2009 CAS Battlebot

by

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BattleBot Team 2009:

Power and Control

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ABSTRACT

At the University of Cincinnati, College of Applied Science, four seniors designed a battlebot for the BotsIQ competition in 2008. BotsIQ is a competition of radio controlled robots which battle for three minute matches or until one robot becomes disabled. If no robot is disabled by the end of the match points are awarded to the team that has done the most damage. Points are awarded by pushing an opponent into an arena hazards. These can include kill saws, flippers, or hammers. Although, originally the competition was organized by BotsIQ, this year BattleBots took over.

BattleBots and BotsIQ are similar organizations, with stark differences. BattleBots is the organization that piloted robot competition for main stream television. The matches use professional level hazards and competitors can be any combination of collegiate and professionals. BotsIQ is an education based division of battling robots, requiring that a design be proven through a report. The arena hazards are not as fierce and competitors can only be from academic institutions.

The 2008 seniors competed in the BotsIQ competition last year, and were rewarded for best design, driver, and won the competition. This year four new seniors: David Amos, Mark Bridewell, Andy Holtkamp, and Cory Kissel are prepared to compete again. The team looked to remain competitive while striving for victory. The twist this year is that the competition was organized by BattleBots and was taped for television.

The weapon and maneuverability systems are keys to offense for a robot. This meant that a user friendly controller was necessary. If the controls were awkward and cumbersome the robot may have never stood a chance. The power and control system focused to keep things simple and robust. Being able to make repairs within the allotted time, and having a power on demand for the match duration can make or break a chance at victory. Through research and customer evaluation the system’s needs were pinpointed. By the end of the report an understanding of concept selection, design, and fabrication will be provided. Along with a complete summary of the competition and results.

PROBLEM STATEMENT & RESEARCH

PROBLEM STATEMENT

In 2008, the University of Cincinnati's College of Applied Science took first place in the BotsIQ competition. BotsIQ is a fighting robots competition involving two opponents. The goal is to knock your opponent out during the match or to win by scoring points. The 2008 champions although successful, acknowledged their robot had several design issues [(1)]. Making improvements was necessary to maintain competitiveness, in the 2009 BattleBot competition. The required design changes were based on what was learned from the 2008 BotsIQ competition. Our team, Marc Bridewell, Andy Holtkamp, Cory Kissel, and I, goal was to remain competitive knowing that the competition would be fierce in 2009. The project was broken into four main components. Cory Kissel constructed the armor and frame. Marc Bridewell designed the weapon. Andy Holtkamp prepared the drive train. I took the task of the power and controls system.

INTRODUCTION

Going into the project under the assumption that the competition was going to be managed by BotsIQ like 2008 was later realized to be incorrect. The 2008 competition was run by the BotsIQ organization, 2009 was run by BattleBots. There are stark differences in how the competitions are run.

BotsIQ is an education based organization which prides itself on competitors who design and construct their robots. It is mandatory to compete that a report is provided, proving that the design is original. The competition, limited to colleges, is judged using specific criteria and focuses on the combat between robots. Matches are three minutes long, with 40 lb hammers as the only hazard [(1)].

In contrast BattleBots is in the business of entertainment television. Reports are not necessary and the competition is not limited to colleges. Professional teams can enter into the competition as well. The matches are heavily persuaded by arena obstacles called hazards. These hazards designed for professional level combat and are control by competition staff. They consist of 100 lb hammers, a popup floor, diamond tipped table saws springing from the floor, and corkscrew saws on the walls [4]. The judging is weighted heavily on audience input, this is so the matches look good for television.

These changes were not presented until late January. Designing was completed and manufacturing had begun. Thus limiting the aggressive changes that could be made to the robot, a decision to continue forward was made.

RESEARCH

Researching began using reference documentation and compiling the information on battery materials. Five main categories of battery power were researched: alkaline, lead acid, lithium, nickel cadmium, and nickel metal hydride.

The alkaline batteries seen in Figure 1 are the most common, easiest to get, and cheapest too. However they are very inefficient for power capacity we were looking for. They have low power capacities because the capacity is strongly dependent on the load, so supplying large amounts of current in short time periods can very troublesome [3]. Since alkaline batteries are not rechargeable constantly replacing them can become very expensive. They are also relatively heavy, and in a competition where weight is a limiting factor.

Figure 1 [13]

Lead acid batteries, developed in the late 1800s, were the first commercially practical batteries. Rechargeable lead-acid batteries have been available since the 1950s and have become the most widely used type of battery today [3]. Lead acid batteries, as seen in Figure 2, can work great for larger low performance type robots. They are cheap and available off the shelf, but lead acid batteries have a problem of being very large and heavy. They need to always be kept charged, and do not have the high discharge rates as more modern batteries [3].

Figure 2 [13]

Lithium batteries, in Figure 3, are the new standard for portable power. Lithium batteries have the same high energy capacity as nickel metal hydride, power output rates like nickel cadmium, and weigh about 20%-35% less [3]. They also have zero memory effect problems, meaning they can be recharged continuously. Lithium batteries although are not as durable as nickel metal hydride or nickel cadmium designs. They can be extremely dangerous if mistreated because lithium ignites easily [10].

Figure 3 [13]

Nickel Cadmium batteries have the highest current output and have the best durability because they have the lowest internal resistance of the batteries researched [10]. However recharging nickel cadmium batteries, like Figure 4, have a downside. Ever notice how some older cell phone batteries just do not last as long on a single charge as when you first bought it? This is called memory effect, nickel cadmium batteries over many charges, begin to store less and less energy after each recharge. In addition nickel cadmium is a heavier material compared to lithium and nickel metal hydride [3].

Figure 4 [13]

Nickel Metal Hydride batteries can be recharged as much as you want, have good current output, and have high energy capacity [3]. In contrast nickel metal hydride batteries have a high self-discharge rate. Leave it for a week or so, and you will find an entirely discharged battery. Fortunately nickel metal hydride batteries can last many more cycles than a nickel cadmium battery. Nickel metal hydride batteries, seen in Figure 5, sustain their voltage for the length of the discharge cycle. This is because the low internal resistance allows the cells to deliver a near-constant voltage until they are almost completely discharged [10].

Figure 5 [13]

An important factory that can make or break you in competition is drivability. Choosing a controller that is user friendly becomes an important decision. There are unfortunately no combat robot dedicated remotes, so the chosen controller will be of the radio controlled car or airplane variety.

A radio controlled car remote, Figure 6, uses a sleek design with a trigger to control the throttle and a wheel for steering. Steering has a more natural feel to it because of the wheel control. The unfortunate downside is that for our robot design we want to be able to have control over four motors independently, meaning that the control must have no less than four channels. The radio controlled car remotes only have capability for three [6].

Figure 6 [6]

This revelation determined that a radio controlled airplane remote would be chosen. These remotes, seen in Figure 7, can come with anywhere between four and fourteen channels. They use two joysticks for controlling and have many switches for settings. Using this style controller allowed the system to utilize a single joystick for the drive train throttle and steering. This while using the opposite joystick to control the speed and direction of the weapon [6].

Figure 7 [6]

The task of transferring power from the batteries to the motors was handled by the electronic speed controllers. Using the signal received from the remote it determines the necessary voltage and polarity needed by the motors and converts it from the static voltage that is held within the battery. User friendliness, being compact, and cost were top priorities. The Vantec controllers, Figure 8, can handle a range of input voltages and have better signal connections. The IFI Robotics controllers in Figure 9 are plug and play, a quarter of the weight, and a quarter of the size. All while handling twice the current at half the price [5].

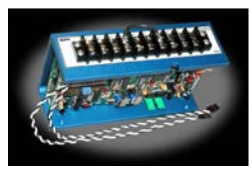

Figure 8 [6]

Figure 9 [6]

CUSTOMER VALUES

After the team agreed on a preliminary feature list, the features were used to create a survey. The respondents were asked to rank the features in order from one to five for their importance (one being least

Table 1-Main Category

Main Category	Ranking
Maneuverability and Control	4.0
Offense	3.0
Defense	3.0

important and five being most important). The survey was taken from fourteen people, hobbyist and engineers, to determine the important specific designs needed in the new robot. The survey results were compiled, and Table 1 shows the main categories and lists them in descending order of their importance to the customer. All rankings and weighted values were obtained from the survey results and can be seen in Appendix B.

Maneuverability was the top ranked category which seems logical, as the robot must be able to move easily through the arena while attacking. Offensive and defensive systems tied for second. This was a good way to design the robot. Equal amounts of offense and defense ensures design was well rounded. Offense is key to disabling opponents, and defense is key to keep from being disabled.

Several key strategies are applied when designing a robot to be agile, controls being one of them. These strategies, under the maneuverability and control category, were ranked in order of customer importance in Table 2. The rankings show what general direction the design took. Starting with the time needed to accelerate and decelerate, followed by simple controls.

Table 2-Maneuverability Category

Maneuverability and Control	Rank
Time needed to accelerate or decelerate.	4.0
Simplistic controls	3.0
If one or more drive motors are disabled still has some drivability	3.0
Consistency of power supply throughout the duration of the match	2.0
Turning radius	1.5
User interface is adjustable	1.0
Automatic operations that do not require input from an operator	1.0

CONTROLS OBJECTIVE

The objective for the electronic components was to allow seamless function between each of the other systems. This involved setting up the remote controller so anyone can use it. There needed be a fair chance for any team member to be familiar with the controls and pilot the robot. Having the extra switches on the controller allowed this to be possible.

To avoid any damage that could be caused by over revving, capping the speed at which the motors can spin was handled using the programming in the controller. The batteries needed to have high energy capacity to supply the motors, being essential to providing a fast start up time and delivering stable voltage for the match duration. These functions were necessary to being competitive. Having a slow startup could allow opponents to attack before being up to speed.

Between matches there is a limited amount of time to swap parts and make repairs. It was imperative to be able to make changes smoothly. Identical parts assisted us in having replacements while keeping cost down. The layout for wiring needed to be neatly placed as well. The layout kept the wiring compact so that minimal current was lost from resistance. Connections had to be sturdy to withstand constant impact and inversion, too. A loss of connection would cause the entire system to collapse. If any of the above aspects failed it could have caused the team to be disqualified.

DESIGN

There are many aspects to designing and preparing the power and control systems. These include, but were not limited to, the choice of battery, wiring, remote control, speed controllers and fabrication. In total the system comprised of four motors, four speed controllers, four batteries, two master power switches, one remote control and receiver, a host of wiring, and a lexan board. The schematic can be seen in Appendix H. The function of the noted systems was vital to the operation of the robot, as well as meeting competition rules.

Employing a six channel 2.4 GHz model airplane remote control, the Spektrum DXi6, was approved for use in the competition. It is also the remote control that team member Cory Kissel is familiar with, using one when he flies his model airplanes. For the robot, the advantage was that the remote gave control of both the drive train and the weapon motors. The ability to control the braking and acceleration, and steering of the robot was necessary to making the controls easy to use. It could also control the speed of rotation and direction of the weapon.

What allowed this was the programming within the controller. It can mix the signals on two of the channels so that the right joystick can control two speed controllers simultaneously. This is called elevon mixing, a feature that is normally used when flying a model airplane [6]. For the robot it was controlling the two drive train speed controllers. What happened was when the joystick was moved in the diagonal directions, the throttle (forward/backward) and rudder (left/right) signals, were blended together to produce the robots motion in the particular direction.

For the weapon motors the remote limited the maximum speed. It allowed the greatest efficiency from our motors, running them at their optimal rating, limiting them to being over driven and damaged. This was necessary due to the weapon system being a 1:1 ratio and being limited to the bearing life rating. By limiting the motor speed we could control the revolutions and overheating. On the other hand the drive system is a 7:1 ratio and can be maximum output to take advantage of this.

The IFI Robotics speed controllers are recommended for use by the motor manufacturer for their robust current handling capacity (7). Their function served to transfer the power received from the batteries to the motors, using a signal from the remote control. Using the wirelessly transmitted remote signal, the receiver passed this onto speed controllers to decide the speed and direction of the motors. The polarity determined the direction of the motors. The voltage regulation done within the speed controller and setup using the remote control determined the motor speed. The higher the voltage equates to more speed.

Choosing what would supply the power to our robot was a very important decision. Knowing that there will be enough power to supply the robot for the duration of the match was critical to our success. If power is lost during a match are disqualified. Based on the research of various battery materials our final choice came down to lithium, nickel cadmium, and nickel metal hydride.

The lithium batteries have the best power to weight ratio. They are very fragile material, being very susceptible to exploding. So to use them in the competition they have to be enclosed in a separate compartment and have to be removed from the robot for recharging (4). Making them more of a hassled than was needed.

Nickel cadmium and nickel metal hydride batteries have similar characteristics, the downside to the nickel cadmium that was that they suffer from memory effect and are heavier.

Since weight was a major concern choosing the lighter option was key. Nickel metal hydride batteries handled the high discharging that was faced, while delivering stable voltage until they were near empty. This is also not to mention that they were the least expensive option.

To figure out how many batteries was necessary it had to be known how much current draw there would be. To achieve this, the load profile method was used. The load profile method is based on an estimation of current draw by the motors during five basic actions. These conditions, in order of severity: stall, pushing, accelerating, cruising, and stopped [10]. Estimating the length of time the robot would spend in the stated conditions during the three minute match, and then multiplied by a scaled amperage of each condition based on the maximum stall current gives the current draw in amp-seconds. Since this is not standard when searching for batteries, it was converted into amp-hours (A-hr). The sum equates a draw of 22.8 A-hr and applying a safety factor of 1.5, adjusts the value to 34.2 A-hr. Now battery size choice could be made.

The chosen battery pack was a 24V, 3.3 A-hr, since the motors run at 24 volts. They have an efficiency rating of 90%, giving an actual capacity of 3.0 A-hr per pack. By also choosing to connect the batteries together in parallel, Figure 10, achieved quadruple the current handling capacity, while keeping the desired voltage. Thus, 3.0 A-hr * 4 Batteries = 12 A-hr. To figure out the discharge capacity, the hourly current is linearly reduced by half until our time range is reached. By rule, current capacity inversely increases linearly by double [10]. Thus achieving 60 A-hr of capacity per 3.75 minutes, more than the calculated value from the load profile of 34.2 A-hr per 3 minute match.

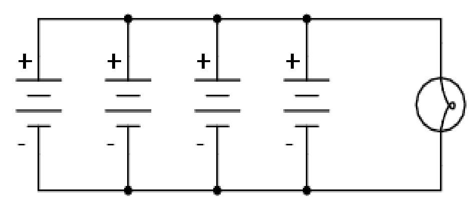

Figure 10

FABRICATION

To make sure that the necessary repairs and diagnosis could be made the electronic components were mounted to a lexan board. The chosen components: the power switches,


Figure 11

speed controllers, and remote receiver. These items were chosen because they could always stay together. In doing so the runs of wire were very short, reducing resistance in the lines. The board and these components then mounted to the bottom plate of armor, keeping it stable within the robot. What this allowed was removal of the components so that the other team members may work on the robot to repair mechanical items, as viewed in Figure 11. Extra care could also be taken of the fragile elements to avoid damage.

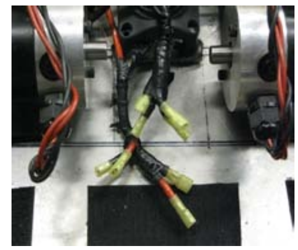

Figure 12

All of the wiring was braided or soldered using 8 and 10 gauge car stereo wire. This worked well giving maximum flexibility working in the confined space. The terminals used spade and ring terminals. The batteries employed insulated male to female connectors. This was substituted over the 2008 Dean's connectors, because they were not a readily off the shelf part. Figure 12 shows how the parallel connection was constructed and how the batteries plugged in.

By making the improvements over the 2008 robot it was much easier to change, repair, and diagnose electronic problems. The wiring was much shorter yielding increased current capacity and less resistance. And the items used could be easily duplicated to have replacements without hassle.

PROJECT MANAGEMENT

TIMELINE

The power and control was designed simultaneously with the other components. Component selections were made prior to the design freeze. This allowed for faster materials ordering. The build schedule was accelerated due to the date of the competition, April 20-24 versus the date of Tech Expo, May 7. Unfortunately the release date of the competition rules, January 26, was such that changes to robot could not be made. Materials were already in the process of being ordered and shipped. This put a disadvantage during the competition, a stronger electronics system could have been developed. There was also a delay in the manufacturing of the other systems, which delayed the installation of the electronics. Table 3 shows the major milestones of the project. The team schedule can be seen in Appendix E.

Table 3-Major Milestones

Major Milestones		
Description	Planned Date	Actual Date
Senior Seminar Report	September 24	September24
Complete Design	November 26	December 12
Design Freeze	November 27	December 13
Ordering Components	January 5	January 12
Electronic Board Assembly	March 16	March 30
Installation of Electrical	March 30	April 10
Testing and Troubleshooting	April 1	April 15
BattleBot Shipment	April 16	April 16
BattleBots Competition	April 20-24	April 20-24
Tech Expo	May 7	May 7

BUDGET

The budget for the project consisted of the items needed for the power and controls, as well as fabrication. The itemized budget for the power and control is represented in Table 4. Due to the struggling economic situation, funding for the project was not received until January. The money was then budgeted to the individual sections of the robot. For the power and control section so save on the cost of materials spare parts were not purchased. Backup components were taken from the 2008 robot. These components, more expensive items included: main batteries, speed controllers, and main battery chargers. The team budget can be seen in Appendix D.

Table 4-Budget List

Component	Quantity	Individual Price	Total
Remote Control	1	$200.00	$200.00
Main Batteries	6	$150.00	$900.00
Speed Controller	4	$180.00	$720.00
Speed Controller Cables	12	$15.00	$180.00
Power Switches	3	$22.00	$66.00
Power Wire	1	$40.00	$40.00
Charger Power Supplies	2	$65.00	$130.00
Receiver Battery	1	$33.00	$33.00
Receiver Battery Charger	1	$35.00	$35.00
Fabrication Supplies		$100.00	$100.00
			$2,404.00

PROOF OF DESIGN

On April 24, 2009 the University of Cincinnati BattleBot Team Cattitude competed in San Francisco, California. The competition featured teams from University of Miami, California Polytechnic State University, Missouri State University, University of California Los Angeles, California State University Long Beach, Bradley University, University of California San Diego, University Puerto Rico Mayaguez, Polytechnics University of Puerto Rico, and University of Wisconsin Stout. The competition was tournament bracket format with double elimination.

In the first match Cattitude competed against Shark Tooth from California State University Long Beach. There were issues with the batteries being self discharged from waiting eight hours to compete. The match went well, doing damage to their weapon. After the match upon inspection, of the electrical components, a loose connection was found. The ring terminal on the power switch was loose. This terminal provides power from the batteries to the drive train. As the match wore on power was intermittent to the drive components. The issue was resolved and was not a factor going forward.

The second bout came against Falcon from University of Wisconsin Stout. This particular team is actually run by a professional battlebot team named Whyachi. They have been competing for over ten years. The robot Falcon has been in existence since 2004, winning multiple competitions. Their experience presented a disadvantage that could not be matched. Cattitude suffered great defeat, being thrown into the air. At which point multiple connections came loose and controls were lost. After the match diagnosis showed that the cables that connect the remote signal receiver and speed controllers came loose. The wires that connect the power switches to the speed controllers using spade terminals came undone also. The loose connections were all repaired and Cattitude moved forward. Falcon went on to win the competition.

The third and final match was against Pharoah from the University of Puerto Rico Mayaguez. At this point in the tournament Pharoah was using back armor that by rule should have been disqualified. The armor was a wedge shape design without an active weapon, which was required to compete. In addition the top plate of armor contained entanglement hooks that trapped Cattitude, making it immobile. The hooks were also banned by rule. Because the governing body turned a blind eye to the cheating Cattitude lacked mobility. Pharoah's entanglement hooks allowed them to carry Cattitude toward the arena hazards. The hooks were eventually damaged by Cattitudes weapon. The judges did not credit us for the damage and followed the persuasion of the audience, which was made up of Pharoah's builders.

Overall the competition was a success. Cattitude received fifth place, not goal but well nonetheless. The unforeseen circumstances hindered performance. All of the connections should use ring terminals rather than spade to keep from coming loose. In hindsight, for future competitions, the electronics system should be beefed up. The motors can handle more voltage than their rated 24V.

This will increase the velocity of the motors providing more energy, allowing them to produce for torque. The weapon could then do more damage, and be less susceptible to braking. The drive would make the robot get up to speed faster. Increasing the voltage can be done by wiring the batteries in series. This would yield a voltage of 48V, double what the robot is currently designed for. Minimal rework would be needed to accomplish such a feat. The batteries on hand could be wired in a series-parallel configuration using the same four batteries. Two batteries and two batteries would be wired in series to achieve the 48V, then those to 48V configurations would be wires in parallel to increase the current. The only items that would need swapped would be the speed controllers and the wiring, because of the increased voltage.

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APPENDIX A

ROBOT BATTERIES

About Batteries
With the advent of portable personal electronics, from cell phones to mp3 players, to laptops and even watches, there has been a massive surge in battery research within the last decade. No longer are your robots limited to bulky low power non-rechargeable batteries, and instead today there is a large assortment to suit your robots' demands.

Ratings
How are batteries rated? With any battery you will see a **voltage** and a **power** rating. Battery voltages can be somewhat complicated. When fully recharged, a battery will often be 15% above its voltage rating. When fully discharged, about 15% below its rating. A fully charged battery will also immediately drop below its rating when driving heavy loads, such as a DC motor. To increase battery **voltage**, wire multiple of them in **series**.

Batteries also cannot supply an infinite current. So expect batteries of different types but equal voltages to have different current outputs. To increase battery **current** output, wire multiple of them in **parallel**. This is why batteries often come in assembled packs of smaller cells. So when using a battery, make sure your circuit handles changes in battery voltage. For the power rating you will see something like 1200mAh. mAh means miliamps per hour. So if it is 1200mAh, that means the battery can supply 1.2 amps for one hour. Or 2.4 amps for 30 minutes. Or .6 amps for two hours. You do the math.

Notes on Parallel Batteries
You must be very careful when wiring batteries into parallel. If you do not follow these following rules, your batteries will do whats called **self discharging**. This is when one battery charges another battery in parallel, resulting in high inefficiency, overheating, and damage.

When you put two batteries together in parallel that do not have equal charges, self discharging occurs. You must make sure that both batteries are the same exact type, and you should only charge and discharge them while connected in parallel. You also should not combine an old battery with a new battery, even if they are the same type, as charge/discharge rates change with age.

Robot Batteries. *Society of Robots.com.* [Online] [Cited: June 24, 2008.]

http://www.societyofrobots.com/batteries.shtml.

APPENDIX B –SURVEY RESULTS

Dear Sir or Madam,

This survey is for a student design team from the University of Cincinnati building a combat robot for the BotsIQ competition in spring of 2009.Thank you for taking the time to answer these questions, the information gathered here will be directly linked to successful selection of components in our robot. Please answer the questions honestly, and keep in mind that this is for educational purpose and not intended to gain an advantage in any competition.

Please rank the following in order of importance on a scale of (1-5)
(1 – Least important, 5-Most important)

- Offence [1 2 3 4 5]
- Defense [1 2 3 4 5]
- Maneuverability and control [1 2 3 4 5]
- Maintenance [1 2 3 4 5]

Offensive Questions (1 – Least important, 5-Most important)

- Time weapon can be ready between uses or at start up. [1 2 3 4 5]
- Destructive capability to opponents [1 2 3 4 5]
- Prevention of stall or binding [1 2 3 4 5]
- Secondary Weapon (back up weapon) [1 2 3 4 5]
- Chance that weapon can cause damage to own robot. [1 2 3 4 5]

Defensive Questions (1 – Least important, 5-Most important)

- Armors ability to withstand or redirect blows [1 2 3 4 5]
- Robot is functional even inverted (flipped upside down) [1 2 3 4 5]
- Weight of frame [1 2 3 4 5]
- Weight of armor [1 2 3 4 5]
- Frames ability to absorb shock [1 2 3 4 5]

Controls and maneuverability Questions (1 – Least important, 5-Most important)

- User interface is adjustable [1 2 3 4 5]
- Simplistic controls [1 2 3 4 5]
- Turning radius [1 2 3 4 5]
- Time needed to accelerate or decelerate. [1 2 3 4 5]
- Redundancy of power supply systems. [1 2 3 4 5]
- If one or more drive motors are disabled still has some drivability [1 2 3 4 5]
- Consistency of power supple throughout the duration of the match [1 2 3 4 5]
- Automatic operations that do not require input from an operator [1 2 3 4 5]

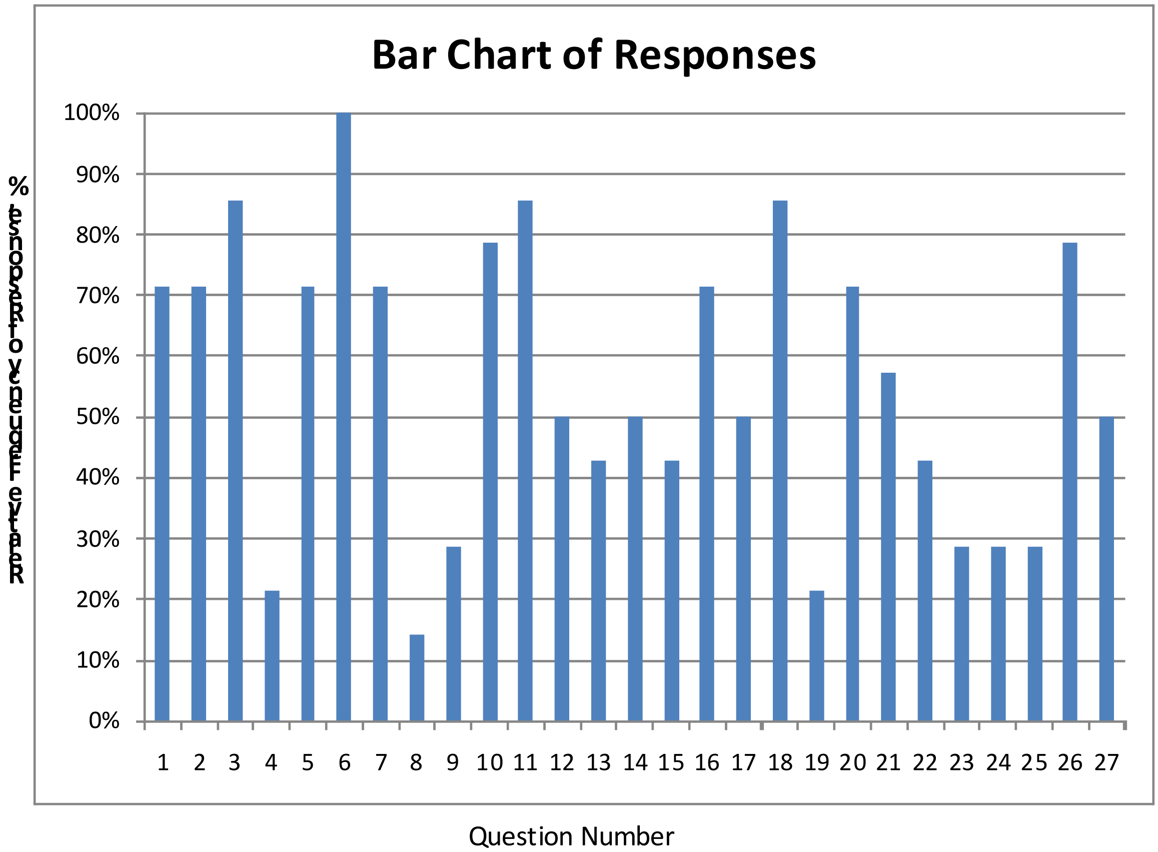
Repairs and Maintenance Questions (1 – Least important, 5-Most important)

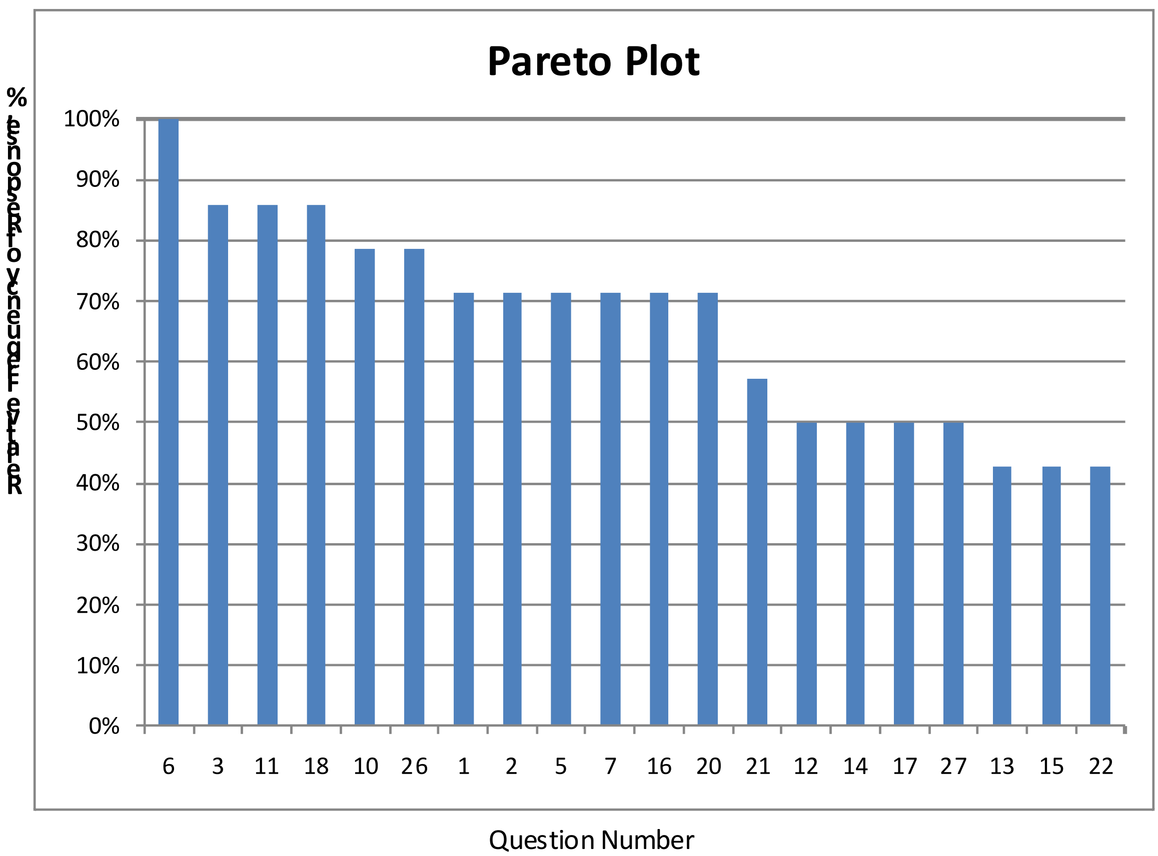
- Modular frame [1 2 3 4 5]
- Modular armor [1 2 3 4 5]
- Weapon is modular [1 2 3 4 5]
- Easy accessibility too components [1 2 3 4 5]
- Time taken to completely replace a component under 20 minuets [1 2 3 4 5]

Number of Questionairs 14

Number of surveys

Question #	**Systems**											%*	Responses with 4's & 5's Relative Frequency	Category Rank
3	Maneuverability and control	1	0	2	0	3	2	4	5	5	7	85.71%	0.857142857	1
1	Offense	1	0	2	0	3	4	4	4	5	6	71.43%	0.714285714	2
2	Defense	1	1	2	0	3	3	4	5	5	5	71.43%	0.714285714	2
	Offense													
6	Destructive capability to opponents	1	0	2	0	3	0	4	4	5	10	100.00%	1	1
5	Time weapon can be ready between uses or at start up.	1	1	2	1	3	2	4	7	5	3	71.43%	0.714285714	2
7	Prevention of stall or binding	1	0	2	1	3	3	4	5	5	5	71.43%	0.714285714	2
	Defense													
11	Robot is functional even inverted (flipped upside down)	1	0	2	1	3	1	4	7	5	5	85.71%	0.857142857	1
10	Armors ability to withstand or redirect blows	1	0	2	0	3	3	4	4	5	7	78.57%	0.785714286	2
12	Weight of frame	1	2	2	2	3	3	4	5	5	2	50.00%	0.5	3
14	Frames ability to absorb shock	1	1	2	0	3	6	4	3	5	4	50.00%	0.5	3
13	Weight of armor	1	1	2	4	3	3	4	2	5	4	42.86%	0.428571429	4
	Maneuverability and Control													
18	**Time needed to accelerate or decelerate.**	1	0	2	2	3	0	4	8	5	4	85.71%	0.857142857	1
16	**Simplistic controls**	1	0	2	2	3	2	4	4	5	6	71.43%	0.714285714	2
20	**If one or more drive motors are disabled still has some drivability**	1	1	2	0	3	3	4	7	5	3	71.43%	0.714285714	2
21	**Consistency of power supply throughout the duration of the match**	1	1	2	0	3	5	4	4	5	4	57.14%	0.571428571	3
17	**Turning radius**	1	1	2	0	3	6	4	2	5	5	50.00%	0.5	4
15	**User interface is adjustable**	1	1	2	4	3	3	4	6	5	0	42.86%	0.428571429	5
22	**Automatic operations that do not require input from an operator**	1	3	2	2	3	3	4	6	5	0	42.86%	0.428571429	5
	Repairs and Maintenance													
26	Easy accessibility to components	1	1	2	1	3	1	4	4	5	7	78.57%	0.785714286	1
27	Time taken to completely replace a component under 20 minutes	1	0	2	3	3	4	4	4	5	3	50.00%	0.5	2


Bar Chart of Responses
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
Question Number


Pareto Plot
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
6 3 11 18 10 26 1 2 5 7 16 20 21 12 14 17 27 13 15 22
Question Number

Product Design Specifications(PDS)

Making the improvements necessary to maintain competitiveness in the 2009's BotsIQ tournament.

Robotic combat matches are won by-

A • Disabling opponent
B • Not being disablebled
or
C • Scoring points by damaging opponent
D • Scoring points by aggressive driving
E • Scoring points stratagy(exploting oponites weakness, or using hazards to own advantage)
F • Preventing opponet from scoring by damaging own robot.

Need- *Constraint that absolutely must be meet.*
Want-*A characteristic that is desirable but must not come at the cost of a "Need".*

Q#	Needs	Criteria match
1	Offence	A,C
2	Defense	B,F
3	Maneuverability and control	D
6	Destructive capability to opponents	A,C
10	Armors ability to withstand or redirect blows	B,F,E
11	Robot is functional even inverted (flipped upside down)	B
16	Simplistic controls	D,E
19	If one or more drive motors are disabled still has some drivability	A

Q#	Wants
4	Maintenance
5	Time weapon can be ready between uses or at start up.
7	Prevention of stall or binding
8	Secondary Weapon (back up weapon)
9	Chance that weapon can cause damage to own robot.
12	Weight of frame
13	Weight of armor
14	Frames ability to absorb shock
15	User interface is adjustable
16	Turning radius
17	Time needed to accelerate or decelerate.
18	Redundancy of power supply systems.
20	Consistency of power supply throughout the duration of the match
21	Automatic operations that do not require input from an operator
22	Modular frame
23	Modular armor
24	Weapon is modular
25	Easy accessibility too components
26	Time taken to completely replace a component under 20 minutes

APPENDIX C

From Survey
Calculated

Relationship Matrix
1 = Weak
3= Moderate
9 = Strong

Q#	Systems	1 Material properties	2 Center of gravity	3 Mass	4 Drive system	5 Design	6 Torque	7 Traction	8 Hardware selection	9 Number of independent systems	10 Acceleration	Customer Importance	Product/Service Current	Product/Service Future	Improvement Ratio	Sales Point	Modified Improvement Ratio	Relative Weight
3	Maneuverability and control	1	3	1	9	9	9	9			3	4.0	3.5	4.5	1.3	1.5	7.7	0.09
1	Offense	9		3		9			3		9	3.0	4.0	4.5	1.1	1.5	5.1	0.06
2	Defense	9	1	3		9		1				3.0	3.5	4.0	1.1	1	3.4	0.04
	Offense																	
6	Destructive capability to opponents	9		1		9						5.0	4.5	5.0	1.1	1.5	8.3	0.1
5	Time weapon can be ready between uses or at start up.		1		3		9				9	3.0	4.5	4.5	1	1	3	0.04
7	Prevention of stall or binding					9			1			3.0	3.0	3.5	1.2	1	3.5	0.04
	Defense																	
11	Robot is functional even inverted (flipped upside down)		1		9	9						4.0	5.0	5.0	1	1.5	6	0.07
10	Armors ability to withstand or redirect blows	9				9						3.5	4.0	4.0	1	1.5	5.3	0.06
12	Weight of frame	3				3						1.5	2.5	4.0	1.6	1.5	3.6	0.04
14	Frames ability to absorb shock	3	3			9						1.5	2.0	2.5	1.3	1.5	2.8	0.03
13	Weight of armor	9				1						1.0	4.5	4.5	1	1.5	1.5	0.02
	Maneuverability and control																	
18	**Time needed to accelerate or decelerate.**		1	3	3	9	9	9			9	4.0	2.5	3.5	1.4	1.5	8.4	0.1
16	**Simplistic controls**				1				9			3.0	3.5	3.5	1	1	3	0.04
20	**If one or more drive motors are disabled still has some drivability**		1		1	9		1	3	9		3.0	2.5	4.0	1.6	1.5	7.2	0.09
21	**Consistency of power supply throughout the duration of the match**					3			9	3		2.0	3.0	3.5	1.2	1	2.3	0.03
17	**Turning radius**		3	1	3	9		9			1	1.5	3.0	4.0	1.3	1.5	3	0.04
15	**User interface is adjustable**								3			1.0	2.5	2.5	1	1	1	0.01
22	**Automatic operations that do not require input from an operator**					3			1			1.0	1.0	1.5	1.5	1.5	2.3	0.03
	Repairs and Maintenance																	
26	Easy accessibility to components					9						3.5	3.0	3.5	1.2	1	4.1	0.05
27	Time taken to completely replace a component under 20 minuets					9			9	9		1.5	3.0	3.5	1.2	1	1.8	0.02
	Absolute Importance	2.87	0.82	0.84	2.12	7.51	2.07	2.19	1.31	1.05	2.09	22.89					83	1
	Relative Importance	###	###	###	###	###	###	###	###	###	###	1						

APPENDIX D

Part Num	Part	Sizes	Quantity	Amount	Total
Frame And Armor					
	Aluminum 7075				
9055k466	Outside	6x0.5x4	2	260.22	520.44
9055k333	Gear Mount	36x2x4	1	327.77	327.77
9055k213	Weapon Side	36x1x4	1	204.59	204.59
9055k423	Divider	36x0.25x4	1	91.81	91.81
	Aluminum 6061				
8975k436		12x0.5x4	2	17.94	35.88
	Armor				3999.00
60355k35	Drive Bearings	0.375	8	5.41	43.28
			Sub Total		5222.77
Drive Train					
6261K151	Chain		1.00	27.4	27.40
6280K411	Sprocket		6.00	12.13	72.78
6261K191	Connecting link		4.00	0.7	2.80
8974K183	Axle material		1.00	28.91	28.91
TW-TWM3M	Gearbox		2	450.00	900.00
S28-150	Magmotor		2	299.00	598.00
			Sub Total		1629.89
Weapon					
6204k181	Pulley		4	14.67	58.68
6054K101	V-Belts		4	7.05	28.20
	W-Pulley	4x7	1	70.35	
2782T890	Weapon Bearing	1.25 id	2	34.52	69.04
S28-150	Magmotor		2	299.00	598.00
	8620 W-material		1	151.18	151.18
			Sub Total		905.10
Power and Controls					
RC-SPM6000BR	Remote Control Receiver		1	49.99	49.99
IFI-V885	Speed Controller w/ 24v fans		4	179.00	716.00
BPK-3300N-24	Batteries (8 gauge wiring, heat rings)		4	169.88	679.52
IFIW-SIG36	PWM Signal Driver Cables		4	15.00	60.00
0-SWHELLA2	Power Switches		3	21.99	65.97
304-1070R	10awg Red	20ft	1	0.83	0.83

304-1070	4awg Black	20ft	1	0.92	0.92
			Sub Total		1573.23
Competition					
Travel Cost (Flying)					3,628
Total Manufacturing					1000
				Grand Total	13,958.99

APPENDIX E

Quarter	Summer 2008																									
Week (Fiscal)	25		26		27		28		29		30		31		32		33		34		35		36		37	
Date	6/15	6/21	6/22	6/28	6/29	7/5	7/6	7/12	7/13	7/19	7/20	7/26	7/27	8/2	8/3	8/9	8/10	8/16	8/17	8/23	8/24	8/30	8/31	9/6	9/7	9/13
	Task																									
Senior Seminar Schedule																										
Problem Statement	20-Jun																									
Research and documnatation			25-Jun																							
List of Features					2-Jul																					
Sponsor Ship letter											23-Jul															
Send out Letter															4-Aug											
Survey											23-Jul															
Send out Letter															6-Aug											
Budget																	13-Aug									
Schedule																			20-Aug							
Rough Draft/Appednices																							3-Sep			

Quarter	Autumn 2008																									
Week (Fiscal)	38		39		40		41		42		43		44		45		46		47		48		49		50	
Date	9/14	9/20	9/21	9/27	9/28	10/4	10/5	10/11	10/12	10/18	10/19	10/25	10/26	11/1	11/2	11/8	11/9	11/15	11/16	11/22	11/23	11/29	11/30	12/6	12/7	12/13
	Task																									
Holidays/Exams/S&E Quarter			Qtr Begins														11-Nov				27-Nov				Exams	
Design Schedule																										
Seminar Final Report			24-Sep																							
Weighted objective method					25-Sep																					
Prof of design statement									15-Oct																	
Prof of design agreement											20-Oct															
Design completed																					26-Nov				12-Dec	
Design Freeze																					27-Nov				13-Dec	

Quarter	Winter 2009																							
Week (Fiscal)	1		2		3		4		5		6		7		8		9		10		11		12	
Date	1/4	1/10	1/11	1/17	1/18	1/24	1/25	1/31	2/1	2/7	2/8	2/14	2/15	2/21	2/22	2/28	3/1	3/7	3/8	3/14	3/15	3/21	3/22	3/28
	Task																							
Holidays/Exams/S&E Quarter	Qtr. Begins				19-Jan																Exams		Spring Break	
Design Schedule																								
Seminar Final Report																								
Weighted objective method																								
Prof of design statement																								
Prof of design agreement																								
Design completed																								
Design Freeze																								
Weapon																								
Order Material	5-Jan				19-Jan																			
Manufacturing of Weapon			12-Jan				26-Jan																	
Finish weapon																	6-Mar		13-Mar					
Drive Train																								
Order Material	5-Jan								2-Feb															
Manufacturing of Drive Train			10-Jan								9-Feb								13-Mar					
Rough assembly					18-Jan														13-Mar					
Frame/Armor																								
Order Material	5-Jan		10-Jan																					
Manufacturing of Frame	5-Jan		10-Jan																					
Rough cut Pieces					18-Jan																			
Finish Frame																	6-Mar		13-Mar					
Manufacturing of Armor					23-Jan																			
Finish Armor																			13-Mar					
Power/Controls																								
Order Material	5-Jan								2-Feb															
Assembly of components			10-Jan																					
Test Assembly					19-Jan																			
Winter Qrt Ending Schedule																								
Oral Design Presentation																								
Design Reports																					22-Mar			

Quarter	Spring 2009																									
Week (Fiscal)	12		13		14		15		16		17		18		19		20		21		22		23		24	
Date	3/22	3/28	3/29	4/4	4/5	4/11	4/12	4/18	4/19	4/25	4/26	5/2	5/3	5/9	5/10	5/16	5/17	5/23	5/24	5/30	5/31	6/6	6/7	6/13	6/14	6/20
	Task																									
Holidays/Exams/S&E Quarter	Spring Break		Qtr Begins																							
Group Ending Schedule																										
Assembly of robot	27-Mar		30-Mar																							
Installation of Components	27-Mar		30-Mar																							
Test/Toubleshoot/Practice	30-Mar		1-Apr																							
Fly to competition							18-Apr																			
Competition									20-Apr																	
Fly Home											27-Apr															
Tech Expo display													6-May													
Tech Expo													7-May													
Final Oral Presentations																			28-May							
Final Report Due																					5-Jun					
Graduation																							13-Jun			

APPENDIX F

Load Profile Method

Conditions During a Match

	Current (Scaled to Maximum Current)
Stall	285 A
Pushing	285 A * 80% = 228 A
Accelerating	285 A * 40% = 114 A
Cruising	285 A * 15% = 43 A
Stopped	0 A

Drivetrain Condition Calculation

	Current		Total		Total
Stall	285 A * 10 s	=	2850 A-sec	->	0.8 A-hr
Pushing	228 A * 35 s	=	7980 A-sec	->	2.2 A-hr
Accelerating	114 A * 30 s	=	3420 A-sec	->	1.0 A-hr
Cruising	43 A * 90 s	=	3870 A-sec	->	1.1 A-hr
Stopped	0 A * 15s	=	0 A-sec	->	0 A-hr

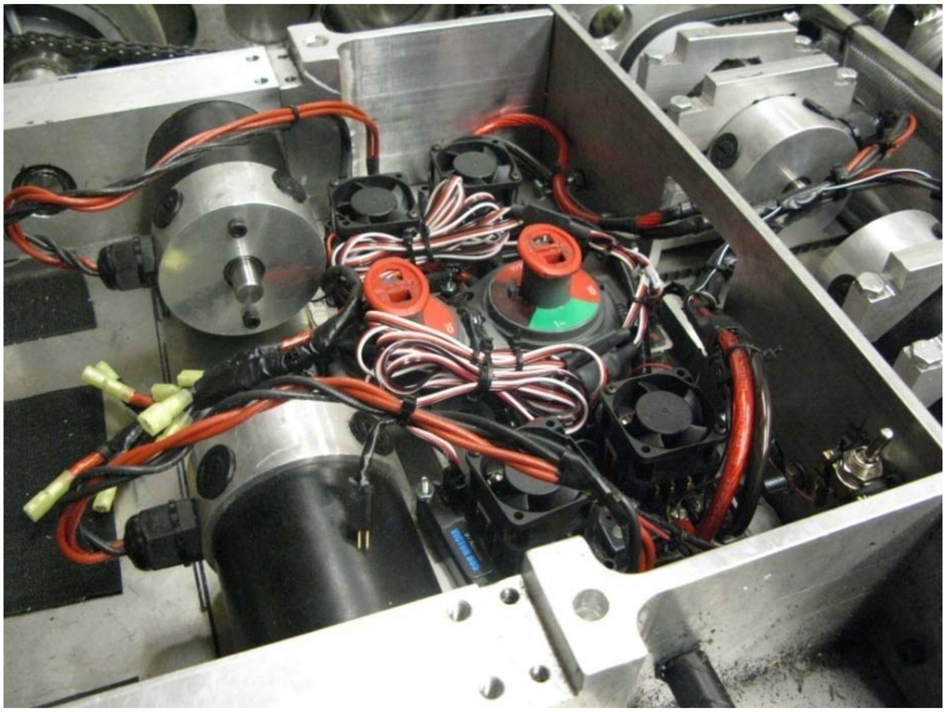
5.1 A-hr * 2 motors = 10.2 A-hr

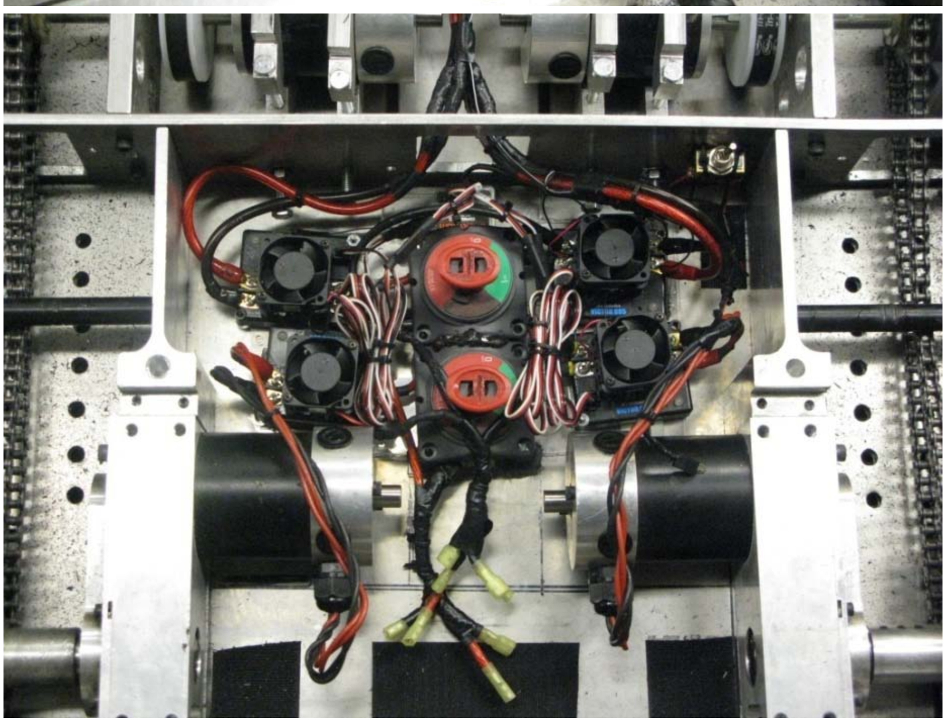
Weapon Condition Calculation

	Current		Total		Total
Stall	285 A * 10 s	=	2850 A-sec	->	0.8 A-hr
Pushing	228 A * 50 s	=	11400 A-sec	->	3.2 A-hr
Accelerating	114 A * 50 s	=	5700 A-sec	->	1.6 A-hr
Cruising	43 A * 60 s	=	2580 A-sec	->	0.7 A-hr
Stopped	0 A * 10s	=	0 A-sec	->	0 A-hr

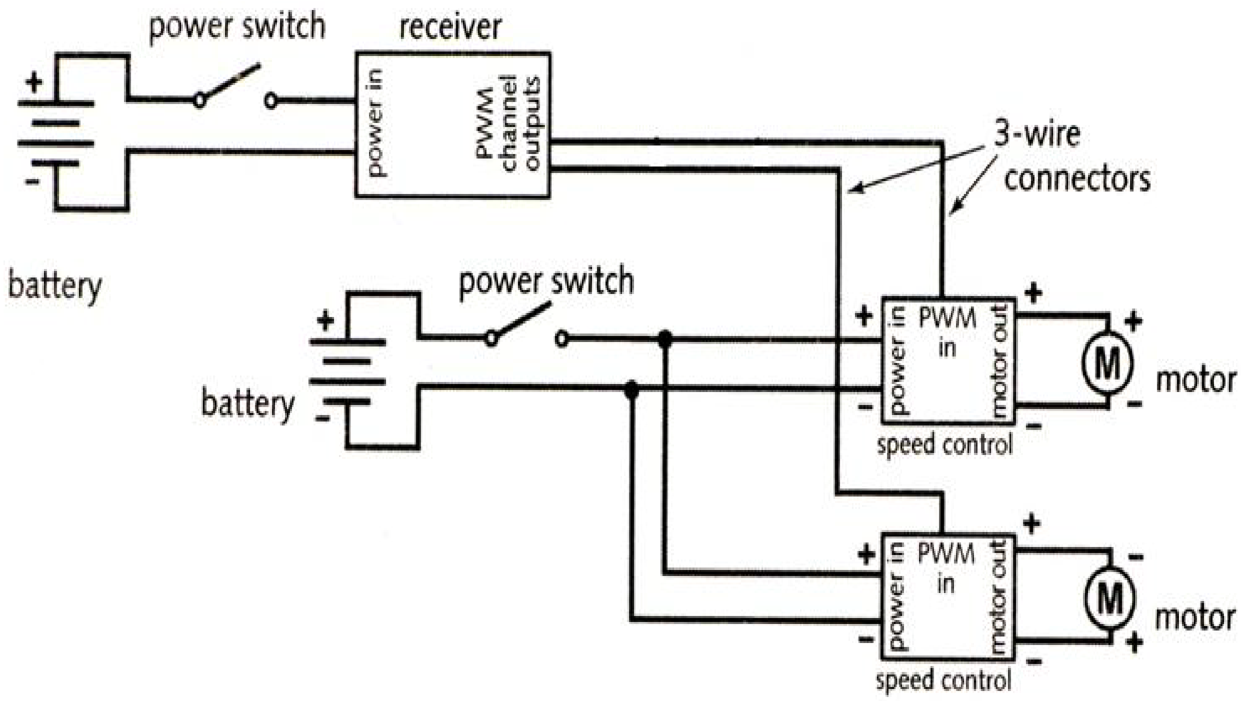
6.3 A-hr * 2 motors = 12.6 A-hr

APPENDIX G





APPENDIX H


power switch
receiver
power in
PWM
channel
outputs
+
-
battery
3-wire
connectors
power switch
battery
+
-
+
-
power in
PWM
in
motor out
+
-
+
-
M
motor
speed control
+
-
power in
PWM
in
motor out
+
-
-
+
M
motor
speed control