ME dept. Sumo Bot Competition

Final Report

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2016-17

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1 BACKGROUND

For this project, Northern Arizona University tasked five engineering teams with designing and manufacturing a 3kg autonomous, 3kg remote controlled, and 25g autonomous sumo robot. Following the same rules as a tradition sumo wrestling match, the goal of the competition was to construct a robot capable of pushing the opponent outside of the ring, or doyho. As an additional challenge, a remote-controlled combat robot was to be constructed. However, at the start of the Spring semester, the 25g sumo robot component was cancelled by the sponsors. Section 1 of this report will give an outline of what the competitions were, who was competing, the relevance of the project, and the sponsor's exact description.

1.1 Introduction

Northern Arizona University held an autonomous and remote controlled sumo bot robotics competition between five teams in May of 2017. There were four teams of mechanical engineers and one team of electrical engineers. Sumo bot competition rules are similar to traditional sumo wrestling matches between human opponents. Two robots enter an arena with the goal of pushing the opposing bot out of the ring. A match consists of three rounds and a round is won by earning a Yuhkoh point. Yuhkoh points are earned when the opponent's bot touches the outside of the ring. Attempts to damage, flip, or jam the opponent's electrical components are prohibited. The official game rules follow those specified in the Unified Sumo Robot Rules. Each team competes in three unique competitions:

- Mega Sumo – Autonomous Class: The mega sumo autonomous class consists of robots that weigh no more than 3kg and fit within a 20cm x 20cm area. Robots can be controlled by any method as long as it is fully contained inside the robot and receives no additional signals or directions from an outside source.
- Mega Sumo – R/C Class: The mega sumo R/C class robots use the same dimensions as the mega sumo autonomous class. However, R/C class robots must be remotely controlled by a human operator. Controllers must be in accordance to FCC regulations and are regulated by tournament officials.
- Nano Sumo Class: Nano sumo class robots must fit within a 2.5cm x 2.5cm x 2.5cm space and weigh no more than 25g. Nano sumo class robots are autonomous and follow the same control restrictions and guidelines as the mega sumo autonomous class competition.

The competition sponsor, Northern Arizona University's Mechanical Engineering department, chose to hold a sumo robot competition as a learning exercise to give students experience in robotics. The competition was also an opportunity for the competing students to showcase their design and problem solving capabilities. Industries such as oil, gas, and environmental maintenance are trending toward robotic forms of maintenance, repairs, and inspections in regions with difficult or dangerous conditions [2]. A sumo bot competition is an effective team project to gain experience in integrating mechanical designs and components with electrical circuitry as well as how to develop algorithms to efficiently complete a task.

Additionally, the team chose to construct a combat robot. Combat rules are less structured than sumo competitions. Almost all weapon systems, except nets/tethers, invisible weapons (RF jamming, EMF fields, etc.), water, and electrical Tasers were allowed [1].

1.2 Project Description

The unified sumo robot rules were created and are maintained by the RoboGames international foundation. The competition is carefully regulated to ensure a fair and safe competition. The unified sumo robot rules include weight, dimensional, and control specifications for each event along with exact rules for how to conduct the event. Following is the original project description provided by the sponsor:

> "Two robots compete in a head-to-head match following the basic system of traditional human sumo matches. Robots are allowed no weapons, and are not allowed to flip each other. The sole purpose is a pushing match between the two robots to force the other from the arena. Multiple weight classes and control systems are allowed (autonomous compete against autonomous and R/C against R/C - they are separate classes and do not compete against each other) [1]."

Robogames combat rules were obtained from the same location as the unified sumo robot rules. Combat rules are based on the Robot Fighting League Standard Ruleset [1]. Following is the original project description provided by the sponsor:

> "Two robots compete in a head-to-head match following the basics of boxing. Robots are mostly tele operated but autonomous control is allowed. Like boxing, the robots are given three full minutes for a round, in which either one of the robots is knocked out or the match time runs out, and 3 judges decide the winner. Most anything goes in terms of weapons, excluding water and electrical tasers [1]."

2 REQUIREMENTS

Design requirements described in the unified sumo robot rules specified size, weight, and control regulations. Using these design requirements, customer and engineering requirements were generated and organized into a House of Quality (HoQ). Customer requirements are weighted by the team to determine their importance during the design process. In addition, testing procedures and design links were developed to evaluate the designs and test how well the engineering requirements are met.

2.1 Customer Requirements (CRs)

The unified sumo robot rules specified size and weight requirements, how to carry a match, and restrictions on weapons, jamming devices, sticky substances, and combustibles. Using these rules and requirements, the team created nine customer requirements and weighted each on a scale of one to five, five being most important, shown in Table 2.1.

The team generated the customer requirements by reading through the unified sumo robot rules. The needs generated this way included: stay under budget, ease of operation, maximize weight for class, and identifying team mark. The rest of the requirements came from a brainstorming session held by the team. Weightings were generated for each need by the team members as well. Each member rated the need from one to five and those values were averaged. The list of requirements generated through brainstorming includes the remaining needs in Table 2.1.

The most noteworthy needs included the defensive capabilities, ease of operation, and adaptive algorithm. A defensive strategy is superior to an offensive strategy because a robot capable of winning and tying will have a better overall performance than a robot that wins and loses. Next, ease of operation was deemed important because each team member must be able to control a robot in a competition. This was only ranked at 3.3, despite its importance, because the robot must only be intuitive enough that everyone can drive it. It did not need to be so easy that it required no practice to effectively maneuver. Lastly, an adaptive algorithm would give a sumo robot a major advantage in the autonomous class competition. This was an extremely difficult thing to create and required much testing and reworking from the programmers. This was achieved by starting on the algorithm early, before the robot was fully designed.

Table 2.1: Customer requirements and weightings created in accordance with unified sumo robot rules

Customer Requirements	Weight (1-5)	Justification
Stay Under Budget	5	The team must stay under the $1,000 budget. Additional funding must be done by team.
Maneuverability	2.3	A more powerful robot is more important than a robot that can turn tightly.
Defensive Capabilities	4	A defensive bot will most likely either tie or win, which is better than losing.
Offensive Capabilities	2.6	An offensive bot will most likely either win or lose, giving it a lower weight.
Speed	2	A fast robot will not overpower a high torque robot.
Durability	4	If a piece of the bot weighing more than 5 grams is detached, it is grounds for instant disqualification.
Ease of Operation	3.3	All team members must be able to pilot all bots.
Maximize Weight for Class	4	Maximization of weight maximizes the frictional force.
Identifying Team Mark	5	All robots are required to have an identifying team mark.
Adaptive Algorithm	3	Allows the robot to adjust and optimize strategy, but is difficult to achieve.

2.2 Engineering Requirements (ERs)

Initial engineering requirements were developed based off the provided official rules for each competition. These types of requirements limit the sizes and strategies that are allowed to be used for the robots. Additional engineering requirements were created based off what characteristics a robot must possess in order to compete successfully in all the competitions.

The most noteworthy engineering requirements are the cost, weight, control capabilities, and motor strength. Costs and weight were the most important. If either of these are broken, the team would be unable to compete. For sumo, coming in underweight was as big a concern as being overweight. This is because weight is directly proportional to pushing force. Weighing less than the opponent, even by a small amount, could potentially mean losing a match. For combat, a low weight for certain designs, such as a wedge, spear, or spinner, would also be disadvantageous. Cost was also very important because, if a design was over budget, it will be impossible to construct.

The control capability and motor strength are the other most important requirements to note. The control capabilities were competition requirements, meaning they were required to compete and were therefore mandatory to meet. Motor strength was equally important because, if weak motors were used, the bot would be unable to win any matches. A table with all engineering requirements and rationale for their implementation can be found in Appendix A.

2.3 Testing Procedure (TPs)

To make sure each design fulfills the engineering requirements, testing procedures were created. To evaluate a designs ability to complete an ER, each design was put through all tests relevant to its competition. Below are the testing procedures that correspond to the House of Quality.

1.) Visual Inspections Test: Each member will individually visually inspect each bot to verify they meet specifications for each competition, including but not limited to: length, width, team logo, RC or autonomous where applicable, and weight.

2.) Component Cost Test: The budget liaison will verify the team stays on budget for each respected bot and any additional funding will be added to overall budget and the liaison will adjust respected budgets with consent of the entire team. This meant the cost does not exceed $100 for the Nanobot, the cost does not exceed $450 for the Mega Sumobot both autonomous and RC, and the cost did not exceed $450 for the combat bot.

3.) Dimensions Test: A simple metric ruler measured length, width, and height of each bot to verify it satisfies each respected competition limit. This means no larger than 20 cm x 20 cm length and width for both Mega Sumobots and no larger than 2.5 cm x 2.5 cm x 2.5 cm for the Nanobot.

4.) Weight Test: A simple scale set to metric weight measured the weight of each bot to verify it satisfied each respected competition limit. This means no more than 3,000 grams for the Mega Sumobot and no more than 25 grams for the Nanobot.

5.) Transfer Rate Test: Careful mathematics ensured the transfer rate was correct, but visual inspection is required to ensure that for every 6 rotations of the motor, the wheel is rotating only once, or less.

6.) Controls Test: Each bot was preset to be either autonomous function after on/off actuation, or remote control function. This means establishing autonomous function on the bot, or setting up a remote-control plug-in that allows a remote control to be used.

7.) Material Strength Test: Three types of materials, plastic polycarbonate, Aluminum 6061 and Titanium class 2 underwent physical strength testing through simple point-impact punching with a hammer and blunt punching with the relative area of a similar bot, then visual inspection determined if the material was suitable. If the material yielded, that indicated it will not suffice for competition, so it required modified through stacking, or disregarded as a potential material.

8.) Sensor Test: A mockup track with the same black and white lines helped test autonomous function so the bot did not drive itself out of the arena, and could respond fast enough to adjust its motion, so it again did not drive itself out of the arena.

2.4 Design Links (DLs)

To further evaluate how well each design fulfilled the engineering requirements, design links were also created. Each link corresponded to an engineering requirement and performance is shown in the House of Qualities. Below are the design links that correspond to the House of Qualities.

1.) Cost Link: The cost was established through the rules and regulations of the school and the team could not exceed the total budget of $1,500 for all designs. Any other money spent would have to be covered at the team's expense.

2.) Weight Link: The weight was established through the rules and regulations of the school and any weight above three kilograms or 25 grams for mega sumo and nano sumo, respectively, accounted for instant disqualification. However, the team wanted to maximize this weight.

3.) Height Link: The height had no limit for mega sumo, but the team wanted this below 20 centimeters, so the bot did not become top heavy. The nano sumo did have a specified height limit, which had to be equal to or less than 2.5 centimeters.

4.) Width Link: The width was established through the rules and regulations of the school and could not exceed 20 centimeters. The team wanted the largest frontal surface area to "ram" the opponent's bot and so the sensors can easily track their bot.

5.) Autonomous Function Link: The autonomous function was established through the rules and regulations of the school. The competition required the team to construct a mega sumo and nano sumo bot with autonomous function.

6.) RC Link: The remote controlled function was established through the rules and regulations of the school. The competition required the team to construct a mega sumo and combat bot with remote controlled function.

7.) Friction Link: The coefficient of friction corresponded to the weight, so maximization of the weight would assist in the overall frictional force. However, the tires had to conduct solid friction with the competition surface to utilize this maximization of weight.

8.) Turning Radius Link: The radius of turning had to be minimal due to the relatively small ring size. The most optimal design was a zero point turning radius, similar to tank treads, but any radius under three centimeters was sufficient.

9.) Material Strength Link: The material had to show enough strength to not bend or break under contact force, but not sacrifice over 70% of total allotted weight to solely the body armor.

10.) Transfer Rate Link: The transfer rate of the motor to the wheels had t be greater than 6 to 1, because this optimizes motor use. A transfer rate slower than this simply underutilizes the power the motor can put out.

11.) Logo Link: The team logo was established through the rules and regulations of the school and the team had to put the logo in a clear and easy-to-see location on all bots.

2.5 House of Quality (HoQ)

The House of Quality (HoQ), shown in Appendix B, compared the customer requirements to team generated engineering requirements (ER's) and then ranked the ER's accordingly based on the team's idea of importance. The absolute technical importance (ATI) was based on the ER's and was the sum of engineering requirements (Scale of importance: 1-low 3-medium 9-high) multiplied by customer requirement weights. The ATI's were ranked based in order from high to low called the relative technical importance (RTI). The first three RTI's in order are material, frontal area, and maximizing the coefficient of friction. Interestingly, the engineering requirements that are required such as a team logo or cost ranked the lowest. The team then established targets for each ER to "aim" for with tolerances either greater or less than said targets. Finally, the team established testing procedures to measure each ER and design links to detail each ER.

3 EXISTING DESIGNS

This chapter contains the design research conducted prior to concept selection. Initial research began by analyzing existing robot designs that fulfill the customer requirements generated in Chapter 2. Three systems are presented. Additional research into subsystem designs was conducted as well. Three existing designs for three subsystems are presented.

3.1 Design Research

To begin research into robot designs, web based research was conducted using a combination of the Northern Arizona University library database, Google Scholar, and manufacturer websites. Information found on system and subsystem level designs was collected to influence design selection.

For system level designs, full scale designs were looked at. Even though the designs researched were not all sumo bots, the information found helped determine general robotics designs such as the different types of motors used, various locomotion techniques (wheeled, treaded, bipod, etc.), and general use of sensors. Subsystem level designs were all individual internal components. This allows the team to start learning the quality, price, and availability of different components needed for construction. The information gathered can be found in the sections below.

3.2 System Level

Initial research started with investigating existing designs. The team began researching system level designs by exploring existing robot designs by professional engineering and robotics companies. Boston Dynamic's BigDog was a robot researched. BigDog is a four-legged robot which is known for its stability while walking through a variety of terrains. The force sensors BigDog uses are the most applicable feature that translated to the design of autonomous sumo bots. Our team's sumo bots must sustain stability in the arena while being pushed which makes BigDog a relevant research topic. Additional companies were researched for their achievements in robotics. ASIMO is an autonomous robot created by Honda which has exceptional detection and obstacle avoidance capabilities. ASIMO was determined to be the next most useful robot to analyze because of its control algorithm. Research continued by utilizing Northern Arizona University's library database, a collection of academic journals. Upon searching through the database, an academic article which outlines the creation process of an autonomous sumo bot was found.

3.2.1 Existing Design #1: Boston Dynamics BigDog

The first design the team looked at was BigDog, created by Boston Dynamics. BigDog is a quadruped robot, designed for rough-terrain by capturing, "the mobility, autonomy, and speed of living creatures" [3]. An image of BigDog with key features highlighted is in Figure 3.1.

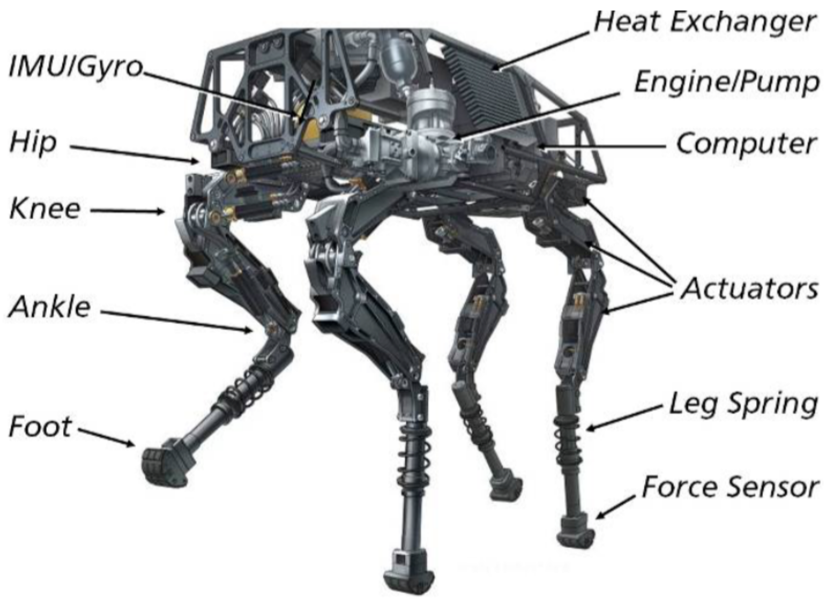


Figure 3.1: BigDog illustration with key features labeled [3].

Even though BigDog is not a sumo robot, it still related to the customer requirements. Both offensive and defensive capabilities require a robot be able to accurately and quickly sense its surroundings. Using a multitude of sensors (approximately 50), BigDog achieves locomotion and stability on rough terrain [3]. Joint sensors measure motion and force while inertial sensors measure the acceleration and position of the robot [3]. The onboard computer uses the sensors' data to coordinate behavior and provide support. In a sumo bot competition, both joint and inertial sensors give the robot the ability to adapt based on how a match is playing out. First, joint sensors could be used to determine contact with the opponent. One use for this could be an algorithm that determines the motors' torque-to-speed ratio based on contact with an opponent. Second, inertial sensors would allow the robot to know if it is successfully pushing or being pushed, sensing the true direction of motion. BigDog's sensing capabilities were a big influence on the final sumo robot design. However, Sensors were only valuable if a robot's algorithm takes advantage of the data collected.

3.2.2 Existing Design #2: Honda's ASIMO

The quality of a robot's control system algorithm determines how well it can achieve its assigned task. In a competitive environment, such as a sumo competition, quickly interpreting sensor data and reacting is paramount. Humanoid or bipedal robots require fast reaction times to prevent falling. Honda's ASIMO is an autonomous humanoid robot that is capable of walking and interacting with its surroundings. An image of ASIMO is shown in Figure 3.2.

Figure 3.2: Illustration of ASIMO Honda robot [4].

Control systems for biped robots are more complex because they fall more easily than other types of robots. Biped robots require dynamic balancing ability; one method to achieve this is passive dynamic walking [5]. Although a biped robot was not the final sumo robot design, the structure of a passive dynamic walking algorithm gave the team an idea of how a control system algorithm is laid out.

A passive dynamic walking algorithm uses dynamic equations to find the physical state of the robot [5]. The system can balance a robot by converting kinematics to a control algorithm, then to an inverse kinematic motion. A visual representation of the process can be seen in Figure 3.3. The algorithm for a sumo robot, although different from a biped robot, would benefit from a control process of the same detail as shown in Figure 3.3. With a general idea of the ideal capabilities of sensors and control systems, actual sumo robot designs were researched.

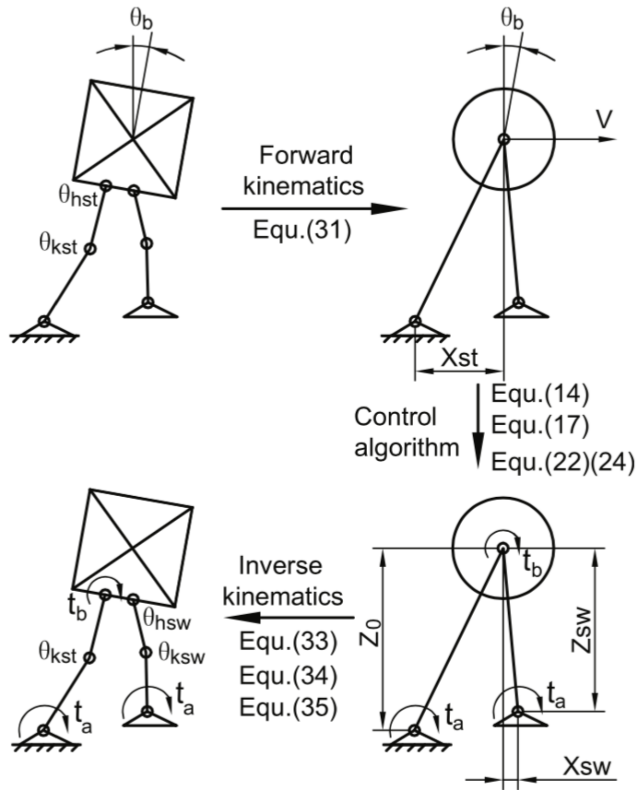


Figure 3.3: Control process for an experimental biped robot [5].

3.2.3 Existing Design #3: Acta Tehnica Corviniensis Mini-Sumo Robot

The University of Politehnica Timisoara published a paper on the construction of a mini-sumo robot in 2015. The article covered multiple factors that influence the quality of a robot including: the sensors, microcontroller, and motors [6]. A microcontroller and circuit board make up the body of their robot. The strategy for constructing this sumo robot was to create a balance between speed and power. The speed-to-power ratio is determined by the transfer rate (ratio of motor to wheel rotations) of the motor [6]. The customer requirements showed defensive capabilities as being more important than offensive capabilities. Therefore, a high transfer rate, or slow and powerful design, was preferred over the balanced design proposed by the University of Politehnica Timisoara. With overall design ideas in mind, specific subsystems were investigated to prepare for component selection.

3.3 Functional Decomposition

The Functional Decomposition, below in Figure 3.4, depicts the general necessity of the team's robots to simply move. There are no armatures or external moving parts, not including wheels, so the team decided that movement was the foremost goal of all robots: Mega sumo, Nano sumo, and Combat. This model elaborates on all processes required to achieve controlled movement, either through autonomous algorithmic control or human interaction remote control. The arrows vary from thick solid, thin solid, and dotted, which represent material flow, energy flow, and signal, respectively. The chart helped the team focus on specific subsystems, such as motor, brain, tires, and body construction. Calculations on these four subsystems proved beneficial in the final report, thus the reason the team had them as primary functions of the Functional Decomposition.

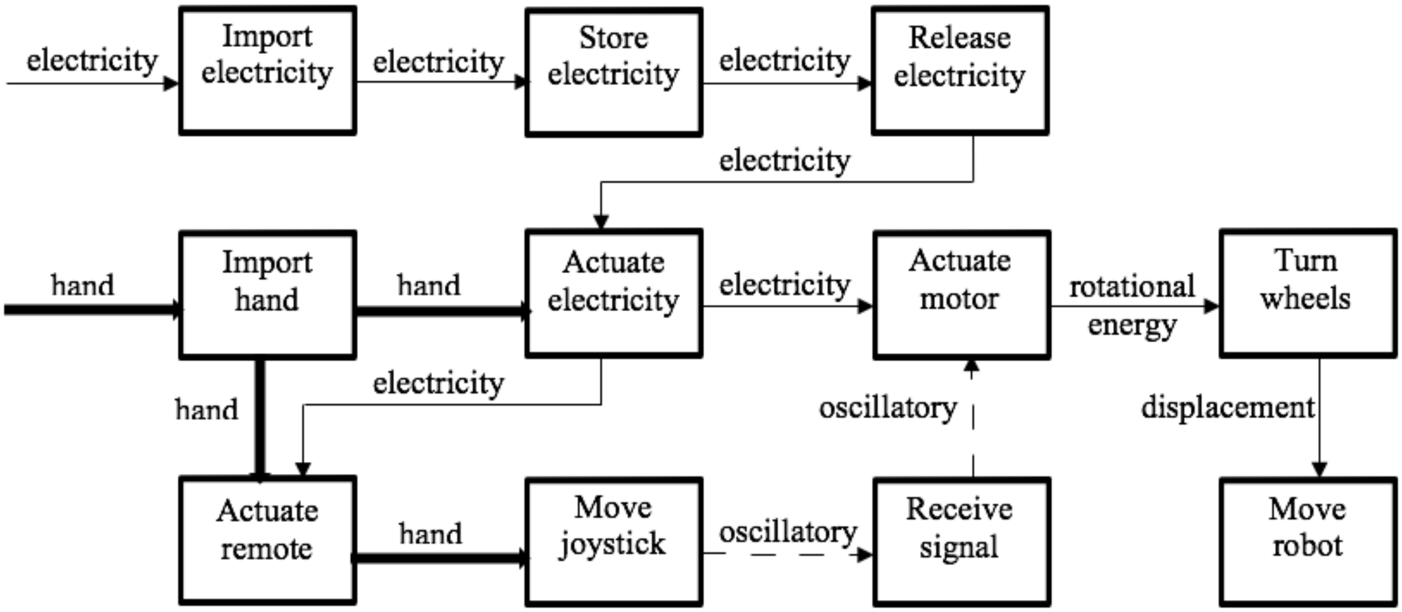


Figure 3.4: Functional decomposition model

3.4 Subsystem Level

A sumo bot, whether it be autonomous or remoted controlled, is comprised of many sub-systems. This section presents three sub-systems that are most critical to the success of a sumo bot. Microcontrollers, sensors, and motors were researched in detail and the team's findings are presented below. These three subsystems were determined to be the most critical because our team concluded that using inferior sensors and microcontrollers, or low powered motors would be the biggest disadvantage during a sumo match. Each of these sub-systems has existing designs with unique pros and cons. Effectiveness and cost were the two criteria measured when researching existing solutions for every sub-system.

3.4.1 Subsystem #1: Microcontrollers

The first subsystem investigated was microcontrollers. A microcontroller is a single integrated circuit designed for a single task or application. The circuit contains memory, a processor, and programmable input and output pins [6]. There are multiple manufacturers of microcontrollers but the most reputable company is Arduino. Arduino was a good microcontroller choice because it was open source, compatible with a myriad of motors and sensors, and was able to power most components. Arduino uses C++ libraries to simplify the programming process or was compatible with MATLAB and Simulink. However, Arduino currently sells nine different models, each designed for a different purpose [8]. The models that the team considered include the Arduino Uno, Arduino Micro, and Arduino Nano. Technical specifications for each microcontroller are shown in Table 3.1 below.

Table 3.1: Arduino microcontroller technical specifications as listed by the manufacturer. Prices are estimates based on multiple retailers [7, 8, 9].

	Uno	Micro	Nano
Operating Voltage	5V	5V	3V
Input Voltage	7-12V	7-12V	7-12V
Digital I/O pins	14	20	14
PWM Pins	6	7	6
Length	68.6mm	48mm	45mm
Width	53.4mm	18mm	18mm
Weight	25g	13g	5g
Price	$11	$25	$15

3.4.1.1 Existing Design #1: Arduino Uno

Arduino Uno is the standard model microcontroller. Even though the Uno is the heaviest option, weighing 25g, it still had an advantage. The main advantage of the Uno was that input and output pins did not need to be soldered onto the board. This makes prototyping and troubleshooting easier for the team during the design process. Purchasing an Uno board only for prototyping was considered while a smaller model would have been installed in the final robot. The capabilities of the Uno are almost identical to the other options making its weight the only drawback. The Uno also costs $11, making it the cheapest available microcontroller [9]. It should be noted that the Uno's weight of 25g meant it could not be used in the Nano sumo robot design. The Nano class maximum allowable weight was 25g. Next the Arduino Micro was examined.

3.4.1.2 Existing Design #2: Arduino Micro

The Arduino Micro is a smaller version of the Uno with the same amount of power. The main drawbacks to the Micro include the cost and that they are difficult to make changes to once installed. The Micro is more than twice the cost of an Uno, costing $25 [10]. Additionally, the micro required any components be soldered to the board. This makes prototyping difficult and the team could have been forced to buy additional boards. However, the low weight (13g), and small area ($864mm^2$) made the Micro a better choice for the final design [7]. An Arduino Micro was a good choice for any robot, especially for the Nano class competition. However, the Arduino Nano has advantages that should be considered.

3.4.1.3 Existing Design #3: Arduino Nano

The Arduino Nano was the ideal microcontroller choice. The board only costs $15, slightly more than the Uno. The board does have the same disadvantage of the Micro where it was difficult to prototype with. However, a light weight of 5g and similar technical specifications as both the Micro and Uno made the Nano a perfect choice for the Nano class or even Mega class sumo robots. The main disadvantage to the Nano was that its production had been discontinued. They can still be found through third party retailers but can be difficult to find. After determining what kind of microcontroller would be used, research into available sensors was conducted.

3.4.2 Subsystem #2: Sensor Selection

Sensor selection is an important part of designing an effective robot. Three types of sensors were investigated: Infrared, ultrasonic, and camera sensors. Any choice would function as the eyes of the robot. An important consideration during sensor selection was the sample rate and distance range. High sample rates allow the robot to adapt more frequently which directly met the adaptive algorithm requirement. A far and short distance sensor could have also been able to sense the opponent anywhere from directly in front of the robot to the other side of the arena.

3.4.2.1 Existing Design #1: Short Range Infrared Sensors

For short range sensors, infrared sensors were researched. The Polulu-Carrier Sharp distance sensor costs $7 and has a measuring range of 20 to 100 mm and a sample rate of 400 Hz [9]. This sensor was a good choice for short ranged sensor. This sensor could be placed on the sumo robot to read anything directly in front of itself. A disadvantage to this sensor was that it cannot sense how far away something is; it can only give a high or low output signal depending on if an object is in its view or not [9]. Sharp sensors are compatible with Arduino as well, making them a good choice [6]. If this sensor was used, an additional long range sensor, of any type, would also have been used. Next, ultrasonic sensors were investigated.

3.4.2.2 Existing Design #2: Long Range Ultrasonic Sensors

For long distance sensing, ultrasonic sensors were investigated. One example of a viable ultrasonic sensors was the Maxbotix ultrasonic rangefinder. This sensor can determine the range of an object between 30cm and 5m [9]. Ultrasonic sensors are a good consideration for a long range but can be expensive. The Maxbotix ultrasonic rangefinder costs $33; ultrasonic rangefinders are also heavy, weighing about 3 to 5 grams [9]. To finish research on sensors, the team looked into using a camera rather than an infrared or ultrasonic sensor.

3.4.2.3 Existing Design #3: Camera Sensors

Camera sensors have more capabilities than ultrasonic or infrared sensors, including tracking movement and distance as well as colors, patterns, faces, and more. The disadvantage to camera sensors was their price. The team looked at the Pixy CMUcam5 Sensor. Although expensive, costing $75, the Pixy sensor is a 25.5g, programmable camera that can detect seven different color signatures, is open source, and processes at 50 frames per second [9]. Using camera sensors could give the robot a better sense of its surroundings. However, the extent of this advantage needed to be benchmarked against the infrared and ultrasonic sensors to determine if the cost was justified.

3.4.3 Subsystem #3: Motor Selection

When selecting a motor, the power and speed of a motor must be determined. Both servo and traditional electric motors were considered. However, this section aims to determine the options for a high, low and balanced power-to-speed ratio or transfer rate. Motors on the market that meet these three specifications and the benefits of their respective strategy were researched.

3.4.3.1 Existing Design #1: High Torque Rate Motors

A high transfer rate means that a motor will produce high torque but low speed. For defensive strategies, high torque was preferred. In a sumo competition, the majority of the match is spent pushing each other rather than moving around each other. Once contact has been made, the robot that pushes with more force, rather than at a higher speed, will win. Transfer rates considered when looking at electric motors were approximately 100:1 [6]. Servo motors were ideal because they give increased control and are easier to track distances the robot moves. Therefore, the motor investigated was the Metal Gear Servo – Micro motor; this motor weights 14.5 grams and produces 2.2kg-cm of torque [9]. This motor was a good example of something to use in the Nano class competition. The disadvantage to this kind of motor was its low speed. If a faster design was decided on, an electric motor would be considered.

3.4.3.2 Existing Design #2: Low Torque Rate Motors

If speed was desired over power, an electric motor would be superior. High speed electric motors would be more ideal for the Mega class competition because they tend to be heavy. An example DC motor the team found was the PMDC 12V 18000 RPM motor by Micro DC Motor [9]. This 255g motor could be used if a high speed, agile robot design is used. However, the team believed this design was not as good as a defensive design. Further benchmarking against engineering requirements was required to determine the optimum strategy. It was also possible that a balanced design would be used.

3.4.3.3 Existing Design #3: Balanced Motors

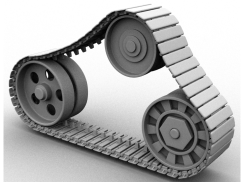
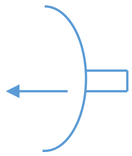
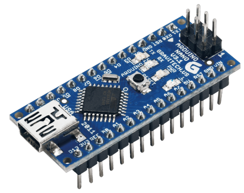
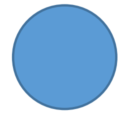
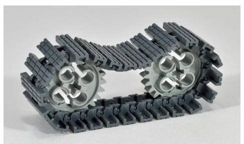
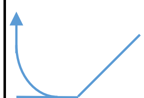
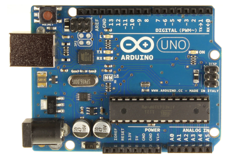
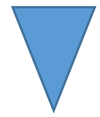
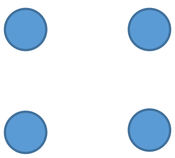
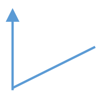
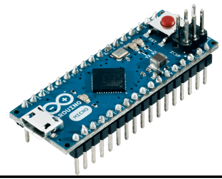
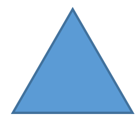
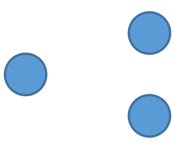
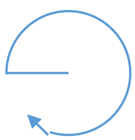
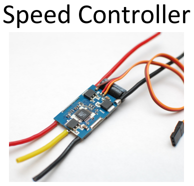
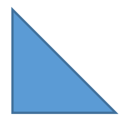
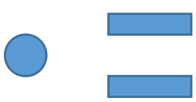
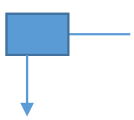
A balanced motor that could produce enough force to push but still be fast enough to out-maneuver the opponent could have been optimal. The University of Politehnica Timisoara recommended a balanced, C.C. Pololu-type motor and L298N motor drivers; this setup is compatible with Arduino and is capable of performing precise operations [6]. This design is assembled onto an Arduino Shield, which is a circuit board that attaches to the top of an Arduino. Again, this design is a good indication of what should be done for the Nano class robot. However, the overall setup and structure of the circuit was a good example for any sized sumo robot.

4 DESIGNS CONSIDERED

To effectively brainstorm design ideas, the team started with a 4-3-1 method. Each of the four team members sketched 3 ideas for 1 minute. After that minute, each member swapped sketches with each other. Each member then spent 1 minute modifying the designs they were given.

Once the team completed the 4-3-1 brainstorming exercise, a morphological matrix, shown in Table 4.1, was created to generate 30 unique designs. The matrix is broken into 6 categories: movement, offense, motor, brain, body shape, and language. For movement, tread designs were considered for their high traction. The various wheel configurations would be faster, but the tri or omni-wheel options would be cheaper. Offensive options included various static and dynamic options. The motor and brain options were those discussed in section 3.3. Body shape was left intentionally vague because the frame had to be built around the other design components. For language, the most feasibly option was C++. Arduino has built in libraries that run C++ code and make the programming process very straight forward. The other languages are feasible, but each has a unique aspect that made it more difficult to implement. Although MATLAB is an easy language to use, running a MATLAB script natively off an Arduino can be difficult to do. Robo Toolbox is a powerful tool but would require the team purchase it for $30.00. Lastly, python and Simulink, although effective tools, would have required a team member learn how to use them.

Table 4.1: Morphological Matrix for generating Sumo robot designs.

Movement	Offense	Motor	Brain	Body Shape	Language
Tri-treads 	Bulldoze 	Electric High Speed	Arduino Nano 	Sphere 	C++
Bi-treads 	Spatula 	Servo High Torque	Arduino Uno 	Cone 	MatLab
Quad-wheels 	Lever vertical 	Electric High Torque	Arduino Micro 	Triangle 	python Python
Tri-wheels 	Spin arm horizontal 	High Torque Servo + High Torque Electric	Speed Controller 	Right Triangle 	MathWorks Robo Toolbox
Omni–wheel 	Push Down 	High Torque Servo + Speed Electric	Raspberry Pi 	Rectangle 	Simulink

As a final aid for combat design ideas, the team referenced the RioBotz Combat Tutorial guide. The team researched a number of design aspects, including internal components, offensive weapons, and armor systems. Three concepts that were used for inspiration include the wedge, horizontal spinner, and drumbot show in Figures 4.1 [7]. Following are the team's top 16 designs. They are a combination of sumo mega class, sumo nano class, and combat designs.

Figure 4.1: (Left to right) – Wedge, horizontal spinner, and drum robot designs [7].

4.1 Sumo Mega Class Designs

For the mega sumo class competition, an autonomous and remote controlled design are required. With a $450 budget for the mega class, the team decided to use a single robot that is capable of both control methods. In total, five mega class sumo robot designs were pursued.

4.1.1 Mega Class Sumo Design #1: Treaded Defensive Shell

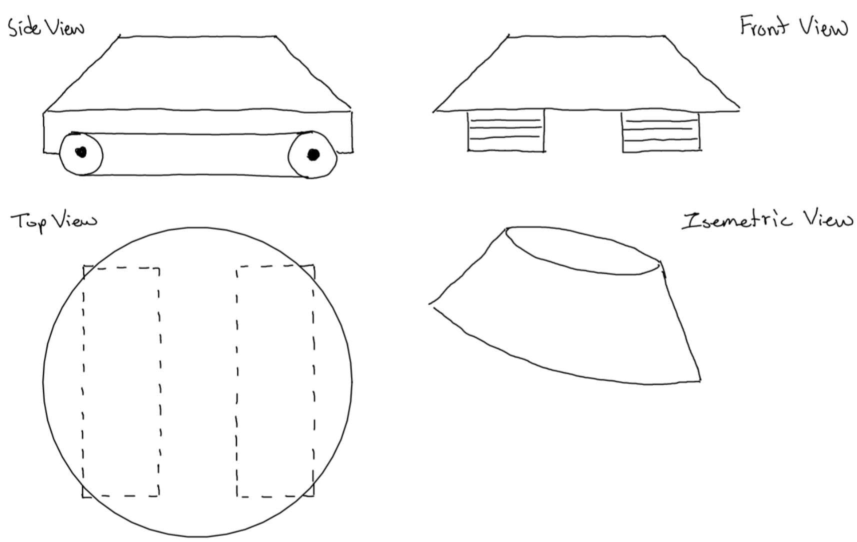


Figure 4.2: Illustration of a treaded defensive shell design for a mega class sumo robot competition.

The first design proposed by the team, shown in Figure 4.2, was a defensive, circular shell. The round, sloped shape made the design easy to size to the maximum area. All space underneath the robot was dedicated to tread space, maximizing the bot's coefficient of friction. Slow speed, high torque motors made this design difficult to push from any direction. The slanted edges could also cause an opponent to drive on top or over the bot instead of pushing it. The weak point in this design was its lack of surface area to push with. A possible lever arm could be installed on one side to help the robot push the opponent, but the additional motor or device used for dynamic movement could have pushed the robot over the 3kg weight limit.

4.1.2 Mega Class Sumo Design #2: One Direction Pusher

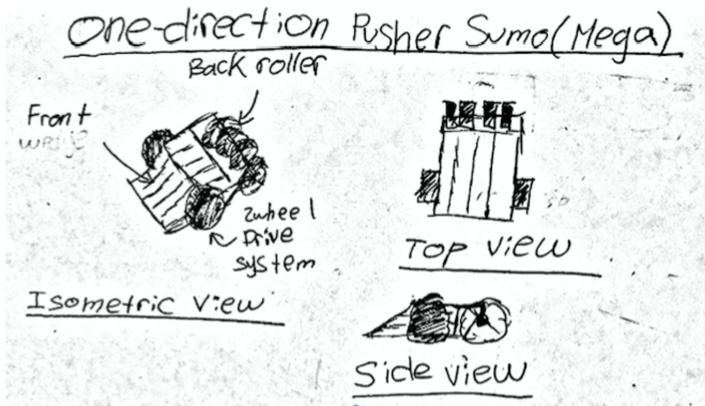


Figure 4.3: Mega class sumo design with a high power and offensive ram.

Shown in Figure 4.3, the one direction pusher had two major components. First was the ram built into the front of the robot. This offensive component would increase the bot's surface area to push with and lifts the opponent off the ground, reducing their traction. The second component worth noting was the back wheel system. This system gave the bot additional traction and power. The disadvantage to this design was the cost. Motors, a battery and speed controllers are the three most expensive components of the robot. Increasing the number of motors and speed controllers could potentially double the price of the bot.

4.1.3 Mega Class Sumo Design #3: Omni-directional Pusher Using Mecanum Wheels

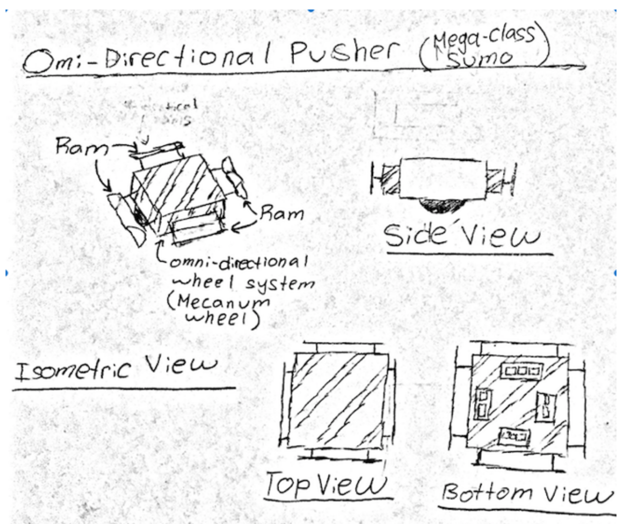


Figure 4.4: Mega class sumo mecanum wheel design, omni-directional pusher

The third design proposed was capable of driving in any direction and utilized multiple rams to aid in pushing the opponent out of the doyho. Mecanum wheels are wheels with small rollers, similar to those in a cylindrical bearing, that rotate perpendicular to the direction the wheel turns in. with wheels oriented perpendicular to each other, as shown in Figure 4.4, the bot could freely move in any direction. Designing an algorithm around this movement system would be both effective and easy to implement. Additionally, when being remote controlled, the maneuverability of the bot would be high. Rams were included on all sides; this prevented the bot from ever having to turn during a match. The disadvantage to this design was the lack of traction. Mecanum wheels would be particularly easy to push against. Alternatively, the wheels could be placed in a 120-degree orientation which would only require three wheels; this is the design covered in section 4.1.4 below.

4.1.4 Mega Class Sumo Design #4: 120º Omni-directional Pusher Using Mecanum Wheels

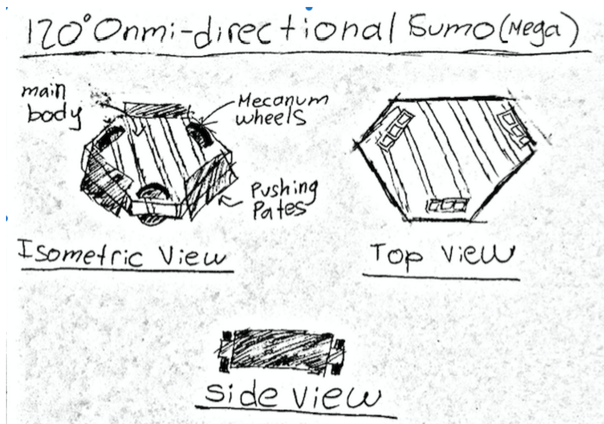


Figure 4.5: Alternative Mega class sumo mecanum wheel design, omni-directional pusher with a 120-degree, 3-wheel orientation system.

The 120-degree omni-directional pusher uses the same mecanum wheel system as the omni-directional pusher. The main difference for this design was that it only used three wheels. This reduced the cost of the robot significantly, since motors are such an expensive component. For additional savings, the rams from the original omni-directional pusher design were replaced with a simple plate. Potentially, a thin sheet of metal or plastic would be used. This still gave increased surface area to aid in pushing, but was more susceptible to failure.

4.1.5 Mega Class Sumo Design #5: High Speed, Front heavy Ram

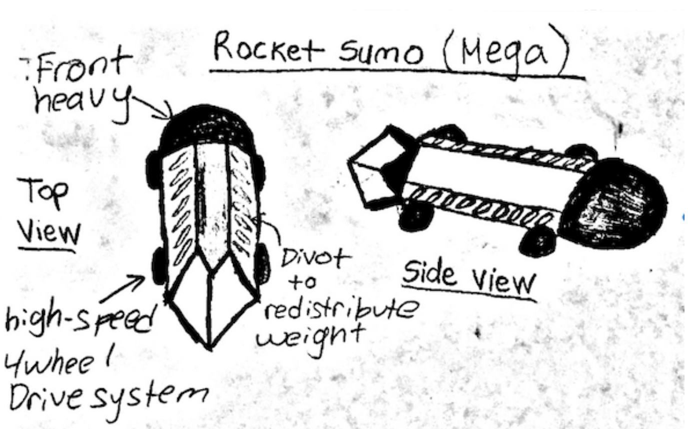


Figure 4.6: High speed, front heavy ram sumo design.

The rocket sumo design was specifically developed for the mega weight class. The design was intended for the largest weight class because it is dependent upon loading up as much weight as possible into the front of the robot. It was referred to as the rocket sumo because this robot had to accelerate quickly in order to be successful. Once a sumo match began, the strategy with this design was to quickly accelerate and strike the opponent with the larger and heavier side of the robot. Each side of the robot had divots which can be seen in Figure 4.6. Removing material from the sides allowed more weight to be added to the front.

This design was risky but, if executed correctly, could be a winning strategy. It had the potential to be the best strategy because any opponent would have difficulties being pushed back by a dense, fast moving object. This design was risky because, if it did not immediately knock the opponent out of the doyho on the first strike, it could perform poorly in a longer and slower paced match.

4.1.6 Mega Class Sumo Design #6: Foldable invertible Sumo

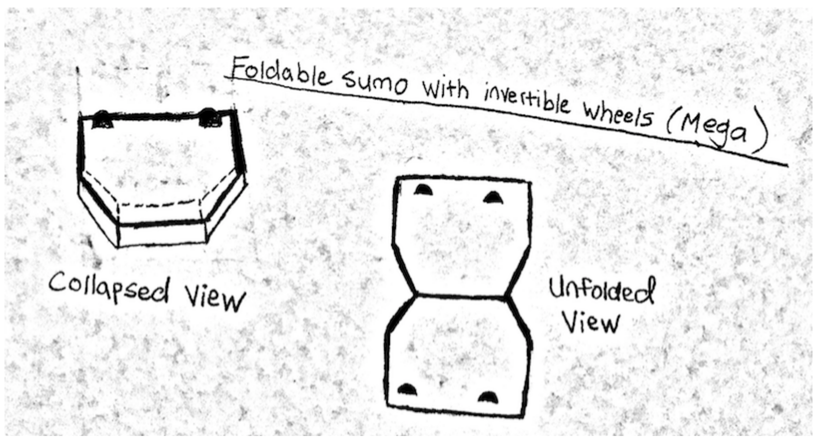


Figure 4.7: Invertible, collapsible, inverted mega sumo robot.

The foldable sumo design is shown in Figure 4.7. This design becomes larger than the maximum dimensions that a regular sumo bot can achieve based off of the restrictions implemented in the official rules for this competition. This design took advantage of the rule that does not enforce height limitations to the robots. When the robot is in its folded or collapsed position, the length and width of the robot would meet the requirements for length and width as described in the official rules. Once unfolded, the robot could double its length. It would achieve this capability by being hinged on the center axis of the robot. The strategy behind this design was to ensure the opposing sumo bot would stay in front of our robot at all times.

With increased dimensions, the likelihood of a robot being able to maneuver around the bot was reduced. This reduced the chance of opposing robots being able to push from the sides or backside of the robot. The downside of this design was it gave opponents a very large surface area to hit and push. One of the main concerns with this design was if the team could make a less dense robot equally as strong as a heavier, condensed robot design. The wheels were moved inward into the body of the robot for defense purposes. In the event an opponent could push from the side, the opponent would not be pushing against a wheel. The team did not want the steering and driving capabilities to be hindered by a wheel being rammed against. Minimizing the height of this robot in its unfolded position could lower its center of gravity and help in equaling the pushing power of a taller opposing robot. The 5 sided shape of each folding half was intentionally chosen because, once unfolded, this robot formed a pocket structure which is where the optimal point would be for this robot to catch and push other sumo bots.

4.2 Sumo Nano Class Designs

For nano sumo bots, the most difficult design challenge was meeting the weight requirements. Therefore, a few internal components, specifically motors, were picked at the beginning. With the internal components in mind, six designs that aimed to reduce frames size were created.

4.2.1 Nano Class Sumo Design #1: Flat Plate Body Design

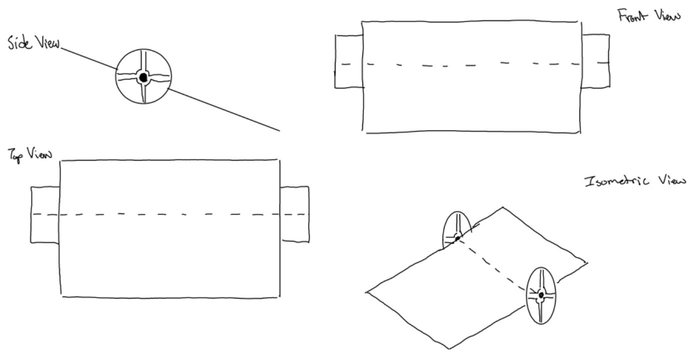


Figure 4.8: Flat-plate body nano class sumo bot design

The first design for a nano sumo bot was the flat plate body design. This concept used a thin, flat plate to mount the electrical components and only two wheels, as shown in Figure 4.8. The plate would be 3D printed to be as thin as possible. With the majority of weight not being used up on the frame, motors were maximized for torque output and wheel thickness was increased to meet the transfer rate and maximize coefficient of friction engineering requirements. In an effort to increase the friction further, various shaped sheets were created and are covered next.

4.2.2 Nano Class Sumo Design #2: Flat Plate, Alternate Form

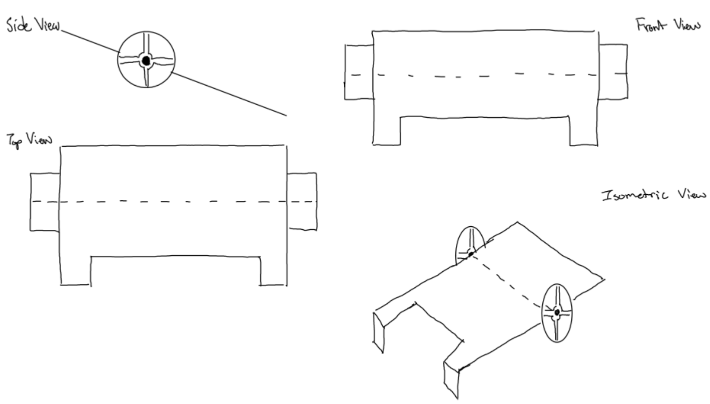


Figure 4.9: An alternative flat plate design which redistributes area to increase traction

The second flat plate design used the same concept as nano design #1. The only difference was that a section of the plates area had been moved from the center of the plate, as shown in Figure 4.9. The section was moved to create two flat feet that rest on the ground. This redistribution of area increased the coefficient of friction which helped the design meet all the engineering requirements. The empty space also acted as a hold to grab hold onto the opponents bot. This design was still just as cheap as design 1 and used the same internal components. For either design 1 or 2, an Arduino lily pad seemed like the optimum choice. This microcontroller weights only 4.7 grams, leaving plenty of weight to go into motors and wheels. The distance between the wheel could also be reduced, freeing up more mass to be put in the feet as well as reduce the bots turning radius which further met the engineering requirements.

4.2.3 Nano Class Sumo Design #3: Flat Plate with a Ram

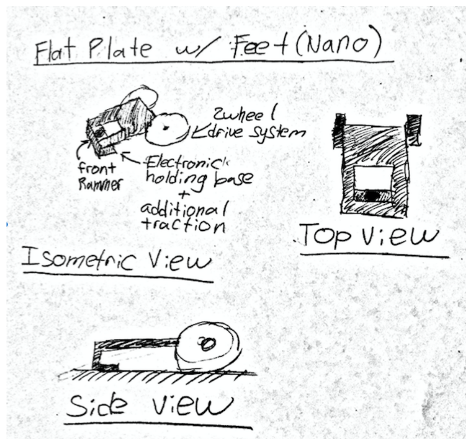


Figure 4.10: Sumo nano flat plate design with a front ram.

Nano class design three further built off the concept displayed in designs #1 and #2. The main differences between this design, which are visualized in Figure 4.10, and the other nano concepts proposed so far was that the area taken out of the center of the bot were used to make a frontal ram instead of feet. The ram also had a bottom section that rested on the ground. This increased the friction more than the feet proposed in design two. The design also moved the wheels to the back and mounted the microcontroller behind the ram. The microcontroller helped weigh down the front of the bot which increased the friction coefficient further. The disadvantage to this design was the ram could potentially be too heavy. The feasibility of this design needed to be further investigated before construction.

4.2.4 Nano Class Sumo Design #4: Ram Bar

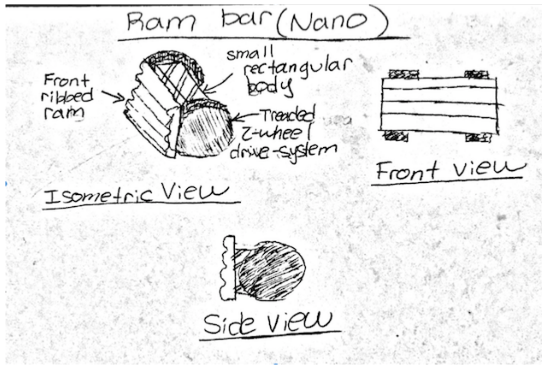


Figure 4.11: Ram bar nano sumo bot design.

Design four, displayed in Figure 4.11, differed from the other designs proposed so far in that the body is not a flat plate. This design used a thin bar, which would house all the internal components, and two thick wheels on each side. A ram would be placed on the front to increased frontal surface area. This design had a low center of gravity, high coefficient of friction, and would not cost more than the other designs proposed. The disadvantage to this design was the small frame. Fitting all the components into the small framed bar would be a challenge. Like design 3, the ram weight could be difficult to optimize, pushing the design over the 25g weight limit.

4.2.5 Nano Class Sumo Design #5: Block Box Design

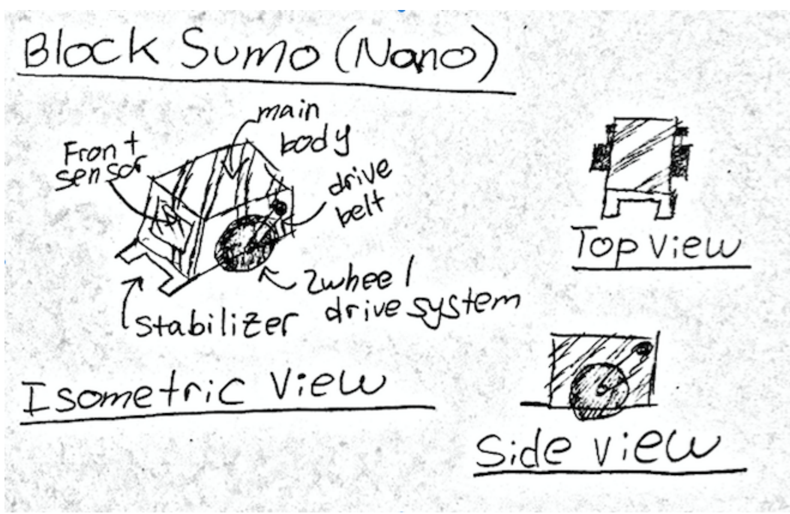


Figure 4.12: Block nano sumo bot design

The next design was also different from the sheet designs. Instead of using a thin sheet to mount components, the components were stacked on top of each other. This achieved the same goal of a sheet, which was to remove weight from the frame to maximize motor size and wheel thickness by redistributing weight. The bottom stabilizer, shown in Figure 4.12, served the same purpose as the feet in design #2, which was to increase friction coefficient. The disadvantage for this design was finding a way to mount the electronics on a circuit board that fits within the body. Constructing a custom circuit board was one possible solution to this problem.

4.2.6 Nano Class Sumo Design #6: Flag Distraction Design

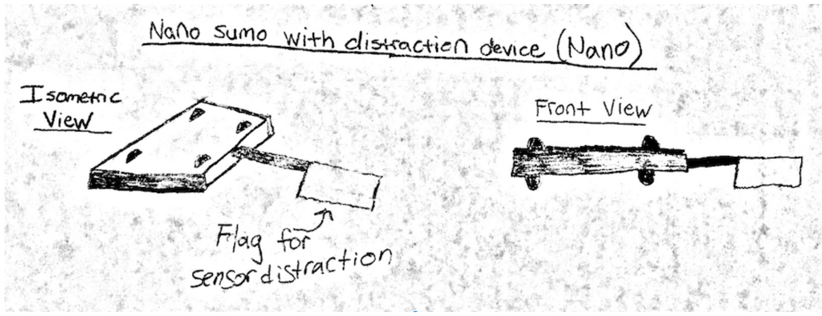


Figure 4.13: Nano sumo design that uses a movable flag to disrupt enemy sensors.

The flag nano robot was designed to disrupt enemy sensors. The goal for this robot was to get enemy sensors to follow the flag, shown in Figure 4.13, instead of the robot itself. If an opposing robot were to hit the flag, the robot would pass under the flag without pushing the robot. The challenge with this design was maximizing the effectives of the distraction device. If the distraction device did not confuse enemy sensors as intended, the flag nano would then be in a disadvantageous situation. The distraction device took up weight which minimized the pushing power this robot can possess.

4.3 Combat Robot Designs

For combat, design concepts were generated by using the Riobotz guide for influence. Rather than using a morphological matrix to generate initial ideas, like what was done for the sumo designs, current designs were studied and weak points in their implementation identified. Five combat designs were created by starting with an offensive weapon or combination of offensive weapons. The rest of the design was then built around the weapon, while minimizing any potential flaws in designs. Due to a low budget of $450 for a combat bot, the team pursued designs with static weapons such as wedges or rams because of their low cost. Defense was also prioritized, meaning the majority of cost would go into durable internal components and strong armor.

4.3.1 Combat Design #1: Invertible Wedge Design

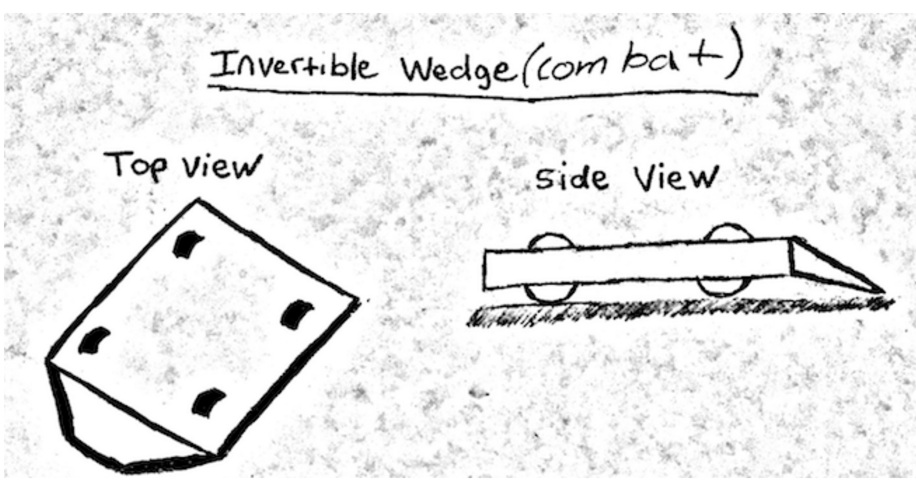


Figure 4.14: Invertible combat wedge

The invertible wedge design, displayed in Figure 4.14, had strategic and financial advantages. A wedge, a static weapon, functions with fewer moving components than other designs. Manufacturing less moving parts was more likely to function as intended. Strategically, the invertible aspect to this design increased the likelihood of winning a combat match. A competitor loses a combat match by not being able to move. Increasing the mobility of a robot, by allowing it to drive upside down or right-side up, was considered an advantage. In combat matches, it is common for a robot to be flipped in an unexpected direction and land on any of its sides.

Since this design wass a static weapon with no additional weapon features, the angle of the wedge itself was important to consider. The angle of the wedge should be 34 to 37 degrees horizontally from the ground depending on the type of metal that is used for the wedge [7]. The angle of 34 to 37 degrees was researched and recommended by the Riobotz guide on the official website for this combat event. These were the recommended angles that gave the best balance between defense and offense. The wedge needed to be designed with two purposes in mind. The first was to effectively deflect enemy blows. The second purpose was to launch opponents in the air. It should be noted that this wedge would only be effective if our speed wass superior to the average speed of the other combat robot types.

4.3.2 Combat Design #2: Invertible Double Wedge Design

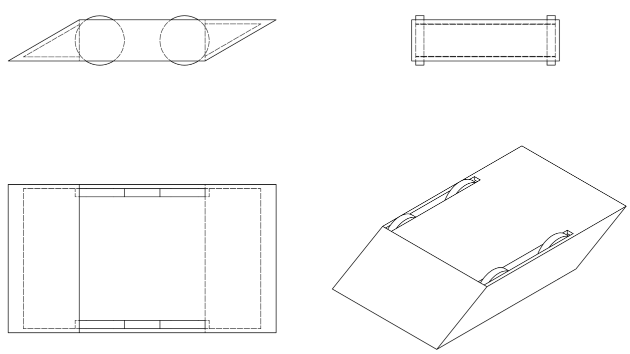


Figure 4.15: Inverted double wedge

The double wedge design, in Figure 4.15, had similar advantages and disadvantages as the invertible wedge design. The double wedge design was invertible, allowing for the correct wedge angle to be available for attacking after being flipped. This strategy helped offensive capabilities while limiting the defensive strength of the robot. An effective wedge needed to be a heavy metal which accounts for a significant portion of the overall weight. Implementing an additional wedge weakens the armor since there is less material available.

4.3.3 Combat Design #3: Wedge-Drumbot Hybrid

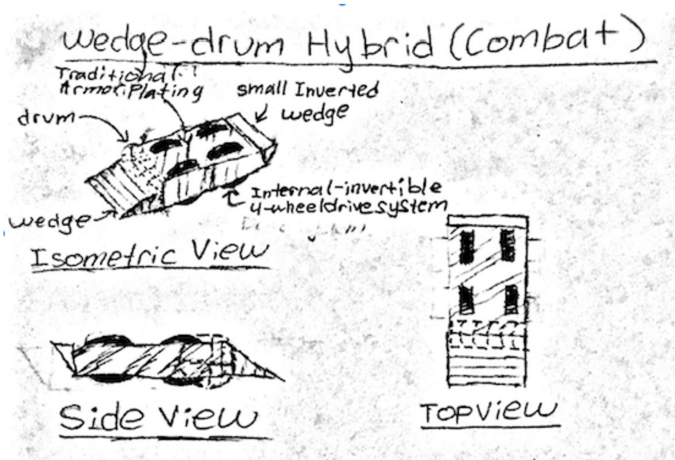


Figure 4.16: Invertible, wedge-drumbot hybrid design.

Combat design three used a wedge and rotating drum as offensive methods. Drumbots usually try to launch the opponent with a fast rotating cylinder. By combining this design with a wedge, as shown in Figure 4.16, the robot would be able to continue fighting even if the drum got damaged or stops working. The design was also invertible. However, the additional motor, power and control required for the drum took away weight that could be applied to armor. This design was also a higher cost than the invertible or double wedge designs because of the additional internal components.

4.3.4 Combat Design #4: Invertible Spinner

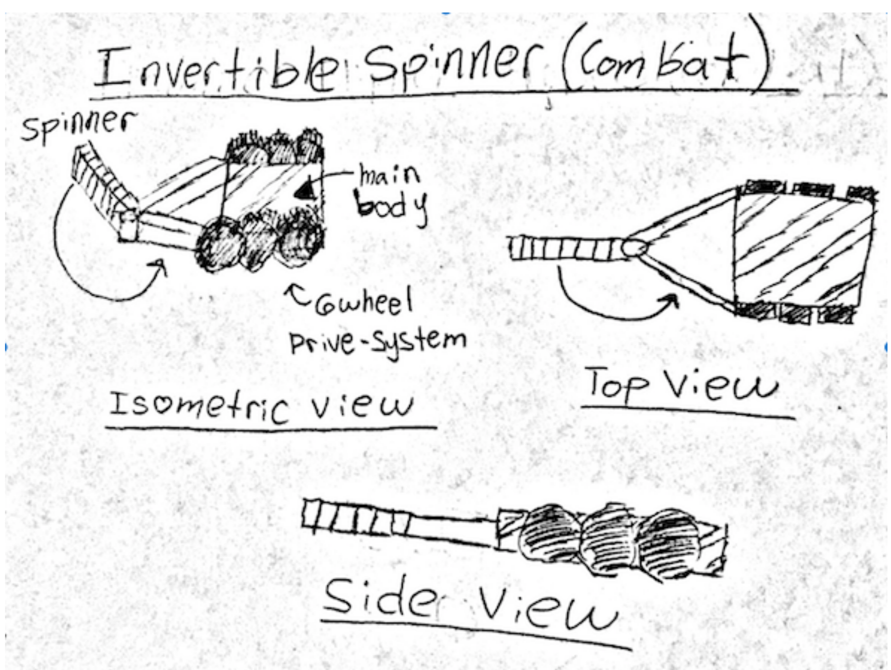


Figure 4.17: Invertible spinner combat bot design.

The next combat design differs from the wedge designs proposed so far. Spinners are highly destructive, using a rotating mass to inflict powerful, destructive blows to the opponent. This design was also invertible. The main weaknesses of spinner designs are in the weapon itself. There are three major weakness with the spinner design proposed in Figure 4.17. First, a slow speed up time for the spinner can cause a loss. If the opponent was quick enough, they can damage or destroy a spinner bot before the spinner had time to reach a speed high enough to be damaging. Second, the motor for a spinner must be of a high quality so it does not break or burn out on impact. Lastly, the analysis to optimize the spinner geometry requires a lot of time and effort, including a potential FEA analysis.

4.3.5 Combat Design #5: Flipping Wedge

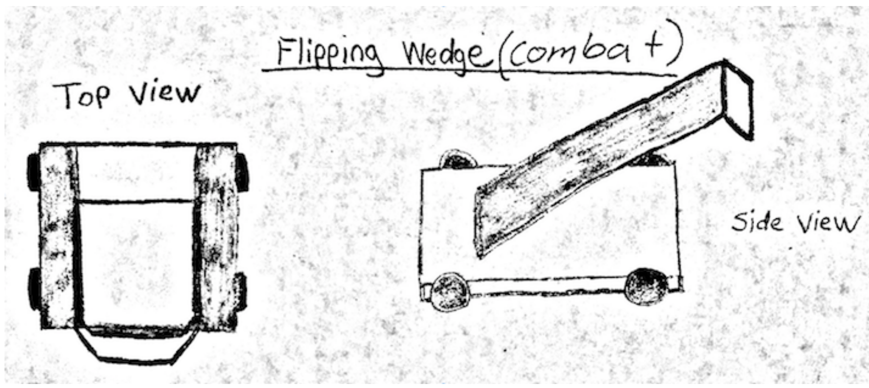


Figure 14.18: Flipper-Wedge hybrid combat design.

The flipping wedge design, in Figure 14.18, was considered a combination robot or a combo weapon. This was because the entire shell of the robot was capable of ramming opponents with a wedge shaped exterior but was also capable of actuating a flipping device to try to overturn enemy robots. There were tradeoffs to consider when the combo weapon was designed. In any given combat match, there can be 15 or more different types of combat robots that can be encountered. Having more than one method of attacking was helpful in facing multiple types of competing robots.

The challenge faced in pursing this design was whether the robot would be capable of flipping right-side up if it got flipped upside down. In theory, it was possible to make the flipping arm capable of pushing the robot up to its correct position. Executing the action would be difficult. The flipping device on this robot would need to accelerate upwards quickly to maximize its effectives. The flipping device should also have the ability to close quickly. Once the flipping device opens up, the body of this robot was exposed and more susceptible to attack. This risk can be negated by having fast responsiveness by the actuating flipping mechanism.

5 DESIGNS SELECTED

Once a number of feasible designs were generated, two selection methods, a Pugh chart and Decision Matrix were used to rank the current designs. In the Pugh chart, each concept was compared to a single datum to determine which ideas met each of the selection criteria most effectively. The decision matrix helped narrow the best designs down to a single or few final concepts to pursue.

5.1 Rationale for Design Selection

For each competition (mega sumo, nano sumo, and combat) a Pugh chart was made to initially rank the concepts. As shown in the Pugh charts in Appendix C, the datum chosen for the mega, nano, and combat competitions were the rocket sumo, flat plate body design, and invertible wedge. The team chose these designs for the datum because they each had strengths and weaknesses. When rated against the other designs, superiority for each design was compared to establish criteria. Three criteria used in the Pugh chart (customer requirements, budget, weight, and identifying mark) are from the Robogames rules [1]. The other requirements were created by the team.

5.1.1 Pugh Chart Results

The Pugh chart revealed the treaded defensive shell, block box, and wedge-drumbot hybrid were the top choices for the mega, nano and combat designs, respectively. The defensive shell's defensive strength, low cost, and simplicity made it an ideal design. However, it only beat the Rocket sumo design by three points. Additionally, its low speed and poor maneuverability means the treaded tank would not be effective at winning matches, only not losing. The superior nano bot was the block bot. This designs low weight, well rounded offensive and defensive capabilities, and extremely low budget was made apparent by its score of four compared to the datum.

For combat, the winning bot was the wedge-drum hybrid. This design was deemed superior with a total of 3 points. By combining a wedge, a naturally defensive static weapon, and a drum, a powerful and strictly offensive dynamic weapon, this design achieved higher defensive and offensive capabilities compared to the datum. The wedge and invertible wheels also gave it additional durability as well. The Pugh chart revealed the hybrid design to have inferior maneuverability, and speed.

Overall, the Pugh charts revealed strengths and weaknesses of each design. However, this was not enough information for the team to make a final decision on the designs. Three decision matrices, one for each competition, were created for an alternate view point of each concept.

5.1.2 Decision Matrix Results

A decision matrix is a strong tool because it gives a quantitative view of each design. The criterion used in the decision matrices, shown in Appendix D, were the engineering requirements from section 2.2. The scores for each device were derived by weighing the importance of each requirement; each concept was then scored on how well it fulfills each requirement. The most important engineering requirements were those enforced by the rules of the competition, (autonomous and remote control, team logo) and the cost. Offensive and defensive capabilities and material were the second most important requirements. The maneuverability, component selection, and dimensions were the remaining requirements. These were not considered as important because the higher weighted requirements either guarantee a dysfunctional bot or a loss in competition.

The Decision Matrices yielded the same results as the Pugh charts. The top ranking designs were the treaded tank shell, block bot, and wedge-drum hybrid. With both the Decision Matrix and Pugh chart giving the same results, the team was ready to decide on a final design.

5.1.3 Final Justifications for Selection

According to the Pugh chart and Decision Matrix, the best designs for the mega sumo, nano sumo, and were the treaded tank shell, block bot, and a wedge-drum hybrid. However, due to cost and time constraints, the designs will be altered.

The mega sumo bot was be a modular design, capable of competing in an autonomous sumo, R/C sumo, or combat competition. The Decision Matrix and Pugh chart revealed the effectiveness, reliability, and low cost of wedge designs which are used in both sumo and combat shells. The sumo design was similar to the rusher bot. Despite its low score in the Pugh chart, the Decision Matrix showed the rusher design shared many strengths with a wedge design. Additional armor was to be made for the mega sumo to turn it into a combat wedge. A dynamic weapon, such as a spinner could also be easily added to improve offensive capabilities. This allowed high quality components, capable of competing at a competitive international level, to be purchased.

The superior nano bot was the block bot in both the Pugh chart and Decision Matrix. When deciding on a final nano bot, this design was the only one that seemed to use feasible components, making it a clear choice. Additionally, the low part number, due to lack of frame, required for the block bot made it a cheap option, opening more of the team's budget to the sumo bot and the combat component. However, a wedge was added to the nano bot as well after seeing their effectiveness across all designs in each Pugh chart and Decision Matrix.

5.2 Design Description

The final designs included an autonomous and remote controlled mega sumo bot. The mega sumo included a removable shell that allowed the bot to be converted to a combat-capable wedge bot. The nano was a scaled down version of the mega sumo that does not use any gear reduction. Additionally, this section will cover all calculations completed for four unique analytical analyses.

5.2.1 Mega Sumo Final Design

The final design perused for the mega sumo bot was a high speed, high torque wedge design. Despite the high score of the treaded shell design, its ability to win a match was still in question. The team decided an offensive design that mimics what had been seen in international competitions was the best direction for the design.

The final sumo design was similar to the rocket or rusher design. The bot used off-the-shelf components to reduce manufacturing time. A 3D model of the sumo design is shown in Figure 5.1 below. The frame consisted of two components, the bottom panel and top cover. Both components were sheet metal. The top shell was one component and removable to allow quick and easy modifications to turn the bot into a combat design. A full CAD package, including part drawings and additional views can be found in Appendix E.

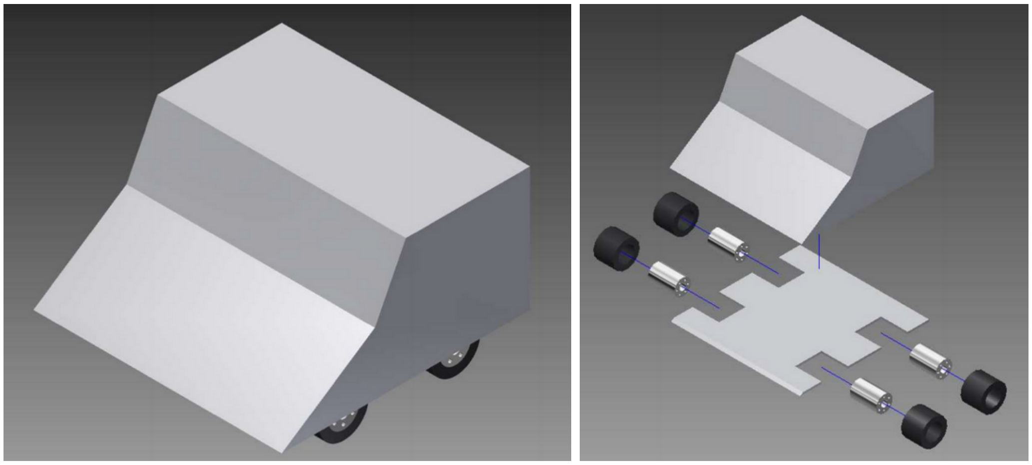


Figure 5.1: Sumo wedge bot design, isometric and exploded view

5.2.1.1 Mega Sumo Wheel Selection

The front wheels of the mega sumo are powered by motors. To maximize traction and friction, the wheels chosen are Colson, 2-inch diameter rubber wheels with a hardness of 65 Shore A [11]. This hardness value was chosen because it is a good balance between not too soft or hard. A wheel that is soft will be shock absorbent and impact resistant, protecting the internal components during impact [12]. However, a hard wheel has better traction. 65 shore is a good middle ground that does not comprise either advantage too heavily. The dimensions of the wheels can be seen in Figure 5.2.

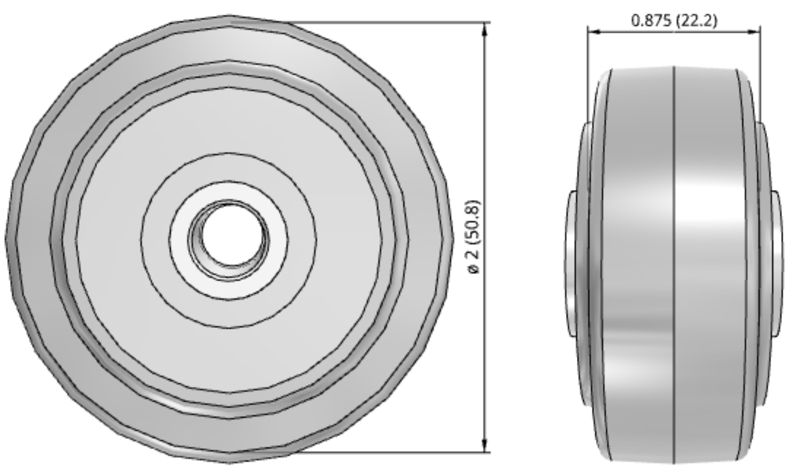


Figure 5.2: Mega sumo bot wheel CAD view with dimensions [12].

5.2.1.2 Mega Sumo Motor Analysis

The motor used in sumo bots affect performance more than any other component. A good motor would enable the robot to have the speed and pushing force necessary to move opposing robots out of the sumo arena. To further improve performance of a motor, gears can be used to increase the torque; thus increasing the pushing force that can be generated. The main factors considered in this analysis are the amount of speed and force that can be possessed by selecting any given motor. Cost between different motors was examined but ultimately it was not a main deciding factor in the final motor recommendation. A quality motor is a valuable resource and it was determined that it would be too difficult to compete at a high level using an under-powered motor.

The analysis performed used a MATLAB script to determine whether a particular motor would provide enough speed and pushing force to be competitive in a sumo match. In order for this to happen, a standard needed to be set to establish what qualifies as a competitive motor. Through researching motor selection by professional sumo bot teams, estimations were made as to what speed and pushing force the team should be striving to obtain. A good motor will allow a 3kg sumo bot to have a max velocity and pushing force of about 8 mph and 6 lb [13]. The last assumption made was that the wheel radius on the sumo bot will be 20 mm.

A variety of motors at different costs were tested for effectiveness. All motors listed in Appendix F along with the variable and Equations used are manufactured by a company called Maxon Motor. Product numbers and additional information can be found on their company website.

Since the motor tested at 60 W did not meet the standards of velocity and pushing power, motors with powers of less than 60 W were not included. Maxon Motor does manufacture a 250 W motor however their 250 W motors are a less realistic option due to weight. A single 250 W motor can weigh as much as 2.1 kg.

The 150 W motor at 7590 rpm is recommended. The motor should have a gearbox that can provide a 4:1 ratio. Using that combination of motor and gear reduction gave the best chance at producing a quality robot.

5.2.1.3 Mega Sumo Motor Selection

To power the sumo bot, high torque, high speed, and a quick response time are all required. The motor selected for the mega sumo bot is the Maxon RE 35 DC brushed motor. Even though brushless motors can have better performance than the brushed motors, they can have compatibility issues with speed or micro controllers; therefore, a brushed motor was chosen. The RE 35 produces 73.1 Nmm of torque and rotates at 7180rpm when supplied with 15V [13]. Weighing only 300 grams, the RE 35 was the ideal motor for a mega sumo bot. Using a gearbox, the torque output can be amplified to create even greater pushing forces. Each motor can be controlled by an Arduino microcontroller and a dual motor speed controller. A drawing of the RE 35 motor is shown in Figure 5.3.

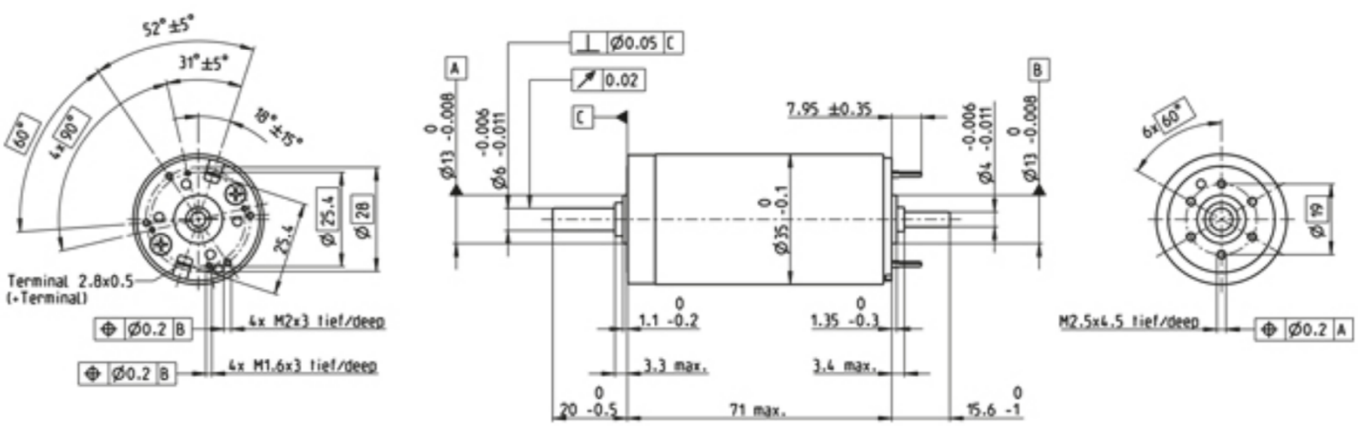


Figure 5.3: Maxon RE 35 15V brushed DC motor, part drawing, SI units (mm) [13].

5.2.1.4 Mega Sumo Cost Analysis

This analysis detailed the cost of a single Mega Sumobot. This included, but was not limited to, motors, gears, wheels, body, controllers, and sensors. The team planned on spending a majority of the budget ($600+) on a single Mega Sumobot. Low quality components are more likely to operate subpar compared to international standard components and break easier when the blunt force of slamming from the opponent is applied; however, the top components are well out of the provided budget, so this cost analysis compared three potential designs. These designs have very simple and cheap components, fair priced and sturdier components, and high-end, very durable, but expensive, components. Additionally, these components are identical to the Remote Controlled Sumobot, so the team may also apply this analysis towards that competition. Before calculations start, assumptions are necessary to understand the total budget that is accessible.

The budget, so generously provided by the engineering department, is totaled at $1,500.00. However, this money was not permitted to be spent on whatever the team deemed worthy. The money must be broken up into four categories: Mega Sumobot Autonomous, Mega Sumobot Remoted Controlled, Nano Sumobot Autonomous, and Combat Bot. From these four categories, $100 had to go towards the Nano Sumobot, $450 towards both the Mega Sumobot Autonomous and Remote Controlled, and $450 towards the Combat Bot. After deliberation, the team decided the Combat Bot is very unlikely to prove successful. So, the team looked into a proof of concept for that design, and proceed with allocating those remaining funds towards the Mega Sumobot Autonomous Class. This decision came from the fact that Combat Bot budgets usually require a minimum of $3,000 for simple construction [1]. Additionally, components are not unbreakable, and quite frequently get broken, so the team would require an entire other set of components as a precautionary measure in case of broken parts at the competition. Due to the newly allocated funding towards that single Mega Sumobot, the team looked into still competing at Robogames, but in the Mega Sumobot competition. Appendix G annotates the various components for a Mega Sumobot and all prices came from JSUMO.com, Robot Marketplace.com or Arduino.com [2,3,4].

Appendix G shows the results of a Low, Medium, and High end design with each respected part type within each category. This means that the first entry is low end, the second is middle and the third entry is high end, and so on for each section. The low end resulting price of $152.81 represents an overpriced car that could be store bought and retrofitted with a new microcontroller for easily half that price. Plus, the components would likely not last for more than a round or two, due to plastic gears and cheap motors. The middle design priced out at $492.73, which was acceptable, but the weight was over by 16%. This could be modified to reduce the weight to competition limit, but the parts show a likeliness to break and fracture. This design left ample “wiggle room” with the budget, but would require significant modification to the frame or motors to cut down on weight. The final design represents some higher end components and comes out to $1,303.48, which surpasses the budget by 30% for the Mega Sumobot Autonomous alone, which is not permitted. However, the components being implemented are classified similar to that of professional Sumobots, which meant competition is feasible at an international level. The weight comes in within allowable tolerance at 2881.5 grams, which still keeps friction high due to maximized weight. The only issue is price and the team looked for outside sources to assist in monetary compensation for retail space on the Sumobot.

Those are the primary results of the table, but Appendix G also specifies the websites this information was accessed from, which can be used for other parts if changes are necessary for money or weight saving. Finally, a “realistic design” shows the parts that the team would need to be considered an eligible competitor at the RoboGames. The Sumobots that compete usually range from $2,000-$3,000, primarily due to motors, so the team may have a hard time with competition. Plus, additional components are required in case of failure, making this design choice very difficult with such a limited budget. The primary function of this cost analysis was to give the team an idea of overall cost of a single, well-performing Sumobot, so that when sponsoring talks come up the team can give them a hard number of what is needed to easily outperform competition at NAU.

5.2.2 Nano Sumo Final Design

The final design for the nano sumo was a scaled version of the mega sumo. However, the nano sumo required fewer components. Rather than using an external gear box, the wheels were mounted directly on the motors. This was necessary to keep the bot under the 25g weight limit. Despite not being in the final concept indicated as best by the Pugh chart and Decision matrix, a wedge was included in the nano design as well. Wedged frames have additional offensive and defensive capabilities which are useful in any competition.

To simplify manufacturing, the nano shell was a scaled down version of the mega shell. However, the part was to be 3D printed using a scaled down G-code converter. This means the CAD files used for the mega sumo were recycled to save the team time.

5.2.2.1 Nano Sumo Motor Selection

Due to their small size, a nano sumo bot did not require a speed controller or an additional power source. Therefore, finding a suitable motor was the most difficult part of designing a nano sumo bot. The team chose the Solarbotics GM-15 motor, a 1.3-gram motor capable of being powered by just an Arduino, with an output of 920 rpm and 25.28g-cm of torque [14]. A drawing of the motor is shown in Figure 5.4. The motor also had a built-in gear box and wheels were 3D printed to mate with the output shaft. This reduced the cost of the nano bot and made construction simple.

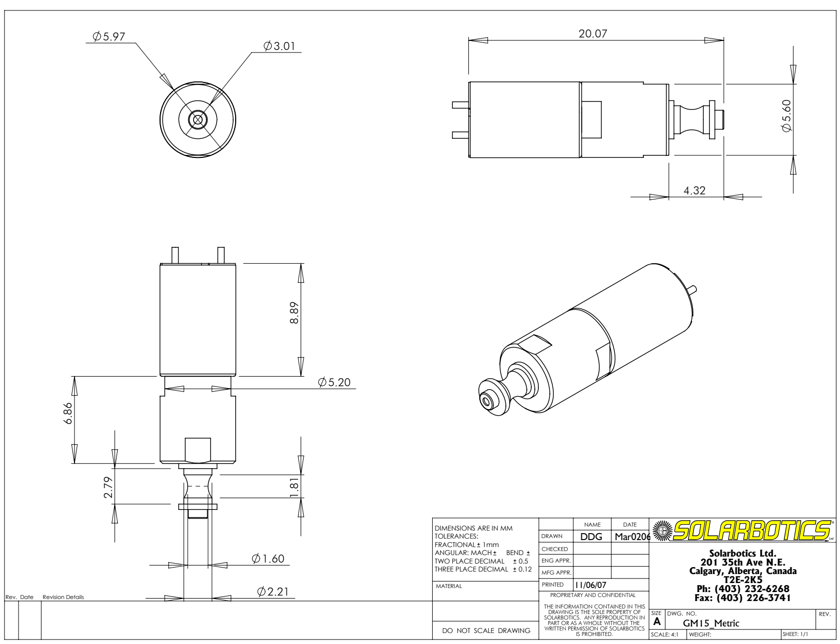


Figure 5.4: Solorbotics DC motor, part drawing, SI units (mm) [14].

5.2.3 Autonomous Control Programming and Algorithm

Both the nano and sumo bot had to be capable of autonomous control. To accomplish this, both bots used an Arduino microcontroller and were to be programmed in C++. Both algorithms would function similarly. Using Opponent and edge sensors, the algorithm powered one wheel to spin in place, once the opponent sensor was triggered, the second motor would be powered to allow the bot to move forward. If at any point the opponent sensor stopped sensing anything or an edge sensor was triggered, one motor would turn off so the bot spun in place and the algorithm repeated.

To prepare for programming the bot, an Arduino was set up to turn a servo motor in one direction. When a light sensor was triggered, the motor reversed direction. The code was written in the Arduino sketch language (a variation of C++) and can be seen in Figure 5.5. A layout of the circuit that was used can be seen in Figure 5.6.

```
Sumo_Proof_of_Concept §
#include <Servo.h> // allow access to servo library functions

Servo myservo; // create servo object to control a server

int sensorPin = A0; // set photoresistor to analog pin A0
int sensorValue = 0; // create sensor value variable

void setup() {

 // servo setup
myservo.attach(8); // set servo to pin 8
Serial.begin(9600); // set serial window readout speed
myservo.write(0);  // set servo to initial position

}

void loop()
{
  sensorValue = analogRead(sensorPin); // Read sensor value
  Serial.println(sensorValue); // print sensor value to output window
  delay(200); // wait 200 milliseconds

  if (sensorValue < 300) // check for a low light value
  {
    myservo.write(0); // if yes, set to initial position
  }

  if (sensorValue > 300) // check for high light value
  {
    myservo.write(180); // if yes, set to end position
  }

}
```

Figure 5.5: Sumo algorithm proof of concept code.

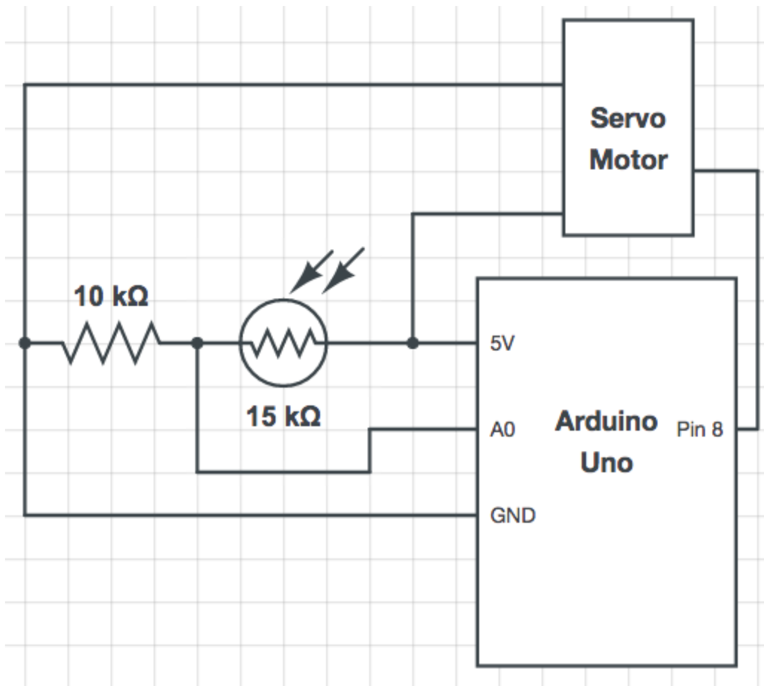


Figure 5.6: Proof of Concept Circuit Drawing

Both bots run the same algorithm. The main difference is that the mega sumo had four edge sensors and the nano bot had only one. However, this meant a single if-statement must be repeated four times, once for each input pin assigned to a sensor, in the code. With an algorithm for both the mega and nano sumo bots, a module for the combat bot can be completed.

5.2.4 Combat Module Final Design

To save money and time, the team decided to create a second shell for the mega sumo bot to give it combat capabilities. The shell design used an offensive wedge with a sharp point. This combines the strengths of a wedge and spear bot design. A spearbot design was chosen over the drum that was shown to be effective in the Pugh chart and Decision Matrix because of the reduced cost. Dynamic weapons require expensive, well protected motors that the team could not afford.

All internal components for the combat design remained the same as what is in the mega sumo. Battery time is the same because matches last three minutes in combat and sumo competitions. Below, in Figure 5.7, an isometric and exploded view of the combat shell on the sumo body can be seen. A full CAD package with measurements can be found in Appendix E.

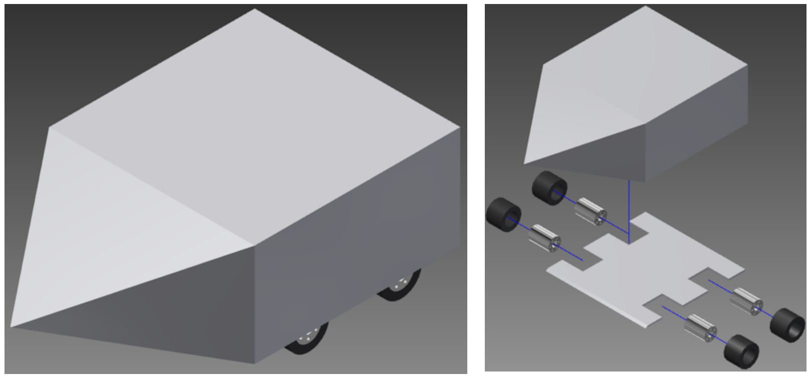


Figure 5.7: Combat bot module isometric and exploded view

5.2.4.1 Shell Thickness and Equivalent Forces Calculations

In designing a combat robot or any other mechanical device, it is important to ensure that the device will be able to withstand the elements of its environment. The environment of a combat robot is extremely unpredictable and hostile. Combat robots can be exposed to extreme temperatures, forces, and chemicals. One of the team's primary focuses was to ensure that the final combat design was able to take any physical beating dealt out by opposing robots. With the design restrictions on combat robots being minimal, there was a wide variety of feasible designs that could deliver high forces at virtually any angle. It was important to narrow down the possible forces to those that have a higher devastating tendency. The odds of the being able to withstand prolonged beating from opposing robots during the competition significantly increased the odds of moving on to the next round.

Table 5.1: Equivalent Forces Variables

Property	**Mass [m]**	**Time [t]**	**rpm**	**Radius [r]**	**Impact Area [A]**
Units	kg	s	rpm	m	m^2
Value	5	2	500	1	0.0001

Nomenclature:

- F: Force (N)
- m: Mass (kg)
- r: Radius (m)
- α: Angular Acceleration $\left(\frac{radians}{s^2}\right)$
- rpm: Revolutions Per Minute $\left(\frac{radians}{s}\right)$
- t: Time (s)
- A: Impact Area (m^2)

The scenario being evaluated was the possibility of facing a combat robot that had a horizontal rotational mass. The mass is being rotated around its body at 500 rpms and contacting with .0001 m^2 of surface area.

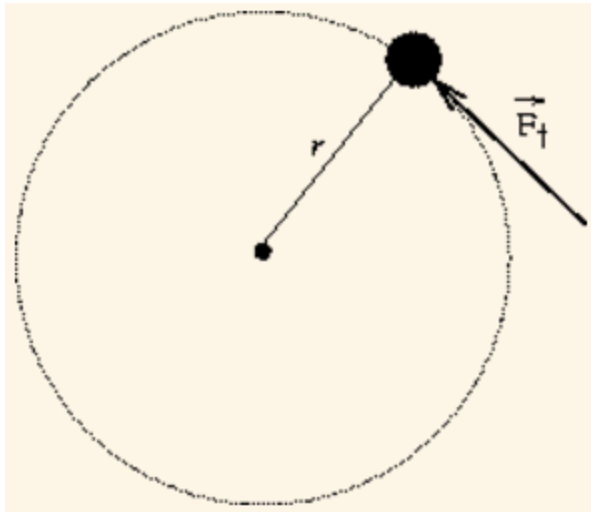


Figure 5.8: Example or rotational mass exerting a tangential force

Table 5.2: Force Equations

Equation / Conversion	Formula	Units
Force Due to Angular Acceleration	$F = mr\alpha$	N
Angular Acceleration	$\alpha = \frac{\pi n}{30t}$	$\frac{radians}{s^2}$
rpm → rev/s	$1\, rev = rpm/60$	rev
Angular Speed	$\left(1 \frac{revolution}{s}\right)\left(\frac{2\pi}{1} \frac{radians}{revolution}\right)$	$\frac{radians}{s}$
Pressure	$P = \frac{F}{Area}$	$\frac{N}{m^2}$

Table 5.3: Force Calculation Results

Property	**rpm --> rev/s**	**Angular Speed [ω]**	**Angular Acceleration [α]**	**Force [F]**	**Pressure [P]**
Unit	rev/s	radians/s	radians/s^2	N	N/m^2
Value	8.333	52.360	5.483	27.416	274155.678

According to the calculations in Tables 5.2 and 5.3, the minimal forces the combat robot could experience were determined. The design and the material of the combat robot should be able to withstand repetitive forces of 28N, and pressures of 274156 N/m^2. To achieve these impacts, the material selection, geometry and layering design play a role in being able to absorb and redistribute the energy being experienced.

6 PROPOSED DESIGN

This chapter covers the proposed designs that were followed at the beginning of manufacturing. As stated previously, manufacturing was simplified by using off-the-shelf components. A number of manufacturers were used, including Maxon, Solarbotics, Colson, RobotMarketPlace, the Arduino online store, and Jsumo. The frames and chassis of both nano sumo, mega sumo, and the combat shell module were to be constructed by the team. For each design, a bill of materials had been created to outline the overall costs and the internal components that will be used.

6.1 Mega Sumo Design

The mega sumo bot required the majority of the funding. As can be seen in the bill of materials, the sumo design goes over the team's budget of $1500 dollars. This was primarily due to three components, the two motors and the speed controller, totaling approximately $1000 alone. However, the team negotiated pricing with Maxon directly. A Maxon representative was confident all three components could be sold for $500 or less if the team agrees to a sponsorship deal. Maxon also seemed open to donating components, bringing the total sumo cost down to only $412, which was under budget. Additional funding through sponsorship, potential donations from NAU, and team contributions were still expected as well. Below, a full Bill of Materials can be found in Table 6.1.

Table 6.1: Mega sumo bot Bill of Materials [9, 12, 13, 14, 15, 16]

Bill of Materials							
Product Name		Mega Sumo Bot					
Team		Team 8 - NAU Sumo Competition					
Part #	**Part Name**	**Qty**	**Description**	**Cost**	**Weight (g)**	**Purchase Source**	**Manufacturer**
1	Maxon RE 35	2	DC Brushed Motor	$369.75	300	Maxon	Maxon
2	4-speed Worm Gearbox	2	Gear Reduction Gear box	$13.99	320	Robot Market Place	Tamiya
3	Performa Treaded Wheel	4	Wheels	$40.00	113	Robot Market Place	Colson
4	Aluminum 6061 T6	1	Sheet metal (15cmx15cm)	$20.75	500	Robot Market Place	Unknown
5	Arduino Uno	1	Microcontroller	$25.00	25	Adafuit	Arduino
6	QTR1A Contrast	4	Edge Sensor	$2.50	0.2	Jsumo	Pololu
7	Pepperl Diffuse Relective	1	Opponent Sensor	$59.00	28	Jsumo	Pepperl
8	FCON 50/5 Motor Controller	1	Speed Controller	$286.28	204	Maxon	Maxon
9	2700mAh 14.8V liPoly Pack	2	Battery	$54.99	234	Robot Market Place	Thunder Power
Total:				$1,438.49	2917.8		

The only component the team had to construct was the aluminum body and frame. This would be done using a CNC Tormach mill in the NAU machine shop. G code was to be generated from the CAD files to prevent human error during the milling process. All other components were to be purchased from the sources stated in the Bill of Materials. The algorithm was programmed and tested in the Arduino sketch language, a variation of C++. A single opponent sensor was placed on the center of the flat front piece, above the wedge. One edge sensor was placed on each corner of the bot. The mega sumo bot design was very similar to the nano sumo. With the same frame design, the only difference for the nano sumo is size, a lack of speed controllers, and fewer edge sensors. To ensure the bot is completed on time, all internal components were to be ordered during the three week break between semesters and the frame was to be constructed at the beginning of the semester, as soon as the team was approved to enter the machine shop. Construction was expected to be completed within two months of the semester beginning. This left enough time to conduct any necessary testing.

6.2 Nano Sumo Design

The final nano sumo design used inexpensive components and limited the number of parts as much as possible. With no gear box and the ability to 3D print the frame and wheels, the total cost of the nano was very low, as shown in the Bill of Materials shown in Table 6.2 below. The exploded and assembly views are the same as the mega sumo. This is because the same CAD file will be used when creating the body. The Files will be scaled to one 1/8 the size and be 3D printed.

Table 6.2: Nano sumo bot Bill of Materials [9, 10, 14, 15]

Bill of Materials							
Product Name		Nano Sumo Bot					
Team		Team 8 - NAU Sumo Competition					
Part #	**Part Name**	**Qty**	**Description**	**Cost**	**Weight (g)**	**Purchase Source**	**Manufacturer**
1	GM-15 Planetary Motor	2	Motor	$7.00	1.3	Solarbotics	Solarbotics
2	Wheel/Frame Filiment	1	Filiment spool	$10.00	10	Amazon	Nau Maker Lab
3	Arduino Lilypad	1	Microcontroller	$15.00	4.7	Adafruit	Arduino
4	QTR1A Contrast	1	Edge Sensor	$2.50	1	Jsumo	Pololu
5	MZ80 Infrared Diffuse	1	Opponent Sensor	$9.50	5	Jsumo	Pepperl
Total:				$51.00	23.3		

Just like with the mega sumo, all components other than the frame were off-the-shelf. The frame was 3D printed. Motors were connected with an adhesive, such as super glue, and the microcontroller was placed directly on top of the motors. The opponent sensor was in the same place as on the mega sumo, on the front plate above the wedge. One edge sensor was placed on the bottom center of the wedge. Without the need for speed controllers, the microcontroller, an Arduino Lilypad, was connected directly to the motors.

The nano bot was to be constructed during the three week break between semesters. Testing and programming would start and a functional design was to be complete by the start of Spring semester.

6.3 Combat Module Design

To turn the mega sumo bot into one capable of competing in a combat competition, an alternative external shell was designed. The only purchase, shown in the Bill of Materials in Table 6.3, required was sheets of steel plating. The plating was used to create a strong frame capable of withstanding the forced expected in a combat competition. The forces assumed were those calculated in section 5.2.4.1, the equivalent force analysis. With 5mm thick armor, the shell should be strong enough to protect all internal components.

The shell was intended to be manufactured on a Tormach CNC located in the NAU machine shop that is capable of cutting steel. The sheet metal could have been cut to appropriate dimensions and then folded into the shape desired. The module would have then been a single component just like the mega sumo shell. Switching between combat and sumo modules would be easy and quick. This component would have to be one of the first made because there is only one machine available that can create this frame. Waiting too long could mean losing access to the machine.

Table 6.3: Combat bot Bill of Materials [9, 12-16]

Bill of Materials							
Product Name		Combat Bot (Total)					
Team		Team 8 - NAU Sumo Competition					
Part #	**Part Name**	**Qty**	**Description**	**Cost**	**Weight (g)**	**Purchase Source**	**Manufacturer**
1	Maxon RE 35	2	DC Brushed Motor	$369.75	300	Maxon	Maxon
2	4-speed Worm Gearbox	2	Gear Reduction Gear box	$13.99	320	Robot Market Place	Tamiya
3	Performa Treaded Wheel	4	Wheels	$40.00	113	Robot Market Place	Colson
4	Aluminum 6061 T6	1	Sheet metal (90cmx90cm)	$56.99	500	Robot Market Place	Unknown
5	Arduino Uno	1	Microcontroller	$25.00	25	Adafuit	Arduino
6	FCON 50/5 Motor Controller	1	Speed Controller	$286.28	204	Maxon	Maxon
7	2700mAh 14.8V liPoly Pack	2	Battery	$54.99	234	Robot Market Place	Thunder Power
Total:				$1,405.73	2889		

Note that the bill of materials shown in Table 6.3 shows all components, included those already purchased for the mega sumo bot. This bill of materials was also not accounting for any discounts or donated components obtained from Maxon through sponsorship. The actual cost of the combat module is just $56.99, the cost of the steel sheet metal that the frame was to be constructed from.

Additionally, sensor costs were removed from the combat bill of materials because it was remote controlled. The exploded view and isometric view of the combat module on the sumo base are the same as those shown in section 5.4.

6.4 Proposed Design Conclusion

Construction of all three bots was expected to be completed within the first two months of Spring semester. The total cost, assuming discounts from Maxon of $500 (which were confirmed by the company), the total costs comes out to just under $1000. The team was right on budget and expected construction to go smoothly. All parts were ordered directly to Flagstaff at between the Fall 2016 and Spring 2017 semesters and arrived before the team was ready to begin construction.

7 IMPLEMENTATION

The implemented design was the same as what was purposed in Chapter 6. However, a few changes were made. These changes included a change to a single 14.8-volt battery, rather than two 11.1-volt batteries in series, and the addition of neodymium magnets to the bottom of the robot to increase downward force. This chapter covers the manufacturing of the frame, the combat and sumo top shells, and the internal component selection. Additionally, a description of the design of experiments with statistical results will be discussed. A detailed schedule of all implementation tasks can be found in Appendix H.

7.1 Design of Experiments

The performance parameter of the Design of Experiments (DOE) conducted was for an edge sensor and requires two replicates. This was a two-level DOE with three design variables which measure the light level, shades of black, and distance from surface. The light level was measured with a photoresistor at standard LED light levels near a window and then "bright" conditions simulated by a flashlight, where output voltages were 250 and 500, respectively. The shades of black were measured on a matte black and reflective surface where output voltages were 35 and 50, respectively. The distance from surface was measured by height above surface at 1 and 3 centimeters. The performance parameter was the difference of voltage output measured by the edge sensor when transitioning from a white to black surface. This change was what the Arduino measured and told the motors to stop, so the design variables were all the aspects that would affect the motor stop time. The actual experiment involved moving the edge sensor from a white to black surface and measured the voltage difference the sensor read. Randomly, the height was changed, the light level was changed, and the black surface was changed. The results of doing this experiment twice are represented by the empirical equation **7.1** below with the standard deviation equaling 54.44 and three times this value totaling 163.32.

$$y = 498.6 - 10.75x_1 + 60.75x_2 - 255.75x_3 \qquad \textbf{Eq. 7.1}$$

This equation, along with the standard deviation, showed that the light levels and shades of black on the arena had little effect on overall performance, but the distance the sensor was placed on the sumobot and where that sits above the arena greatly hampers the outcome. These results were confirmed by the response diagrams in Appendix I, where the Figures I1-I3 show the respected response diagrams. Figure J3 shows a large slope, thus making it an important design variable. A large difference between the white and black surfaces makes it easy for the sensor data to notice the transition, but when the edge sensor was barely off the surface, this difference drops significantly. This would be difficult for the edge sensor to relay to the motors quickly and could result in the motors not stopping quickly enough. Therefore, these variables were chosen, because the edge sensor needed to find the edge and instantly turn off the motors, otherwise the sumobot would drive off the edge. Thus, the overall light level and black level of the arena would not harshly affect the sensor, but the sensor had to be placed as close to the ground as possible. The DOE and response diagrams for the three design variables are below in Appendix I.

7.2 Initial Manufacturing

To fill all design requirements, a single robot was manufactured that is capable of meeting all requirements. This is accomplished by including an RC receiver and microcontroller in the same robot. Additionally, as discussed earlier, two top shells were to be constructed. The sumo shell was made of quarter-inch aluminum with relief cuts that brings the total weight below the 3kg weight requirement. The combat shell used the same design but will not have relief cuts to increase its strength and weight. The combat shell also used a pointed wedge design to increase the potential damage it can inflect at high speeds. The internal components did not need to change because the combat design was based on a basic wedge design. Table 7.1 shows the bill of materials for all purchased materials. The metal used for the frame is not included because it was donated to the team. No additional purchased were required for the completing of the project. The manufacturing was broken into four components: internal component selection, internal frame and component mounting, outer sumo robot and combat shells, and writing the algorithm which will control the sumo robot during the autonomous competition.

Table 7.1: Finalized Bill of Materials [9, 12-16]

Part Type	Part Name	Qty	Cost ($)	Manufacturer
Motor	Maxon RE 35 15V DC Motor	2	$200.00	Maxon
ESC	Sabertooth Dual 32A Motor Driver	1	$129.99	Dimension Engineering
Opp sensor 1 (front)	Diffuse type reflective	2	$59.00	Pepperl+ Fuschse
Edge Sensor	QTR1A Contrast	4	$2.50	dimension Engineering
Wheels (pair)	Hardened Rubber 40x30mm Pair	1	$44.95	jsumo
Magnets	Neodymium,15x5mm	10	$2.50	jsumo
gears	6,4:1 2-stage Reduction	2	$60.00	jsumo
Micro controller	Arduino Uno	1	$27.99	Arduino
Battery	3200mAh, 14.8V lipo	1	$49.99	Flagstaf Hobbies
Transmitter/reciever	6 channel transmitter/reciever bundle	1	$60.00	Flagstaff Hobbies
shipping fees	Jsumo	1	$45.10	Jsumo
Total				**$1,031.02**
Remaining				**$468.98**

7.2.1 Internal Components

Both designs used the same internal components. The key electrical internals included: the motors, electronic speed controller, microcontroller, sensors, transmitter, receiver, and the battery. These components were purchased off the shelf rather than manufactured from scratch. The mechanical internal components, which were also purchased off the shelf, include: wheels, magnets, and gears.

The electrical components were all chosen to be able to accommodate the motors. The Sabertooth 32 Amp speed controller was necessary because the motors can pull up to 47 Amps at stall. Although the robot was not expected to stall, with a heavy load, the motors could pull up to 30 Amps. The speed controller was also compatible with both an RC receiver or an Arduino Uno. The battery selected supplied 14.8-volts which was very close to the recommended 15-volts that Maxon recommends for their motors. Lastly, two types of sensors were selected. First, the opponent sensors, the Pepperl+Fuschse infrared sensors had a range of 1000mm. This allowed the robot to sense the opponent but not pick up objects outside the arena. The QTR1A contrast sensors sensed color transitions and could be calibrated to see the white border line of the arena. These sensors were also of a high enough quality that they would not pick up scratches or defects in the arena's surface. Lastly, the transmitter and receiver combo was a six-channel pair, this was enough slots to have a forward, reverse, left, and right command. Two additional slots were left open in case the team decided to add a dynamic weapon before completion of the project.

The mechanical components selected were all purchased from Jsumo, a manufacturer in Turkey that specializes in sumo robot components. The wheels selected meet the recommended 30mm thickness and were made of a hardened rubber of 64 Shore A hardness to maximize traction and minimize shock on impact. The gears selected were a two stage, 6,4:1 reduction. They were made of hardened steel to ensure they did not suffer any damage during either a combat or sumo competition. This specific reduction was selected because the gears were made to pair with the wheels that were purchased.

7.2.2 Internal Frame Construction

The internal frame was to be used for the sumo and combat robot. An image of the internal frame with all the components inside can be seen in Figure 7.1.

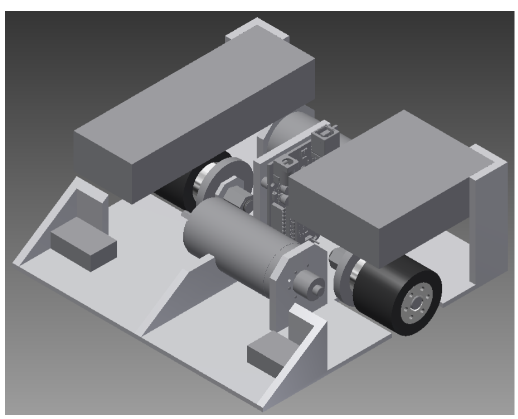


Figure 7.1: Internal frame with mounted internal components

The frame was constructed out of aluminum metal that was scrapped from a large table, which was donated to the team free of cost. The base plate, side plates, front wedge, and gear shafts were manufactured. The base plate was shaped on a manual mill and the shafts were grade 8 bolts which were turned on a lathe. An example of the shafts that were made can be seen in Figure 7.2. This shaft design was chosen due to high strength and low cost. The bolts were donated to the team.

Figure 7.2: Gear Shaft design example

The skeleton of the frame was 3D printed to further reduce weight of the frame. The outer shell was expected to be strong enough that these components would not break during competition.

7.2.3 Outer Shell Construction

Both the sumo bot and combat bot outer shells were to be constructed in the same way and out of the same material. Both were made using the same aluminum sheet metal that was used to make the base. Each shell was a single piece which was placed on top of the base plate. The shell was screwed into place on the sides directly into the sides of the base plate. The shells were constructed by folding one piece of metal into the desired shapes. For the sumo robot, a wedge was used to allow the robot to lift the opponent and prevent them from gaining traction. The combat bot used a pointed wedge to maximize damage on impact, as mentioned earlier. Figure 7.3 shows CAD images of both shells.

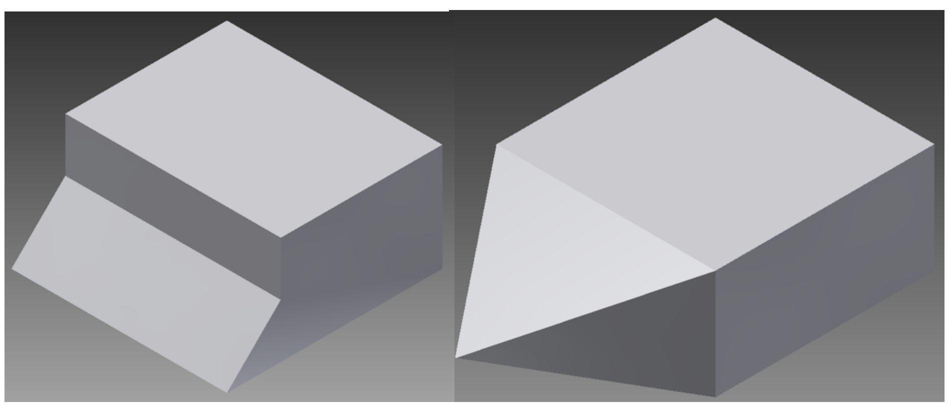


Figure 7.3: Sumo (left) and combat (right) shell CAD designs

7.2.4 Autonomous Algorithm

For the autonomous competition, the sumo robot had to be able to control itself without receiving any inputs or information from a human controller. To accomplish this, an algorithm that used input data collected from the edge and opponent sensors was uploaded to the Arduino microcontroller. The algorithm consisted of three section: the defining of all variables, the setup, and the main loop.

The first part of the algorithm, shown in Figure 7.4, defined all variables. The first variable defined is the motors. This is done with by uploading a custom library (line 3) made by the speed controller manufacturers, Sabertooth. The motors were called ST1 and ST2 and were given an input range of 0 to 128 (lines 5-6). Next, the opponent and edge sensors are defined and assigned to their respective input pins (lines 8-13).

Capstone_Code §

```
1  // Code Autonomous Robot
2
3  #include <Sabertooth.h>
4
5  Sabertooth ST1(128); // Designating motor 1 as ST1
6  Sabertooth ST2(128); // Designating motor 2 as ST2
7
8  int Opp_1 = A0  // Infared sensor connected to analog pin A0
9  int Opp_2 = A1  // Infared sensor connected to analog pin A1
10 int Edge_1 = A2 // Edge sensor connected to analog pin A2
11 int Edge_2 = A3 // Edge sensor connected to analog pin A3
12 int Edge_3 = A4 // Edge sensor connected to analog pin A4
13 int Edge_4 = A5 // Edge sensor connected to analog pin A5
14
```

Figure 7.4: Defining variables in the algorithm

With each variable defined, the initial setup was conducted. This section of code was shown in Figure 7.5. This step assigned each sensor as an input (lines 20-25). Next, in accordance with competition rules, the robot would delay 5000 milliseconds before it starts moving (line 27). For the final step in the setup, the motors were both commanded to go forward at full power (lines 31-32).

```
17 void setup()
18 {
19
20   pinMode(Opp_1, INPUT);
21   pinMode(Opp_2, INPUT);
22   pinMode(Edge_1, INPUT);
23   pinMode(Edge_2, INPUT);
24   pinMode(Edge_3, INPUT);
25   pinMode(Edge_4, INPUT);
26
27  delay(5000);       // Wait 5 seconds before the sumo match begins.
28
29
30 // Sends the robot straight forward after the 5 second delay
31    ST1.motor(1, 127);  // Go forward at full power.
32    ST2.motor(1, 127);  // Go forward at full power.
33 }
```

Figure 7.5: Algorithm setup loop

The last, and most important, section of the algorithm was the void loop. This loop ran continuously until the robot shut down or ran out of battery. This section of code consisted of six if statements. Each statement checked the edge and opponent sensors to determine what direction the sumo robot should move in. For opponent sensors, the statements determined whether the opponent was in front of, behind, to the left, or to the right of the sumo robot. Based on the opponent's position, the robot would either charge forward, turn left, turn right, or turn around. The other two loops check the edge sensors. If an edge sensor was triggered, the robot reversed to prevent it from driving over the edge. If an edge sensor was not triggered, the robot followed instructions determined by the opponent sensor readings. Note that the code currently states HIGH or LOW for sensor outputs. The values that correspond to HIGH and LOW values had to be determined based on the lighting conditions. The void loop can be seen in Appendix J.

7.3 Final Manufacturing

After beginning manufacturing, the team decided to change the overall design each design. Instead of doing as single top shell that was replaceable, the team decided to build two separate frames that used the same electronics. This change was made so that the sumo robot frame could better meet the engineering requirements and match what the research showed was more common among professional designs. Note that the internal component selection and programming discussed in Section 7.2 was unchanged.

7.3.1 Sumo Robot Frame Design

The new sumo robot frame was constructed with 1/8th inch mild steel. The frame consists of two parts, a bottom steel housing to hold the motors, gears and wheels and a top housing to hold the electronics. The bottom housing consists of a base, two side panels, a middle rib for structural support, and a front scraper. These pieces were tack welded together to hold them together. A CAD image of how these pieces connect can be seen in Figure 7.6. Each of these pieces had a number of relief cuts made to reduce weight.

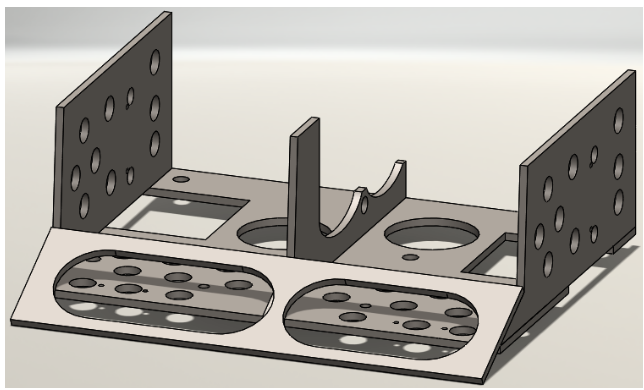


Figure 7.6: Fully assembled base frame without any internals

The bottom frame held the motors, edge sensors, and magnets. The motor mounts were custom made with aluminum. Six screws held the motors in place, as shown in Figure 7.7. After constructing the base and mounting the motors, the edge sensors and magnets were mounted. Figure 7.8 shows the base of the bot and specifies which screws correspond to which component.

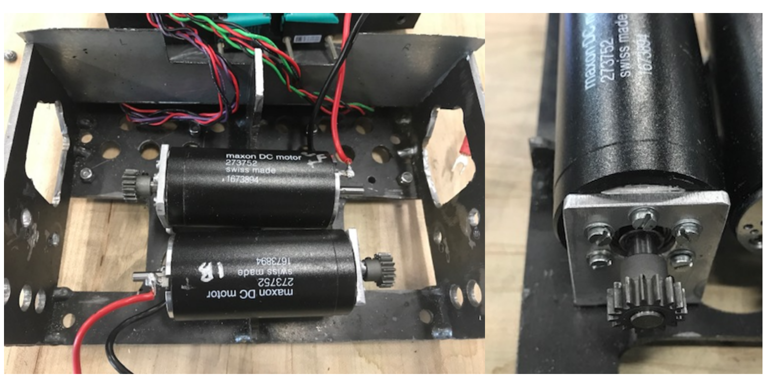


Figure 7.7: Mounted Motors

Figure 7.8: Base fastener location reference

Lastly, the gears and wheels were mounted on 1/4th inch steel rods. Plastic spacers hold the gears in place. Figure 7.9, which shows the layout of the shafts, demonstrates how the gears were connected. Rather than using the intermediate gear for additional reduction, it was used as a direct ratio so that the pinion gear lined up better but reduced the gear ratio from 6,4:1 to 2.5:1. Although this reduced the overall toque of the robot, the team thought the robot would still have an acceptable amount of torque to be effective.

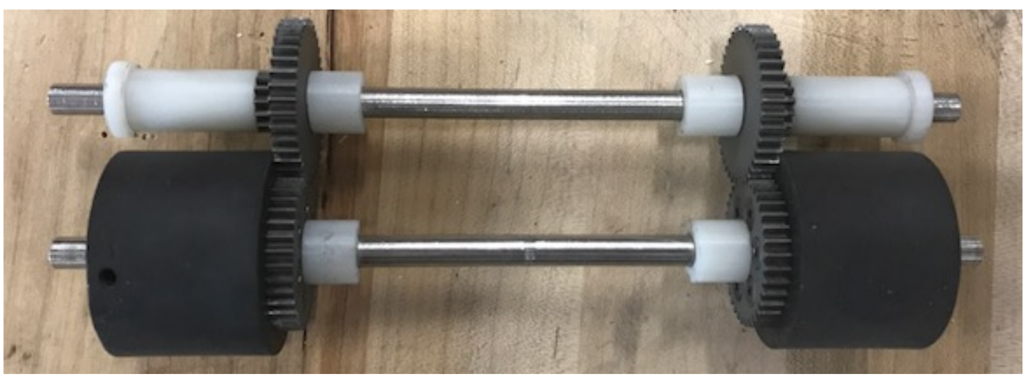


Figure 7.9: Shaft wheel, spacer, and gear layout

For housing the electronics, the team 3D-printed a top housing, shown in Figure 7.10, that held the battery, speed controller, microcontroller, and RC receiver. Although the components were not bolted and secured down, a top cover made sure nothing fell out. In addition, the components fit tightly together so that there was not any room for them to move around during operation. The top housing bolts to the bottom housing with M6x80 screws that thread through the base of the bottom housing, as shown above in Figure 7.8. Lastly, the top housing had four screw holes in the front that the opponent sensors attach to the bottom of.

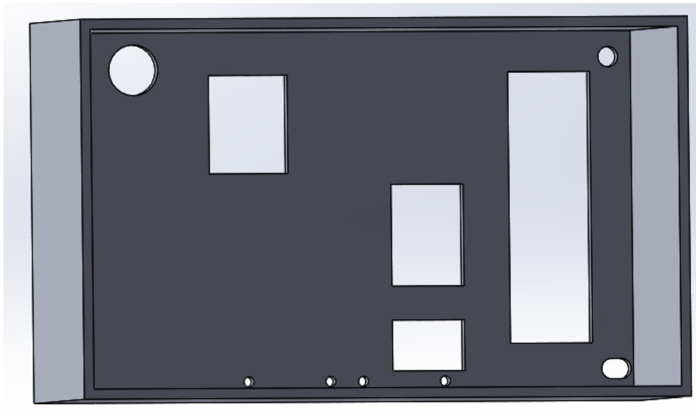


Figure 7.10: Empty top housing before instillation

After completing the main frame, relief cuts were made to reduce weight. Figure 7.11 shows a member of the team making the relief cuts as well as the robot with all components mounted and all relief cuts made.

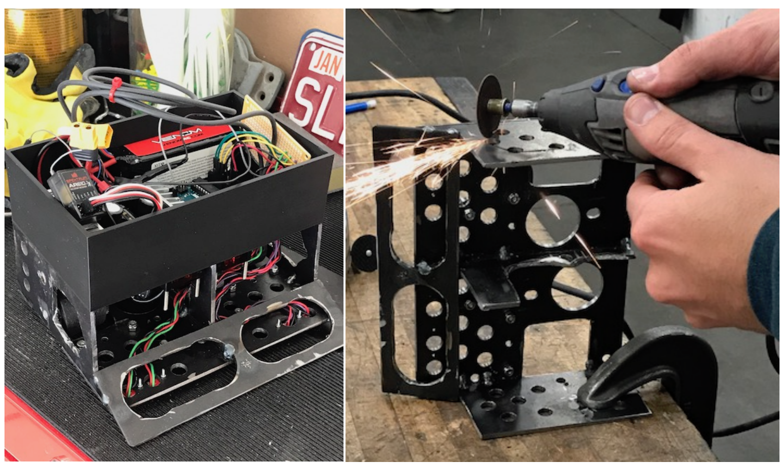


Figure 7.11: Relief cuts and final frame without side panels.

With the frame complete, the frame was then surrounded with panels and skirts made of 28-gauge galvanized steel. These plates served a few purposes. First, they protected the internal components from being damaged during competition by covering up the relief cuts. Second, they made sure that that was no clearance between the frame and the ground. This prevented the opponent's robot's scoop from getting under the bot. Lastly, the panels made the robot look more professional. The side and back panels were held on with 8-32x3/16 screws. The front panels were attached using JB weld. Figure 7.12 shows a final image of the robot, fully constructed with all panels attached. Figure 7.13 shows the final circuit to demonstrate how all the electronics were connected.

Figure 7.12: Fully assembled sumo robot

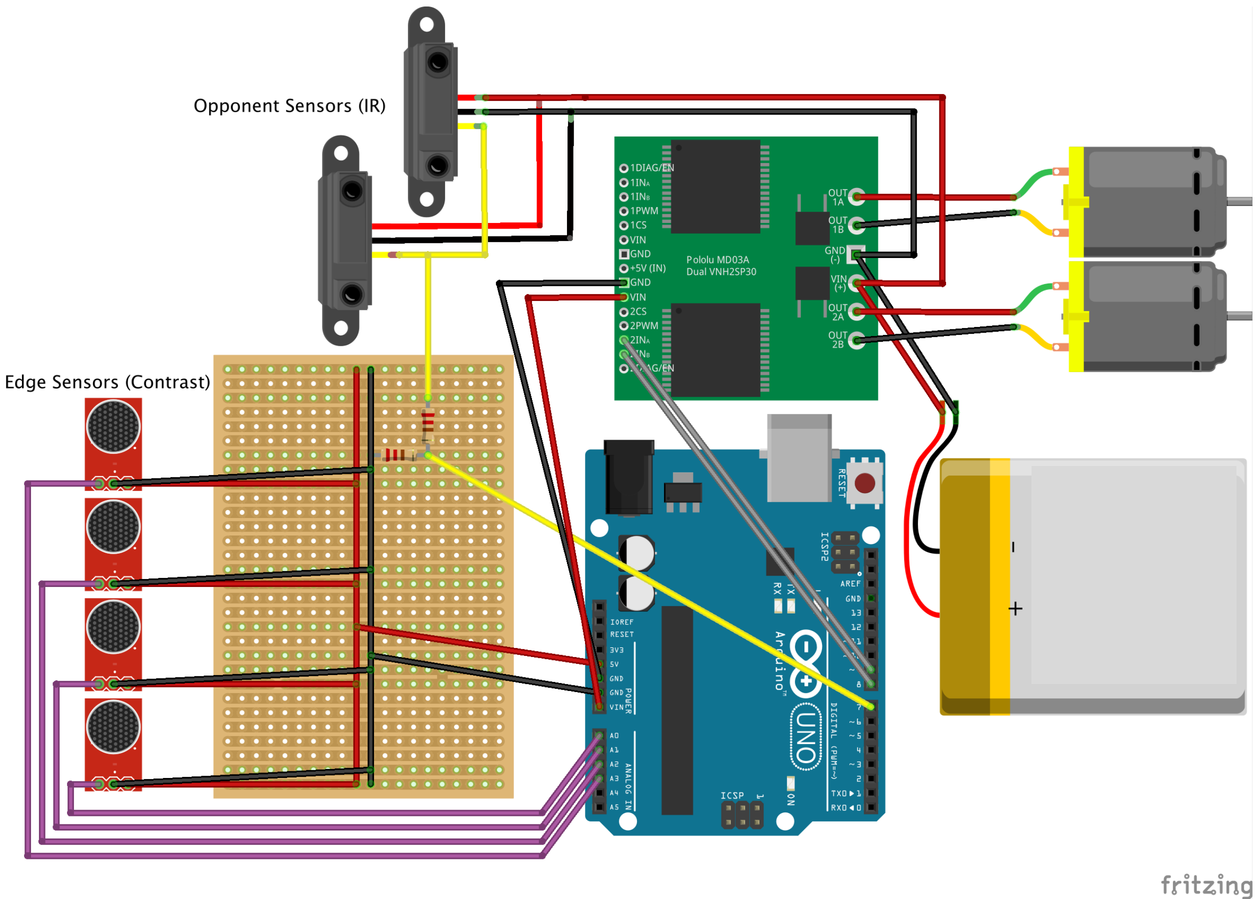


Figure 7.13: Complete electrical circuit

7.3.2 Combat Robot Frame Design

As originally planned, the combat robot uses all the same internal components as the sumo robot. The sensors do not need to be implemented because there is no autonomous component for the combat robot. The combat robot was still constructed with 1/4th inch aluminum but was changed to be a simple wedge design just like the sum robot. This was done because it was both easier and cheaper to construct. The original pointed shell proved difficult to build in a way that would not fall apart on impact.

Manufacturing consisted of two parts: the outer frame and the internal mounting. For the outer frame, a base place was made with three slots, as shown in Figure 7.14, that the mounting components would attach to. The base plate also has two sides cut out of the sides that the wheels are mounted over. This allowed the wheels to be fully contained and prevent them from being hit or damaged.

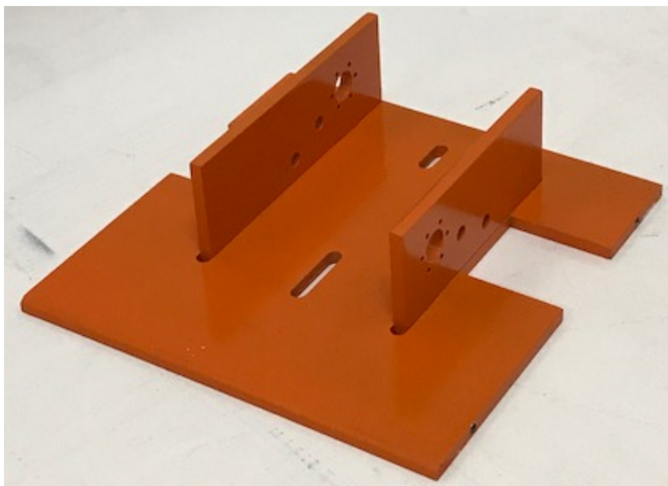


Figure 7.14: Combat base plate with mounting hardware

The rest of the frame consists of six parts: a top, two side panels, a front wedge, and a front face plate. Each piece was tapped and threaded to allow a total of 20 screws to be used to attach all of the components. The final frame did not require any relief cuts. The robot was designed for a 10-pound competition and the final frame weighed 2360g. With internal components, the final weight was approximately nine pounds. Figure 7.15 shows the frame with the side and back panels attached as well as all pieces except the top.

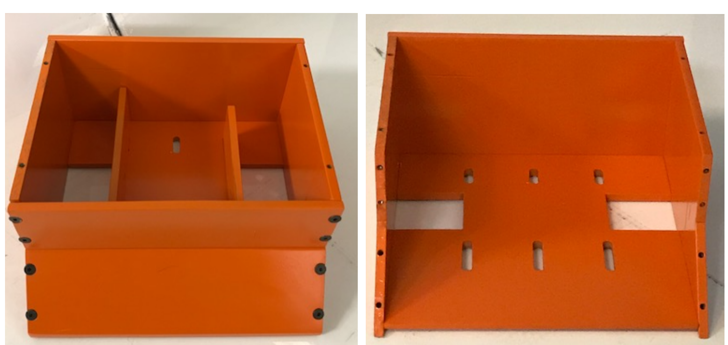


Figure 7.15: Combat frame assembly views

For internal mounting, the gears were used as the original 2-stage, 6,4:1 reduction ratio setup. The motors were also mounted using the same method as the sumo robot. The gears and wheels mount on individual pieces, prototypes of which are shown in Figure 7.16.

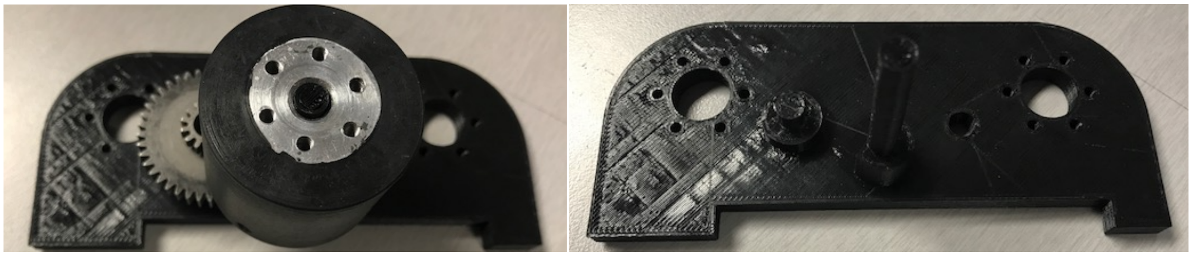


Figure 7.16: Gear and wheel mounting components

The components are held in place by having the mounting rods press against the side panels. The full mounting components are held into place because it fits both into the slots on the bottom and is pushed down on from the top by the top piece. A final image of the fully constructed frame is seen in Figure 7.17.

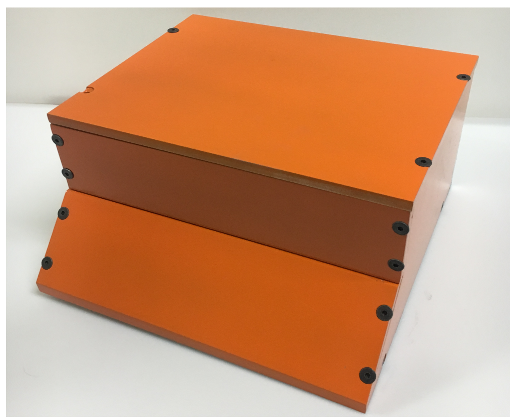


Figure 7.17: Fully assembled combat robot

8 Testing

During testing, the used the testing procedures outlined in Section 2.3. These procedures were used to ensure all engineering requirements were met. Both engineering and customer requirements are summarized in Table 8.1. In this Chapter, how each procedure was conducted is discussed as well as the results. Appendix K summarizes the results of each test.

Table 8.1: Customer and engineering requirements

Cusomter Requirements	Weight	Engineering Requirments
Stay Under Budget	5	Total cost below $1,500
Identifying Team Mark	5	Team Logo
Maximize Weight for Class	4	Weighs 3,000 grams
Durability	4	Maximize frontal area
Defensive Capabilities	4	Minimize height for all designs
Ease of Operation	3.3	Remote-control capable
Adaptive Algorithm	3	Autonomous - control capable
Offensive Capabilities	2.6	Maximize Coefficient of Friction
Maneuverability	2.3	Small radius of turning
Speed	2	High motor transfer rate

8.1 Testing Procedure Results

In this section, each testing procedure will be discussed. How it was conducted, the results, and which engineering requirements it satisfied are mentioned. Overall, all requirements were met and all tests were passed by both designs.

1.) Visual Quality – For the visual quality inspection, both robots were looked at by each team member to ensure that it looked professional and effective. For the both designs, the team agreed that robots looked highly professional. The combat robot was painted a clean, bright orange and sumo robot was painted a dark black. All components were attached in a sturdy, professional way that helped cause the designs to pass the visual quality test. During the inspection, the team also made sure that the identifying team mark was clear and visible. The top cover, which contains the team's logo, was visible and meets the engineering requirement of having a visible team logo.

2.) Total Component Cost – The total cost was calculated by adding up the total cost of all components and purchases. The engineering requirement of having the total cost below $1,500 was met because the final cost of both designs was $1,095 which is $405 under budget.

3.) Dimensions Test – This test only applied to the sumo robot because the combat robot does not have any size requirements. The final measurements, which were taken with a traditional metric ruler, was a length of 19cm and a width of 17.5cm. This both satisfied the competition restrictions of 20cmx20cm and met multiple engineering requirements. By having a large width, the front scraper, which was the third point of contact for the robot, had a high amount of surface area with the ground. This helped to maximize the coefficient of friction between the robot and the ground and gave a large frontal area, meeting two more engineering requirements.

Even though it was not being required, this test was still conducted on the combat robot. The final measurements were exactly 20cmx20cm. This helped the robot meet the same engineering requirements of maximize frontal area and coefficient of friction.

Both designs also had their heights inspected. After both designs were complete, the efficiency of hardware mounting was inspected to deem whether or not the height could have been minimized. Even though the designs were not perfect, the team agreed that the height was low enough to satisfy the minimize height requirement as well.

4.) Weight Test – For this test, both robots were weighed using a digital cooking scale. With all components, the sumo robot weighed a total of 2886g and the combat robot weighed 4080g. Both robots were just under the maximum weight requirements. Therefore, the engineering requirement maximize weight for class was met.

5.) Transfer Rate Test – During this test, the transfer rates were tested for both designs. This was done by counting how many rotations of the motors it took to rotate the wheels one full rotation. For the combat robot, the full gear reduction ratio was 6,4:1, which is greater that the required 6:1. However, the sumo robot only has a gear reduction ratio of 2.5:1. Despite not meeting the target reduction ratio, the team considered this acceptable because the motors already produced a significant amount of torque that was deemed acceptable to be affective. With reduction ratios, the amount of torque produced gave both robots significant pushing power. This meets the high transfer rate requirement for both designs.

6.) Controls Test – The controls test was conducted in two parts. For the RC component, the team had each member drive the robots to make sure it was intuitive and easy. During this test, the turning radius and speed was looked at. At full speed the robot was capable of going much faster than would be required. A tank style control scheme was also used to allow a zero point turning radius. The second part of the controls test was to see the autonomous control function. This test was conducted by placing the sumo robot in the arena and making sure it would not drive off the arena and could successfully push various object in random locations out of the arena. Both control methods were effective. Therefore, the engineering requirements of remote-control capable, autonomous-control capable, and small radius of turning were all met.

7.) Material Strength Test – This test involved hitting each frame material with a blunt impact force, such as a hammer, and checked for yielding. Both the aluminum used for the combat robot and steel used for the sumo robot was tested and did not yield. Although this test did not correspond with any specific engineering requirements, it did relate to customer needs. The durability and defensive capabilities needs were both proven to have been met with this test.

8.) Sensor Test – This test involved making sure that the edge and opponent sensors had acceptable output speeds and values that could be read by the microcontroller. Table 8.2 shows the specific outputs and specifications of both sensors. This test further ensured that the autonomous-control capabilities were met.

Table 8.2: Opponent and edge sensor test results.

Sensor Testing Results	
Opponent Sensor Detection Range:	0-1000mm
Opponent Sensor Reaction Time	Instant
Edge Sensor Detection Range:	0.5-7mm
Edge Sensor Reaction Time:	Instant
Edge Sensor Transition Output Difference:	≅2.5 Volts

Overall, all the engineering requirements were met. Both designs were considered effective and, after testing, were thought to be competitive and stand a good chance of winning the sumo robot competition on campus. With all testing complete, no major changes were made to the designs.

9 Conclusion

After manufacturing and testing was complete, the team competed in the NAU sumo robotics competition. The sumo robot performed well and was the overall winning design in the competition. With the competition complete, the team analyzed the overall performance of the members and final results of the project. Overall, the team effectively met the purpose and goals laid out in the team charter, which was to win the competition. However, the ground rules and coping strategies were not effectively followed which caused some problems in both team dynamics and meeting deadlines.

9.1 Contributions to Project Success

The biggest contributors to the project's success was the hard work and diverse skills of the team. All members were dedicated to completing the projected and scarified time and money to make the team succeed. The components chosen, despite being expensive, were well worth the cost because of their performance. Specifically, the Maxon motors that were used were a major contributor to the sumo robot's success. The magnets were also a major success. Future sumo robot projects should make sure to use both of these components. However, it should be noted that both high power motors and magnets need to be used together. Without the magnets, the robot will not be capable of stopping in time to not drive over the edge of the Arena. If high power motors are not used, the magnets will prevent the robot from being able to move.

The team's system of using text and email for most communications was partially effective. It allowed all members to stay in touch and update each other on the progress of individual components of the project. The coping strategies and ground rules that said all controversy was handled through voting was also partially effective. When the team was able to vote, problems were quickly and effectively dealt with.

The team used two main tools that were most effective. First, during the research phase, the team focused heavily on what professional teams did rather than trying to come up with unique ideas. This allowed the team to focus heavily on component selection and implementation rather than research and concept generation. The other main tool used was the angle grinder and dermal in the machine shop. Rather than using high precision tools like mills and lathes, the team used tools that were quick and effective by doing most measurements by hand and tracing lines on the materials. Despite using less precise tools, the final products were highly professional, correctly dimensioned, and effective.

9.2 Opportunities for Improvement

During the project, the team ran into a number of problems in team dynamic and meeting deadlines. Despite the team charter saying that team votes would be used to solve problems, there were times where some members did not have an opinion on an issue. This caused some conflicts to only be between two members. These problems were unable to be solved with a vote and caused unnecessary tension. Another problem was that hard deadlines were not enforced. Due to lax deadlines, some tasks got continuously pushed back which left little time for final testing to be conducted. The team was unable to dedicate enough to time to get the algorithm in the state that was wanted. Although the algorithm functioned fine and was potentially able to win competitions, it was not adaptive in the same way the team wanted. To improve this, a number of organizational actions could be taken. The first is that the team agree to hard deadlines for individual team members rather than just overarching goals. The team could also refrain from assigning major tasks to individual members. By multiple people trying to work together, they may be more motivated to meet deadlines.

For manufacturing, the biggest negative decision made by the team was taking so much time to finalize the design rather than starting construction sooner. Despite trying to make sure the design was perfect, roadblocks such as figuring out wiring or sensor placement was only encountered once building began. The team is better off building sooner to make sure problems are encountered early rather than over planning.

The final and most important setback for the team as not having spare components. Moments before competition, the team shorted out the speed controller which made the sumo robot unable to function. The team was able to get replacement parts before the competition started but was not able to engage the autonomous functionality with the new components. For future teams that compete in a competition, it is paramount that spares of all parts, especially electrical components, be purchased and brought to competition.

9.3 Technical Lessons

This project taught the team a number of important technical lessons. Despite all having experience with manufacturing, no one on the team had experience sizing and selecting electrical components. When sizing components, it is important to start with the motors and select all other components from there. After knowing the amp and voltage requirements of the motors, a speed controller that can supply a higher amperage than the motors will draw at stall will prevent pulling too high of a current and destroying the controller. After those are selected, a battery that is able to supply the specified voltage to the motors can be chosen.

The team also learned about programming sumo robots. Some members learned how to program in the Arduino sketch language. Others learned how to troubleshoot circuitry and algorithms to find what exactly a robot is seeing and why it is reacting the way that it is. The final algorithm changed heavily over time as the team learned more about the functions and capabilities of Arduino micro controllers as well.

Overall, this project gave the team insight into how to implement hardware, software, and design decisions into a single project as well as how to function as a team and communicate effectively. Despite the overall success of the project, the difficulties that the team ran into gave the opportunity to practice problem solving, effective communication, and leadership.

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11 APPENDICES

Appendix A: Engineering Requirements and Rationale

Table A1: Engineering requirements will team justifications/rationale.

Engineering Requirements	Rationale
Total cost for all robots does not exceed $1,000	$1,000 is the total amount of money provided to us by the NAU Mechanical Engineering Department.
Maximize weight for each class	Maximizing our robots to the allowable weight for each competition increases the total force that we can exert on opposing robots.
Minimize height for all robots	This will lower each robot's center of gravity which helps pushing capabilities.
Maximize frontal area	Increased frontal area gives robots more pushing power.
Autonomous	This requirement strictly applies to the autonomous sumo competitions.
Remote Controlled	This applies to the RC robot competitions.
Maximize Coefficient of Friction	Higher friction with the ground helps with resisting opposing pushing forces.
Smallest radius of turning	Out maneuvering opponents is an advantage.
Material with high strength and low weight	Material selection can make a difference in competitions if all other factors are equal.
Transfer rate of motor	High torque motors increase pushing power in the sumo events. In the combat event high torque motors won't burn out as easily.
Team logo	Robots are required to have a identifying mark.

Appendix B: House of Quality

Customer Requirement	Weight	Engineering Requireme	Cost does not exceed alloted budget	Maximize Weight for each class	Minimize Height	Maximize Frontal Area	Autonomous	Remote Controlled	Maximize Coefficient of Friction	Smallest Radius of Turning	Material w/ High Strength/ Low Weight	Transfer Rate of Motor	Team Logo
Stay Under Budget	5		9	3			1	3			9		1
Maneuverability	2.3			1	3	3	3	3	9	9		3	
Defensive Capabilites	4			3	3	9		3	3	3			
Offensive Capabilites	2.6			3	3	3	9	3	9	3			
Speed	2			9	3		9		3		3	9	
Durability	4			3			1				9		
Ease of Operation	3.3			1	3	9		9	3	9		9	
Maximize Weight for Class	4			9	3	9	3		9		9		
Identifying Team Mark	5		3										9
Adaptive Algorithm	3						9	3		3		3	
Absolute Technical Importance (ATI)			60	106.4	54.6	116	96.3	80	108	79	123	63.6	50
Relative Technical Importance (RTI)			9	4	10	2	5	6	3	7	1	8	11
Target Unit of Measurement			USD	g	cm	cm^2	-	-	no unit	cm	Mpa	no unit	-
Target			1000	3000	20	300	N/A	N/A	0.8	2.5	TBD	50:1 .	N/A
Tolerance			<1000	<3000	<20	>200	N/A	N/A	>0.65	<3	TBD	>50:1	N/A
Testing Procedure (TP#)			2	4	3	3	1,6,8	1,6	4	1,3	7	5	1
Design Link (DL#)			1	2	3	4	5	6	7	8	9	10	11

Approval	**Date:**
Team member 1: Hunter Lane	Nov 14 2016
Team member 2: Graham Rose	Nov 14 2016
Team member 3: Sean Sussman	Nov 14 2016
Team member 4: Jordan Ziegler	Nov 14 2016

Figure B1: House of Quality with customer and engineering requirements; weightings; ATI, RTI, targets, target units, and team approval signatures.

Appendix C: Pugh Charts

Table C1: Mega Sumo Pugh Chart

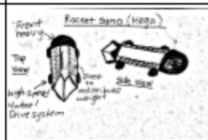
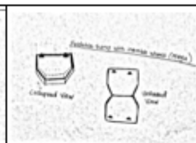
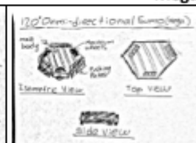
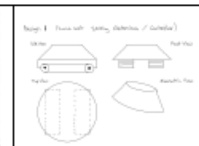
	Mega Sumo					
						
Selection Criteria	Rocket Sumo	Foldable	Omni-direction	Rusher	Pusher	Tank
Stay Under Budget	DATUM	+	+	0	0	+
Maneuverability		-	+	-	+	-
Defensive Capabilities		+	-	+	+	+
Offensive Capabilities		0	0	+	0	0
Speed		0	0	-	-	-
Durability		0	+	-	0	+
Ease of Operation		+	-	+	-	+
Maximize Weight for Class		0	+	-	0	+
Identifying Team Mark		0	0	0	0	0
Adaptive Algorithm		0	0	0	0	0
S +		3	4	3	2	5
S -		1	2	4	2	2
0		6	4	3	6	3
Total		2	2	-1	0	3
Rank		3	2	5	4	1

Table C2: Nano Sumo Pugh Chart

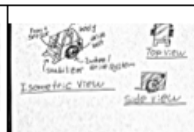
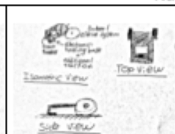
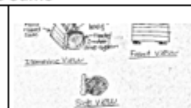
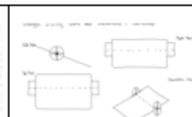
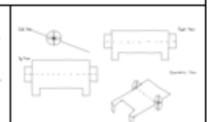
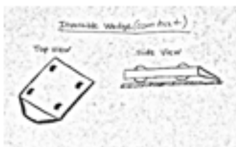
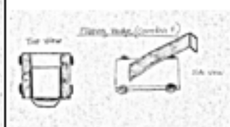
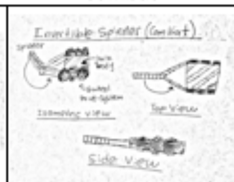
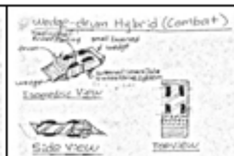
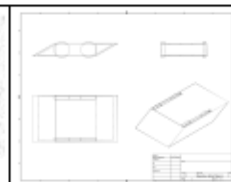
	Nano Sumo					
						
Selection Criteria	Distraction Device	Block Bot	Footsy Bot	Ram Bot	Chariot	Plow Cart
Stay Under Budget	0	+	+	0	DATUM	+
Maneuverability	-	-	+	-		-
Defensive Capabilities	0	+	-	-		+
Offensive Capabilities	0	+	0	+		0
Speed	+	0	0	-		-
Durability	+	+	+	+		+
Ease of Operation	0	+	-	+		+
Maximize Weight for Class	-	0	+	-		+
Identifying Team Mark	0	0	0	0		0
Adaptive Algorithm	0	0	0	0		0
S +	2	5	4	3		5
S -	2	1	2	4		2
0	6	4	4	3		3
Total	0	4	2	-1		3
Rank	4	1	3	5		2

Table C3: Combat Bot Pugh Chart

	Combat				
					
Selection Criteria	Invertible Wedge	Flipping Wedge	Invertible Spinner	Wedge-Drum Hybrid	Landship
Stay Under Budget	DATUM	+	0	0	+
Maneuverability		-	-	-	-
Defensive Capabilities		-	+	+	+
Offensive Capabilities		0	+	+	-
Speed		0	0	-	-
Durability		-	+	+	+
Ease of Operation		+	-	+	-
Maximize Weight for Class		0	+	+	+
Identifying Team Mark		0	0	0	0
Adaptive Algorithm		0	0	0	0
S +		2	4	5	4
S -		3	2	2	4
0		5	4	3	2
Total		-1	2	3	0
Rank		4	2	1	3

Appendix D: Decision Matrices

Table D1: Mega Sumo Decision Matrix

		Mega Sumo					
Engineering Requirements	Weight	Rocket Sumo	Foldable	Omni-directional	Rusher	Pusher	Tank
Cost does not exceed budget	9	1	3	1	9	3	9
Maximize Weight for each class	3	3	1	3	1	3	9
Minimize Height	1	3	9	9	3	1	9
Maximize Front Area	3	1	3	9	9	3	3
Autonomous	9	1	1	0	1	0	0
Remote Controlled	9	0	0	1	0	1	1
Maximize coefficient of friction	1	3	1	1	9	3	9
Smallest radius of turning	1	1	3	9	0	9	3
High strength/ low weight material	3	3	3	1	0	3	9
Transfer rate of motor > 50:1	1	9	3	3	9	3	3
Team Logo	9	1	1	1	1	1	1
	Raw score	64	82	88	150	88	186
	Rel. rank	6	5	4	2	3	1

Table D2: Nano Sumo Decision Matrix

		Nano Sumo					
Engineering Requirements	Weight	Distraction Device	Block bot	Footsy bot	Ram bot	Chariot	Plow cart
Cost does not exceed budget	9	3	3	1	1	3	3
Maximize Weight for each class	3	1	9	3	9	1	3
Minimize Height	1	1	1	3	3	9	9
Maximize Front Area	3	3	3	1	9	3	3
Autonomous	9	1	0	1	0	0	1
Remote Controlled	9	0	1	0	1	1	0
Maximize coefficient of friction	1	3	1	9	1	1	3
Smallest radius of turning	1	3	3	9	1	9	9
igh strength/ low weight material	3	3	3	3	3	1	1
Transfer rate of motor > 50:1	1	3	3	9	3	1	1
Team Logo	9	1	1	1	1	1	1
	Raw score	76	98	78	98	80	88
	Rel. rank	6	1	5	2	4	3

Table D3: Combat Bot Decision Matrix

		Combat				
Engineering Requirements	Weight	Invertible wedge	Flipping wedge	Invertible spinner	Wedge-drum hybrid	Landship
Cost does not exceed budget	9	3	3	3	3	3
Maximize Weight for each class	3	9	9	9	9	9
Minimize Height	1	9	3	9	9	3
Maximize Front Area	3	3	3	1	3	9
Autonomous	9	0	0	0	0	0
Remote Controlled	9	1	1	1	1	1
Maximize coefficient of friction	1	3	3	9	9	3
Smallest radius of turning	1	9	3	3	9	1
High strength/ low weight material	3	9	3	3	9	9
Transfer rate of motor > 50:1	1	9	3	9	9	9
Team Logo	9	1	1	1	1	1
	Raw score	138	102	114	144	142
	Rel. rank	3	5	4	1	2

Appendix E: Final Design CAD Packages

Appendix E1: Mega Sumo CAD Package

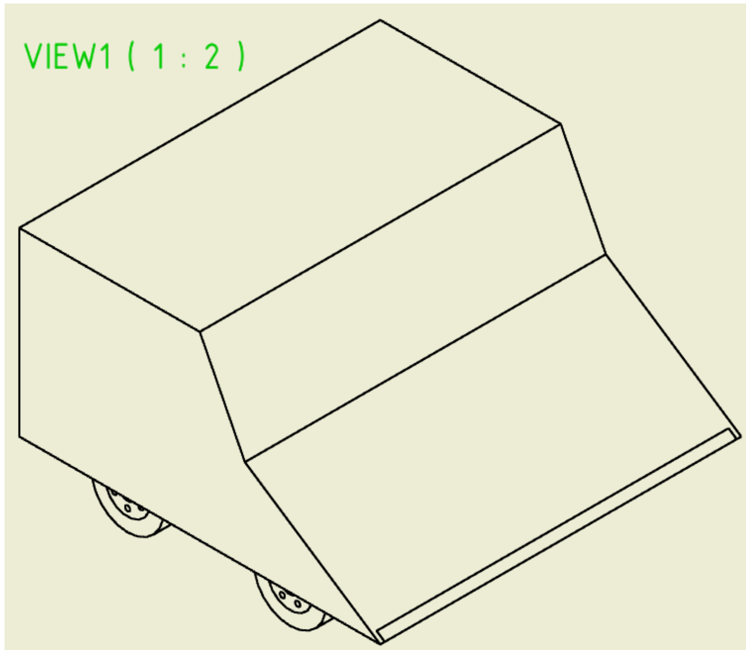


Figure E1: Mega sumo isometric view

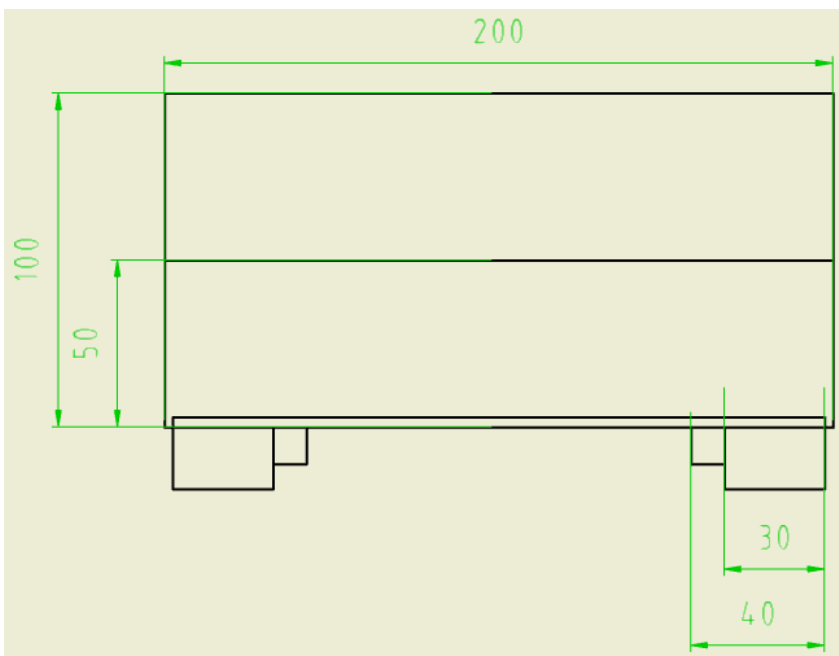


Figure E2: Mega sumo front view with dimensions (mm)

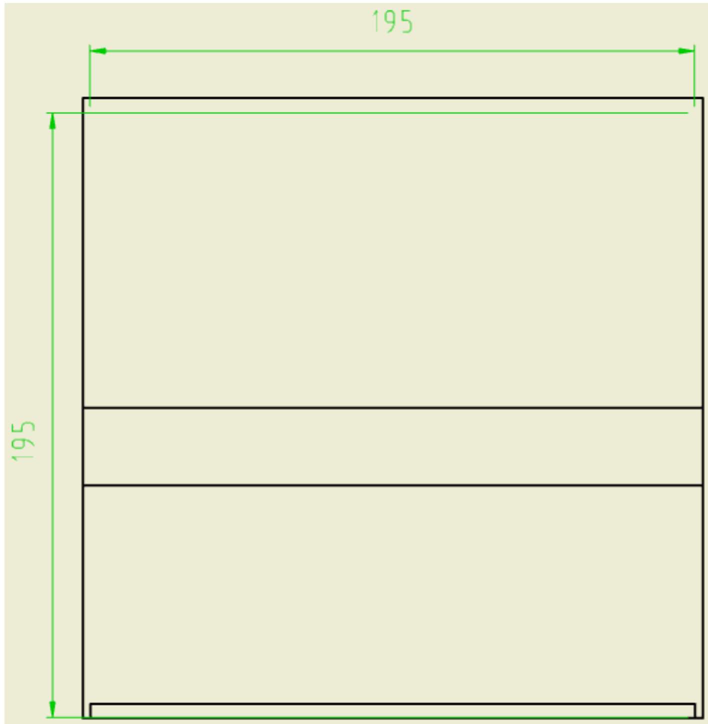


Figure E3: Mega sumo top view with dimensions (mm)

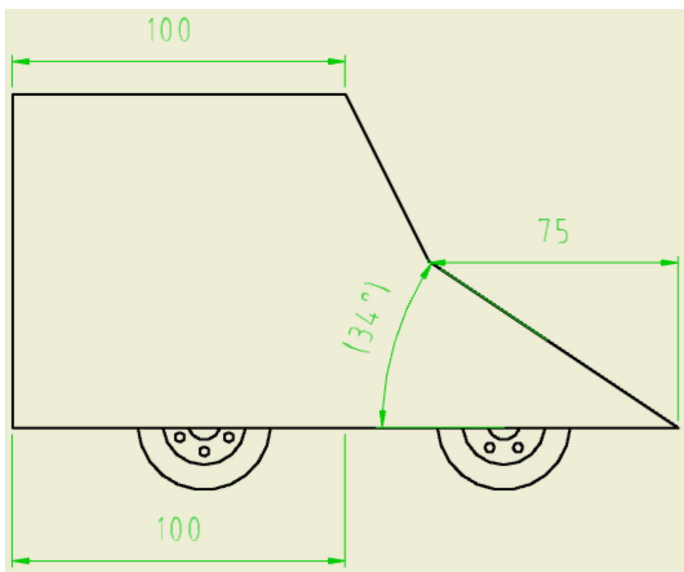


Figure E4: Mega Sumo side view with dimensions (mm, degrees)

Appendix E2: Combat CAD Package

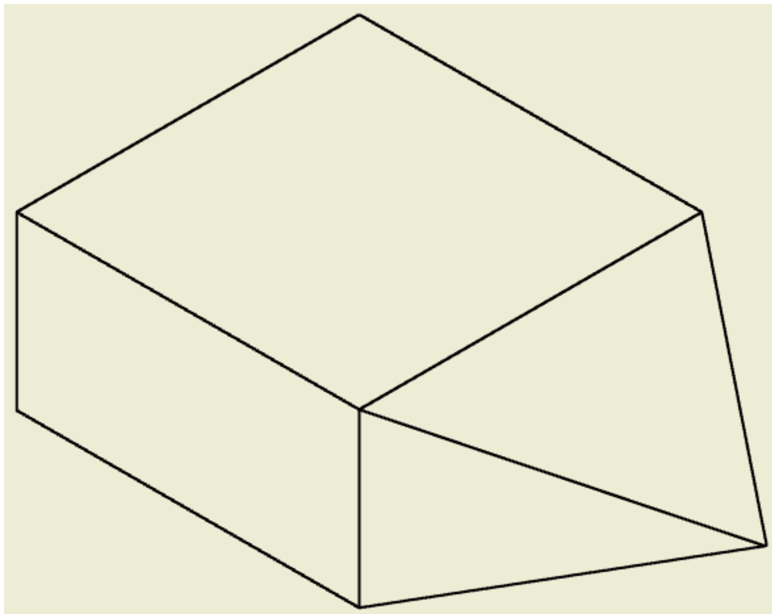


Figure E5: Combat bot isometric view

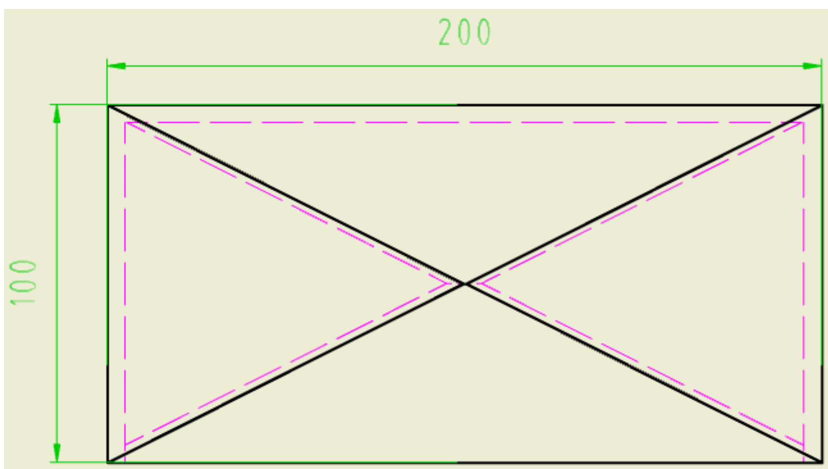


Figure E6: Combat bot front view with dimensions (mm)

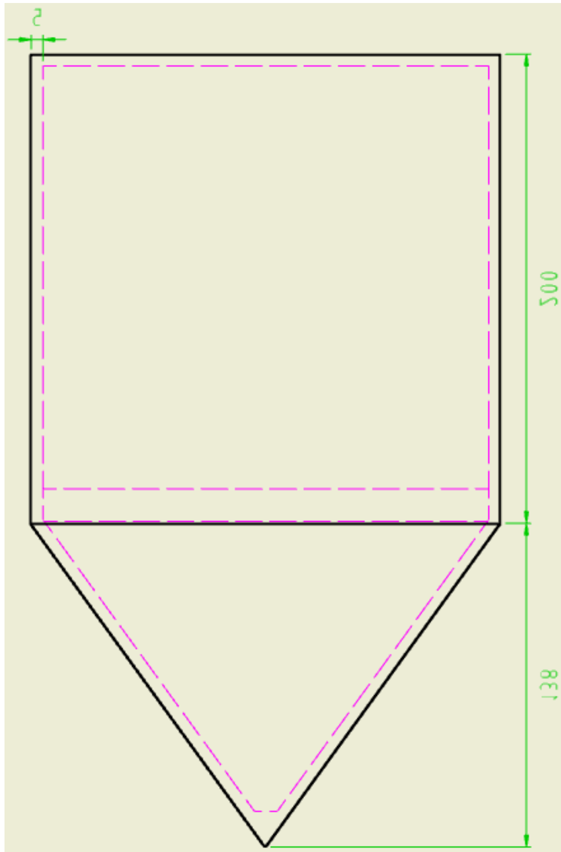


Figure E7: Combat bot top view with dimensions (mm)

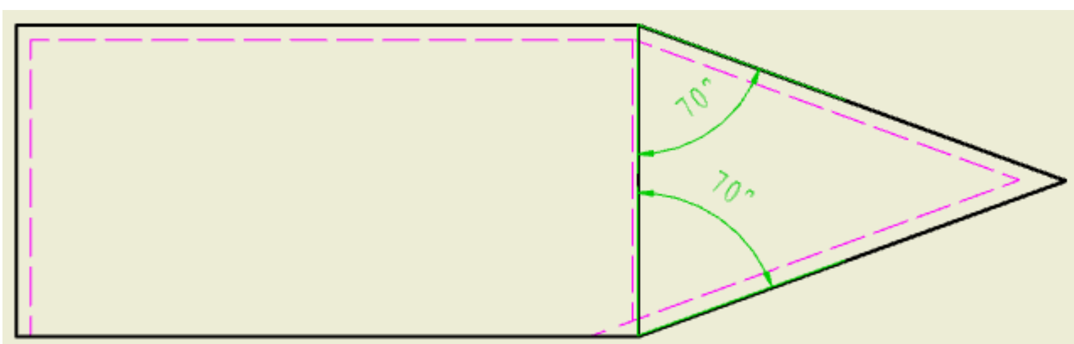


Figure E8: Combat bot Side View with Dimensions (mm, Degrees)

Appendix F: Motor Selection Results

Table F1: Motor Selection Results

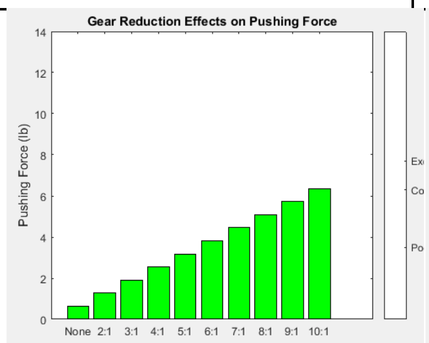
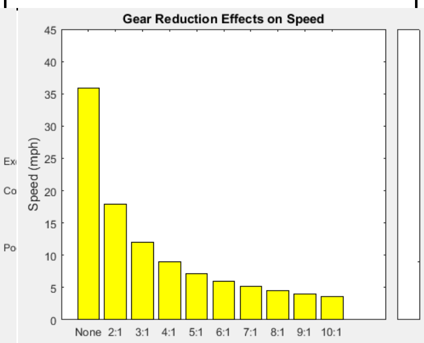
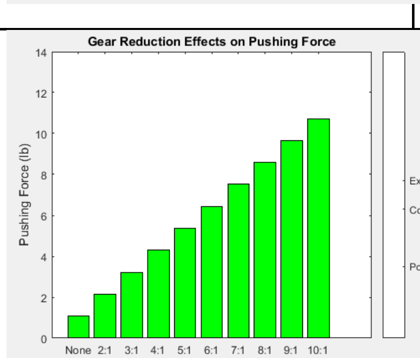
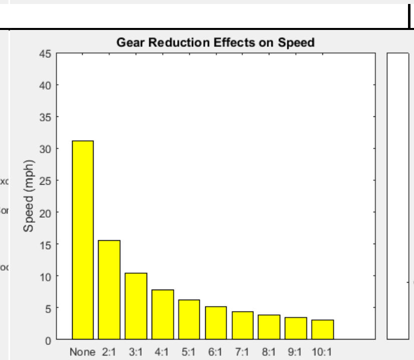
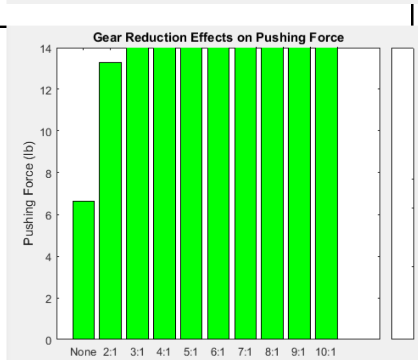
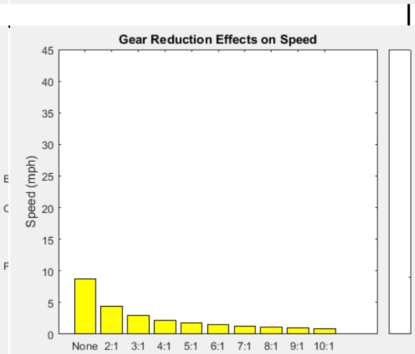
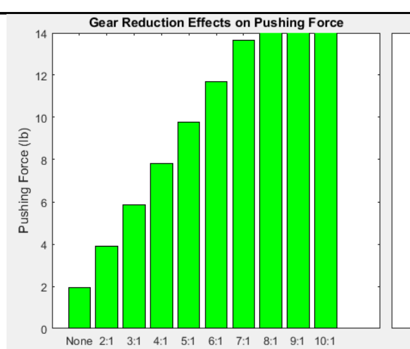
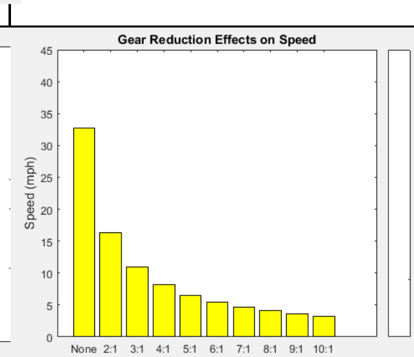
Motor	Pushing Force	Velocity	Comments	Cost
60 W 8810 rpm .87 efficiency			A 60 Watt motor will not have the correct balance between velocity and pushing force	$278
90 W 7740 rpm .86 efficiency			This motor using a 6:1 gear ratio would be a viable option	$295
150 W 2130 rpm .88 efficiency			This motor can be slightly better than the 90 W motor without using any gears	$382
150 W 7590 rpm .92 efficiency			This motor can have competitive velocity and exceptional pushing force at a 4:1 gear ratio	$382

Table F2: Motor Selection Variables

Variable	Variable Name	SI Units	English Units
P	Power	W	hp
T	Torque	Nm	lb-in
S	Speed	rpm	rpm
PF	Pushing Force	N	lb
WR	Wheel Radius	m	in
V	Velocity	m/s	mph
D	Diameter	m	ft

Table F3: Motor Selection Equations

Equation	Units	Reference
(1) T = (63,025 * P) / S (2) T = (9.5488 * P) / S	(1) lb-in (2) Nm	[2]
(3) PF = T / WR (4) PF = T / WR	(3) lb (4) N	[3]
(5) V = (D * π * S *60) / 5280 (6) V = (D * π * S) / 60	(5) mph (6) m/s	[4]

Appendix G: Mega Sumo Cost Analysis Results

Table G1: Cost Analysis of Low, Medium and High End Components [8, 15, 16]

Mechanical						
Motors	Weight (g)	Cost $	Required	RPM		Website
MP12 Micro Gear Motor 6V	11	9.95	2	15000		JSUMO
DeWalt 36V Hammerdrill	807	99.99	2	15600		Robot Marketplace
Maxon RE35 DC 24V	340	360	2	7800		JSUMO
Gears	Weight (g)	Cost $	Required	Low Gear Output RPM		Website
4-Speed Worm Gearbox Tamiya	320	13.99	1	84		Robot Marketplace
Planetary Gearmotor	454	53	1	139		Robot Marketplace
DeWalt 36V 3-Speed Gearbox	585	77.99	1	400		Robot Marketplace
Wheels	Weight (g)	Cost $	Required	Wheel Diameter (mm)		Website
FingerTech Snap Wheels	0.6	3.34	2	25		Robot Marketplace
SLT20P Steel Silicone Wheel	52	18	2	38		JSUMO
FingerTech Mecanum Wheels v2	60	77.99	1	54		Robot Marketplace
Body Material	Weight (g)	Cost $	Required	Dimensions (cmxcm)		Website
Plastic Polycarbonate	336	25.44	1	30x30		Robot Marketplace
Aluminum 6061 T6	1202	20.75	1	15x15		Robot Marketplace
Titanium Plate Grade 2	1331.5	164.695	1	15x15		Robot Marketplace
Electronics						
Micro Controllers	Weight (g)	Cost $	Req	Comments		Website
Arduino Uno	25	25	1	Lightweight, Easy to Program		Arduino
Arduino Yun Shield	32	44	1	Heavy weight		Arduino
Arduino Zero	12	50	1	Simple debugging		Arduino
Edge Sensors	Weight(g)	Cost $	Req	Sense Distance (mm)	Response Time (s)	Website
QRD1114 Optocoupler	1	1.95	4	6	1	JSUMO
QTR1A Contrast	1	2.5	4	6	1	JSUMO
LineTracker Sensor Board	15	5.95	4	Senses changes in Dhoyo ring		JSUMO
Opponent Sensors	Weight (g)	Cost $	Req	Sense Distance (mm)	Dimensions (mm)	Website
Mz80 Infrared Diffuse Relective	15	9.5	2	100-800	20x20x45	JSUMO
MR45 Industrial Diffuse	15	32	2	450	30x25x15	JSUMO
Pepperl Diffuse Relective	28	59	1	0-1000	35x15x23	JSUMO
Speed Controllers	Weight (g)	Cost $	Req	Comments		Website
Wasp Single-Channel	9	35	1	Low Cost and Lightweight		Robot Marketplace
Sabertooth 2x12 Dual Motor	43	65	1	RC AND Autonomous		Robot Marketplace
Sabertooth 2x32 Dual Motor	125	130	1	RC AND Autonomous		Robot Marketplace

Combination of Parts		
Overall Sumobot	Weight (g)	Cost $
Low End	747.2	152.81
Middle	3483	492.73
High End	2881.5	1303.475
Realisitic Design	2264	1210.54

Appendix H: Manufacturing Schedule

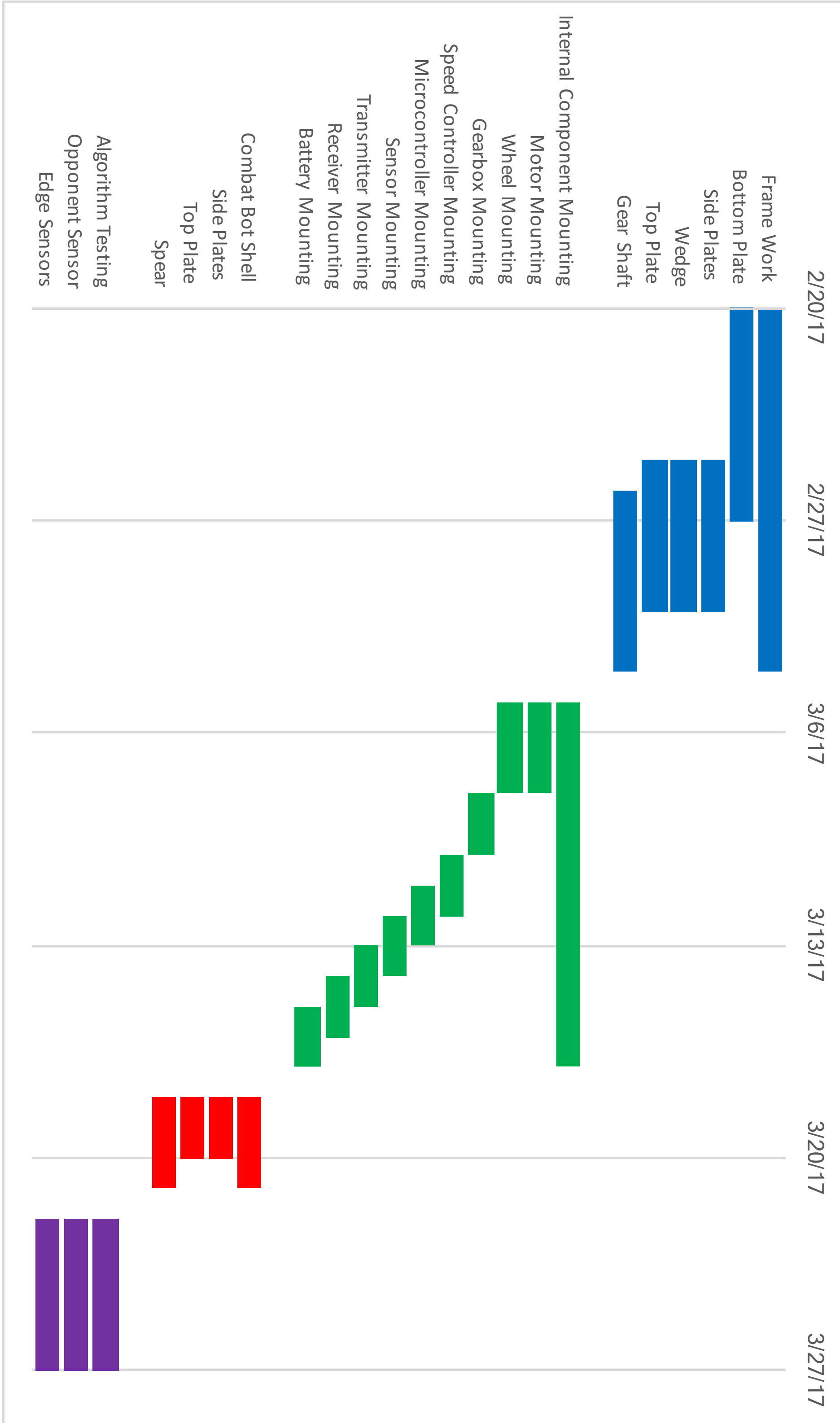


Figure H1: Schedule of Implementation Tasks

Appendix I: DOE Statistical Results and Response Diagrams

Table I1: Statistical Results of DOE

This sheet is currently set for a 2^3 factorial experiment.					m =	2	experiment levels			
Edge Sensor Data					n =	3	number of factors or design variables			
Recorded:	3/1/17				Fraction =	1	fraction of full factorial experiment			
					N =	8	number of experimental combinations/trials			
					r =	2	number of replicants			
		distance from surface	shades of black	light level						
	I	x3	x2	x1	y1	y2	ybar	SSe,i		
1	1	-1	-1	-1	610	663	636.5	1404.5		
2	1	1	-1	-1	250	195	222.5	1512.5		
3	1	-1	-1	1	660	710	685	1250		
4	1	1	-1	1	225	190	207.5	612.5		
5	1	-1	1	-1	860	847	853.5	84.5		
6	1	1	1	-1	350	300	325	1250		
7	1	-1	1	1	850	835	842.5	112.5		
8	1	1	1	1	310	123	216.5	17485		
Effects		-511.5	121.5	-21.5						
ß's	498.63	-255.75	60.75	-10.75						
SS		1046529	59049	1849		ybarbar	498.63	23711	= SSe	
dof		1	1	1				2963.9	= St^3 = MSe	
MS		1046529	59049	1849						
F		353.0948505	19.92290498	0.62384547				163.32	= 3*St	
Pr(F)		6.64689E-08	0.002101254	0.45239509						
						SSTrial	1E+06			
Variable Actual values										
		low (-1)	high (+1)		units					
x1	[	250	500]		volts					
x2	[	35	50]		volts					
x3	[	1	3]		cm					

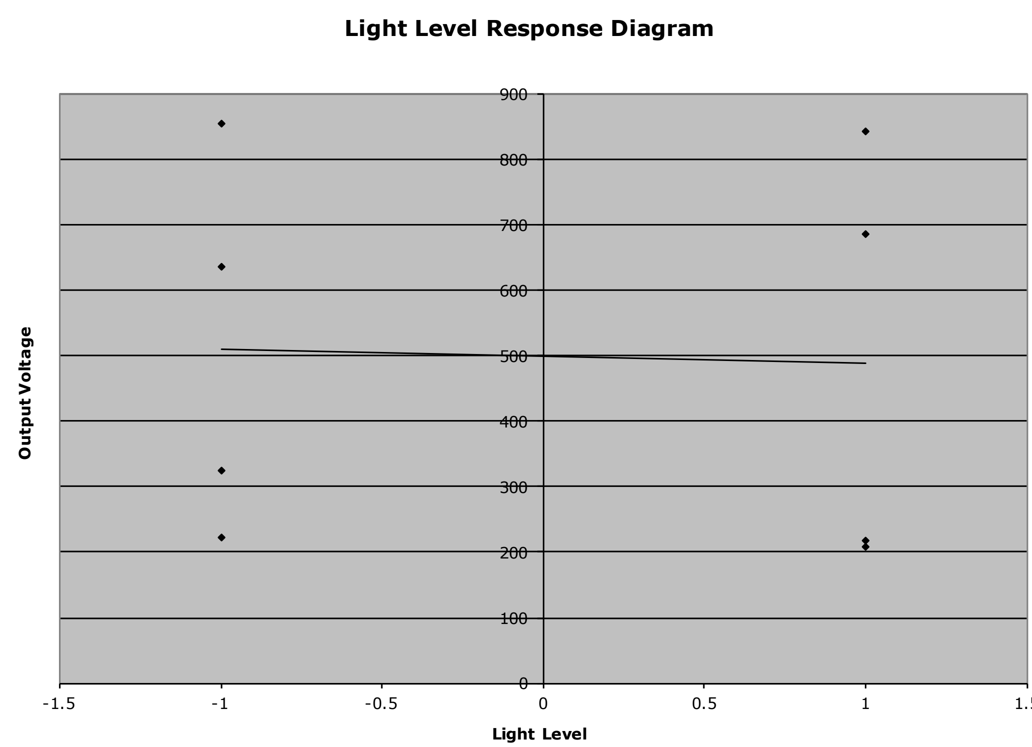


Figure I1: Response Diagram of Light Levels

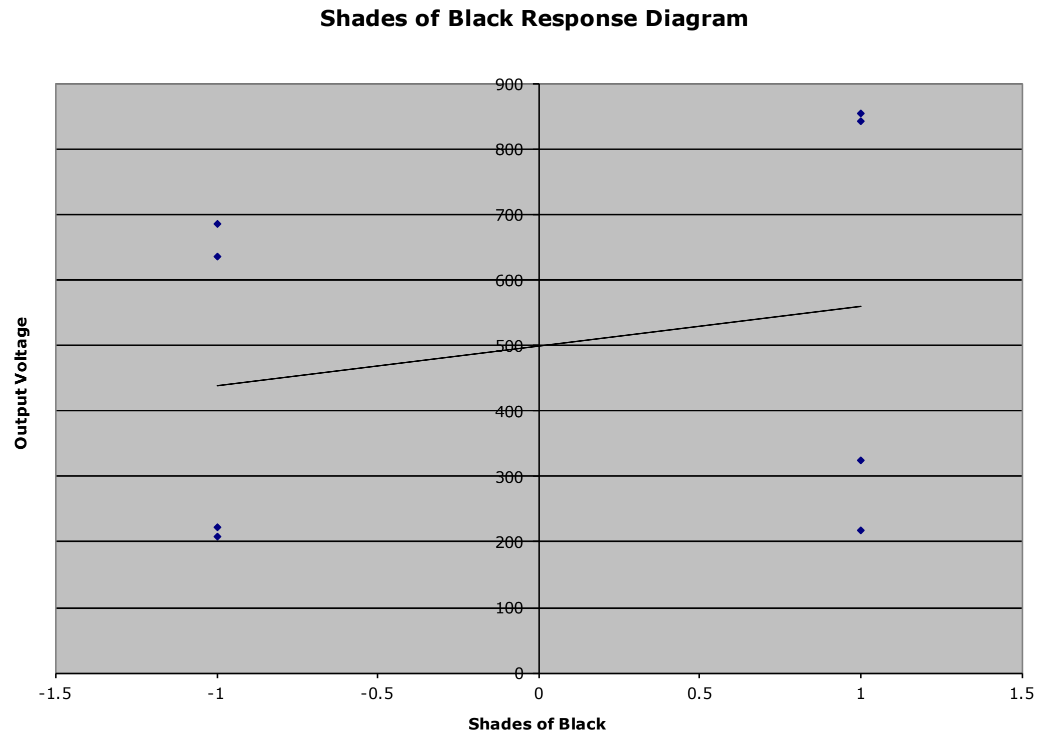


Figure I2: Response Diagram of Shades of Black

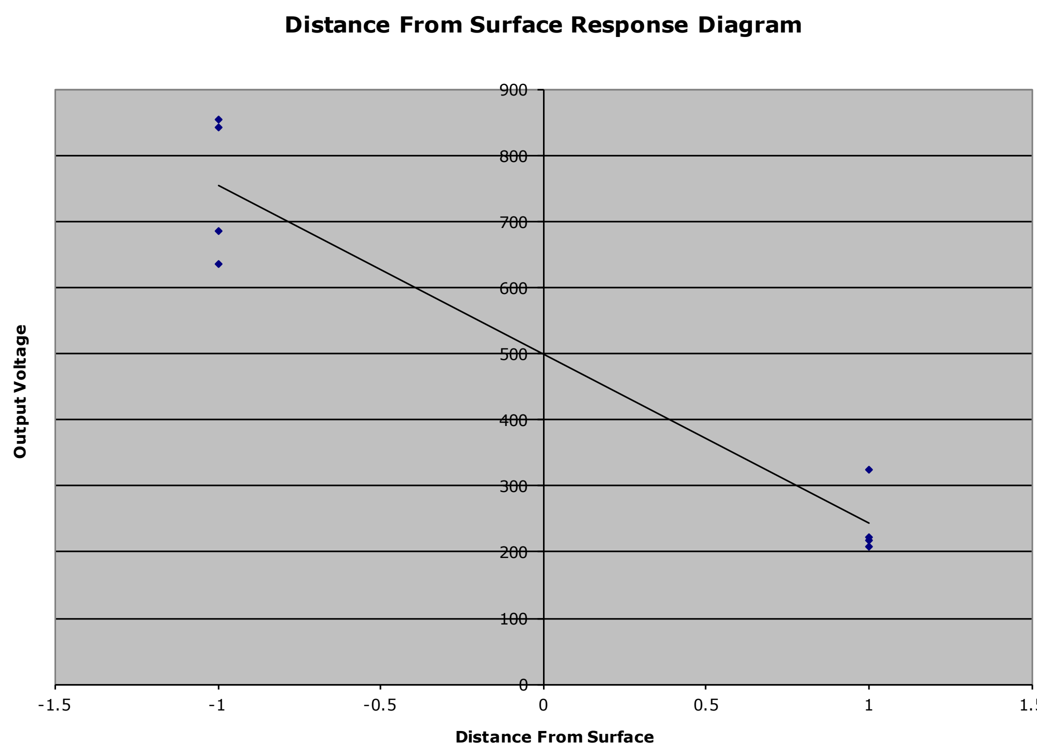


Figure I3: Response Diagram of Distance from Surface

Appendix J: Autonomous Algorithm Void Loop

Capstone_Code §

```
void loop()

{

// Contine forward if opposing robot is detected
if (Opp_1 == HIGH && Opp_2 == HIGH)
{
   ST1.motor(1, 127);  // Go forward at full power.
   ST2.motor(1, 127);  // Go forward at full power.
   delay(500)
}

// Turn the bot by stopping one motor if the robot is about to drive off the edge.
if (Edge_1 == HIGH || Edge_2 == HIGH && Opp_1 == LOW && Opp_2 == LOW)
{

   ST1.motor(1, -127);  // Negative 127 indicates reversing at full speed
   ST2.motor(1, -127);
   delay(500)

  ST1.motor(1, 0);  // 0 indicates stop spinnning one motor to allow the robot to turn
  ST2.motor(1, 80);  // turn at 80/127 speed
  delay(500)

  ST1.motor(1, 127);  // continue the robot forward at full power after the turn
  ST2.motor(1, 127);
  delay(500)

}

// Move forward if back edge sensors are HIGH
if (Edge_1 == HIGH && Edge_2 == HIGH)
{
   ST1.motor(1, 127);  // Go forward at full power.
   ST2.motor(1, 127);  // Go forward at full power.
   delay(500)
}


// When opposing robot is to the left
if (Opp_1 == HIGH && Opp_2 == LOW)
{
   ST1.motor(1, 127);  // Go forward at full power.
   ST2.motor(1, 70);  // Go forward at 70/120 power.
   delay(500)
}

// When opposing robot is to the right
if (Opp_1 == LOW && Opp_2 == HIGH)
{
   ST1.motor(1, 70);  // Go forward at 70/120 power.
   ST2.motor(1, 127);  // Go forward at full power.
   delay(500)
}

// Stops the robot if all Edge sensors are HIGH
if (Edge_1 == HIGH && Edge_2 == HIGH && Edge_3 == HIGH && Edge_4 == HIGH)
{

   ST1.motor(1, 0);
   ST2.motor(1, 0);
   delay(500)

}

}
```

Figure J1: Sumo Robot Algorithm void loop

Appendix K: Testing Procedures Results Summary

Table K1: Summary of testing procedures results

Overall Testing Procedures	
Test	**Results**
Visual Quality Inspection - Each member individually inspects each bot to verify they meet the required specifications and look professional	Both designs appear professional and meet all requirements
Total Component Cost - The budget liason verifies the total component's costs are below the team's budget of $1,500	Total cost: $1,095 ($405 under budget)
Dimensions Test - Using a metric ruler, length, and width of the robot is measured to verify it satisfies the competition limits	Sumobot dimensions: 19x17.5cm
Weight Test - Using a digital metric scale, each robot is weighed to verify they satisfy competition limits	Sumo weight: 2882g Combat frame weight: 2363g
Transfer Rate Test - The motor's transfer rate is measured to ensure that for every two and a half rotations of the motor, the wheel is rotated one or less times	Final gear ratio is 2.5:1
Controls Test - The R/C and autonomous functions are tested to ensure the robot is capable of being controlled accurately and easily with each method	Autonomous and remote control capable
Material Strength Test - The strength of each robot is tested through a point-impact punching force produced by a hammer. As long as no yielding occurs, the material is considered to have passed	Sumo material (mild steel) and combat material (aluminum) both did not yield under stress
Sensor Test - Sensor outputs are tested on an arena built to the specifications in the Unified Sumo Robot Rules. Each sensor's response time must be below 3 milliseconds to ensure the robot can respond quickly in the autonomous competition	All sensor speeds are acceptable. See sensor testing table for results