine LED current
 Set pins
 Copy over adaptor board snail
 Capacitance for the LM41300
 Decoupling capacitance
 Current limiter for aux. power
 5V Switching regulator 250-300mA



Current sense is 377mA per amp
 Check the components for the electronics and the power connector



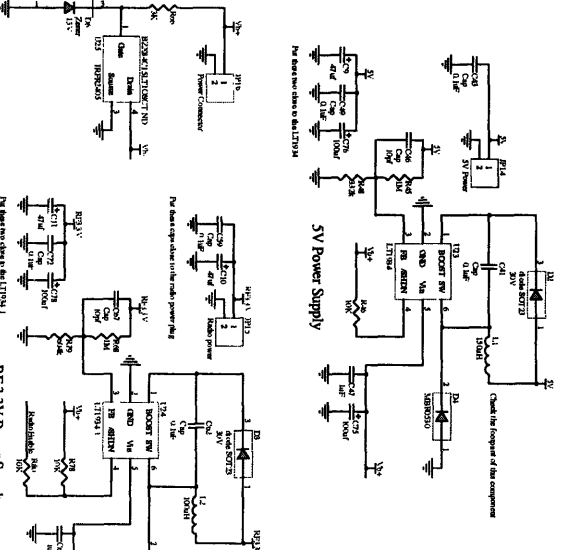
Battery voltage measurement



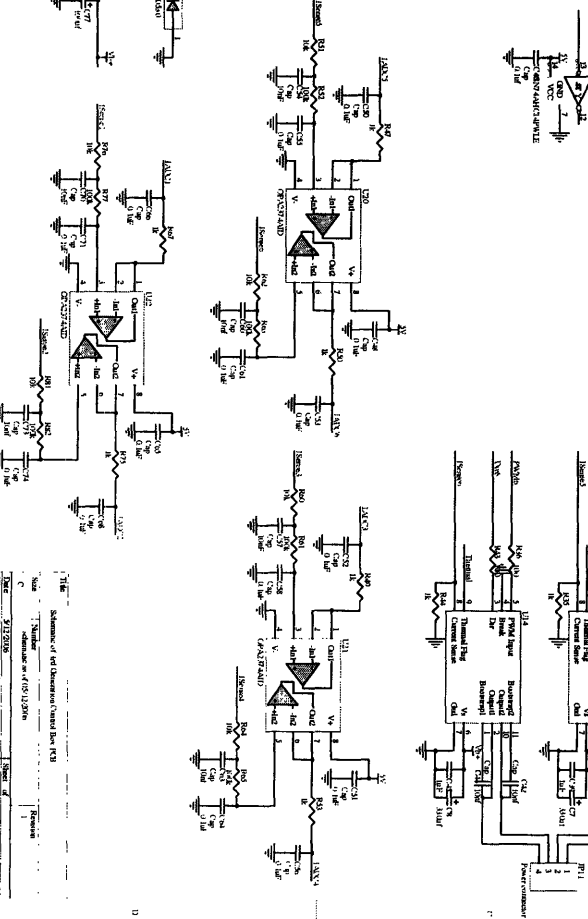
Don't forget to set LED resistor values!!!



5V Power Supply



RF 3.3V Power Supply



1. Title: Schematic of a 3.3V Microprocessor Power Supply
 2. Author: [Name]
 3. Date: [Date]
 4. Version: 1.0
 5. Description: Schematic of a 3.3V Microprocessor Power Supply