Sumo Robot Competition

Bryan Wilson
Student Author
Ohio Northern University
Ada, Ohio 45810
Email: b-wilson.1@onu.edu

Tyler Germann
Student Author
Ohio Northern University
Ada, Ohio 45810
Email: t-germann@onu.edu

Dr. Khalid Al-Olimat
Chair, Electrical & Computer Engineering and Computer Science Department
Student Group Adviser
Ohio Northern University
Ada, Ohio 45810
Email: k-al-olimat@onu.edu

Abstract

Sumo robot competitions have been prevalent in Japan, with the first competition being held in 1989 with only 33 robots, and its popularity has only been growing exponentially since its inception. For example, in 2001, the number of robots entered into the Japanese competition was over 4,000. In the early 1990s, the sumo robot competition was introduced into the United States. Currently, most of the IEEE Student Activities Conferences (SAC) added the sumo robot track to the list of the conference competitions.

There is a distinct lack in current literature (such as technical papers or conference proceedings) regarding how to build a sumo robot. Thus, the purpose of this paper is to outline and explain the design process of a robot that will compete at the IEEE Student Activities Conference (SAC) Sumo Robot Competition tracks. Two different designs are explained; the first is utilizing both a commercial off the shelf (COTS) kit along with custom chosen components, and the other design utilizing only custom chosen components.

In addition to the design alternatives, the paper will discuss the decision matrix that includes the factors and the criteria for the selection of each component and the final decision on which design to go with for the competition. Discussions of the realistic constraints, the construction phase, the testing, the budget, and the project schedule are included in the paper as well.

The authors strongly believe that this paper will help other students who are interested in building a sumo robot and will save them a great deal of time in looking for material regarding building a sumo robot.

Problem Statement

The Electrical & Computer Engineering and Computer Science Department (ECCS) at Ohio Northern University would like a team of students to participate in the Sumo robot competition at the IEEE Student Activities Conference. In addition, the department would like the robot to be displayed and demonstrated to prospective students and their families during admission visitation days.

Project Objectives

The objective of this project is to build a robot that serves two purposes: to be entered into the Mini-Sumo Robot Competition and to be used as a showpiece for the Engineering College. In order to be entered into the competition, all of the competition rules must be adhered to, which includes constraints such as weight and cost. During the competition, this robot must be capable of autonomously locating the opposing robot and pushing it out of the ring. Finally, the robot should be durable enough to be demonstrated to prospective students during college events.

Literature Survey

Sumo robot competitions have been prevalent in Japan, with the first competition being held in 1989 with only 33 robots, and its popularity has only been growing exponentially since its inception. For example, in 2001, the number of robots entered into the Japanese competition was over 4,000, according to Pete Miles in his book that aims to serve as a general guide for building sumo robots[1]. In the early 1990s, the sumo robot competition was introduced into the United States, and a person named Bill Harrison quickly became its largest advocate. From there, he and a colleague created the mini class of sumo robots (weighing in at 500g total) in order to invite more people to design and compete, as it would be cheaper than the 3kg class of regular sumo robots that are utilized in Japan[1]. Thus, the competition in the US was born.

Much like the regular sumo competitions (in which two opposing people aim to push each other out of a ring), the robot variant of this event pits two robots against each other, each aiming to push the other robot out of the ring, called a dohyo[1]. Each competition is governed by a set of rules, which aim to keep the ensuing competition fair and exciting. For the mini-sumo class, here are some important rules, found in the second reference[2], which is the document that served as last year's sumo competition rules at The Ohio State University:

1. The mass limit of the mini-sumo robots is 500 grams (1.1 lbs)
2. The dimensions of the robot cannot exceed 10 cm by 10 cm (3.93 in by 3.93 in)
3. There is no limit to the height of the robot

These three rules serve as the guiding principle for which platform is chosen in a design. If any of these requirements are not met, the robot will be disqualified. Each match of the tournament consists of up to three rounds – the robot that wins two out of the three rounds will advance to the next stage in the tournament. Effective points, known as yuko, are awarded in the following cases[1] :

1. when a robot pushes another robot out of the ring
2. when the opposing robot drives out of the ring
3. when the opposing robot is disqualified, or

4. when two yusei points are received.

To receive a yusei point, the opposing robot must get stuck on the border line and not be able to move off of the line. Thus, to win a match, a team must receive two yuko points.

Because the basic idea is to push another robot out of the dohyo, there are various governing scientific principles that must be considered in order to have an effective sumo robot design. In summary, here are the important principles, according to[1]:

1. Output Torque: The robot must possess enough torque in order to be able to push the mass of the other robot out of the ring (in most cases, more than just the mass alone, since the other robot's wheels will also be opposing the robot's push). The relationship between torque and applied force is shown in (1). F is the force in Newtons (N), T is the torque in Newton-meter (N·m), and r is the distance in meter (m) between the point that the force is applied and the point of rotation:

   $$F = \frac{T}{r} \tag{1}$$

   As can be seen, if the torque is greater for a given lever arm, the force applied will be greater. From this, it can be concluded that smaller wheels would be better – this is due to the fact that given a specified torque, if the wheel is smaller, there will be a greater output force. To increase or decrease torque, gear ratios can be utilized.

2. Pushing force: Because there is a specific coefficient of friction associated with materials on other materials (specifically, types of wheels in contact with the dohyo), it follows that there is then a force needed in order to overcome this coefficient of friction in order to push something. Equation (2) illustrates this idea, where F_f is the frictional force in Newtons (N), μ is the coefficient of friction, and F_N is the normal force of the robot in Newtons (N) (which is equal to the force of its weight):

   $$F_f = \mu F_N \tag{2}$$

   The force exerted by the wheels and motors must be greater than this frictional force, assuming the other robot is stationary.

3. Momentum: If the robot has a higher momentum, it is more likely to displace the other robot, since an object with higher momentum is harder to resist/stop. Momentum equation is presented in (3), where P is the momentum in Newton-seconds (N·s), m is the mass in kilograms (kg), and v is the velocity in meters per second (m/s):

$$P = mv \tag{3}$$

Because velocity and torque are inversely proportional, there must be a good balance between these two items in order to have an effective robot.

Overall, these equations denote the basic theory behind the sumo robot. If these ideas are taken into consideration effectively, then the robot possesses a better chance of performing admirably.

Current implementations have some differences and many similarities. However, the overall system of the sumo robot is the same – the following is a list of the necessary components for a sumo robot, as highlighted in first reference[1], along with some generalizations:

1. Sensors: Both line sensors and opponent detection sensors are needed. Line sensors are utilized so that the robot does not drive out of the ring unintentionally, and opponent sensors are utilized in order to determine in which direction to travel to attack the opponent. Generally, the line sensors are phototransistors, which can sense reflectivity, while the opponent sensors are either infrared (IR) or ultrasonic sensors.
2. Motors: Generally, there are two to four motors per mini-sumo robot. There are various types of motors, but the two main types of motors utilized in this class of competition are small DC motors and continuous rotation servo-motors.
3. Power: In general, in the mini-sumo class, most of the kits utilize four AA batteries in order to power the entire device (which includes sensors, motors, microcontroller, etc.). Some have rechargeable batteries, which are usually of the Lithium-Polymer (Li-Po) variety. Any type of battery can be utilized as long as it can effectively power the robot for an entire match.
4. Control: Overall, the prominent method of controlling the robot is by utilizing a microcontroller such as an Arduino or a BASIC Stamp module. One design exception, however, implemented control via only discrete components. In all methods, the overall goal is to determine a control solution that can integrate with the sensors and motors in order to cause the robot to function properly.

As a brief comparison, three different kits were taken into consideration as an initial starting point from which to then create two custom designs – the Parallax SumoRobot[3], the Solarbotics Sumovore[4], and the FingerTech Cobra chassis implementation[5] (an image of each can be seen in Appendix A). The Parallax robot has continuous rotation servo-motors, is powered by 4 AA batteries, is controlled by a BASIC Stamp 2 module, has 2 line sensors, and 2 IR sensors for opponent detection. The Solarbotics Sumovore is controlled with discrete components, is powered by 4 AA batteries, has 2 DC motors, and has similar line and opponent sensing as the Parallax robot. Finally, the FingerTech Cobra chassis has 4 DC motors, 3 line sensors, and is powered by a rechargeable Li-Po battery (the other components are excluded – the designer chooses opponent detection as well as the method for controlling the robot). As seen, these three designs have both similarities and differences, which all factor into which design performs the best.

Some limitations of these current designs include the method utilized for powering the actual robot. The implementations with 4 AA batteries are cheap; however, these batteries, as noted in reference 1[1], may not last for multiple matches. This causes them to be thrown away, thus potentially impacting the environment. Also, because this robot is eventually going to be utilized for demonstrations, it makes sense to have a solution that can be recharged, since that would incur a smaller cost over time. Another limitation is the motors – because these robots are small, the motors utilized have to be equally small. The continuous rotation servos do not provide much mechanical advantage; however, they are very light. In comparison, the DC motors are heavier, but have a higher mechanical output. Another drawback is that some of the DC motors then need motor controllers, which can be realized in the form of solid state H-bridges[1] – this incurs higher cost in the end, but allows for more flexibility in utilizing DC motors.

The design concept that will be presented in this proposal is a general combination of different pieces of current implementations. Because more mechanical power is needed, DC motors are going to be utilized, while an implementation with a microcontroller will be presented, as it allows for greater expandability. Finally, for powering the robot, a rechargeable battery will be utilized for economic reasons.

As a side note, there is a distinct lack in current literature (such as technical papers or conference proceedings) regarding how to build a sumo robot. Most of the information above was attained from[1], while different product websites were consulted for the kits listed earlier. Although this is the case, there is some literature on how to program the sumo robots effectively. Two papers found, reference[6] and reference[7], related to control functionality. In[6], which is a paper by Hamit Erdem, a fuzzy logic implementation is utilized in order to result in faster tracking of an opponent, which then results in quicker target acquisition. In this scenario, the robot with a fuzzy logic controller can respond faster and consequently attack the opposing robot. As a result, the robot can respond more efficiently to the dynamic environment of combat. In[7], which is a paper taken from the publication Robotica, a multi-phase genetic programming approach is explored for the control of the robot. According to the authors, genetic programming "applies genetic manipulations to the functions and operators of a control program or other representations of a controller in an autonomous system"[7]. In essence, the original functions are "mutated" by means of parameters and values as "training" occurs. After enough training has been done, the robot should be able to then respond to any given situation. Given the topics of the two papers as well as the lack of literature on how to build the robot, this suggests that the majority of the time should be spent on refining the algorithm that controls the functionality of the robot. Thus, when determining the optimal design, this must be a consideration.

Realistic Constraints

Performance:

- The robot must detect the opposing robot if it is within 50 cm with 90% accuracy and a response time of 10 ms or less.
- The robot must detect the arena border with 100% accuracy to avoid round loss.
- The robot should be less than or equal to the maximum weight limit of 1.1 lbs.
- The robot should not exceed the dimension restrictions of 3.93” x 3.93” x h”

Functionality:

- Vision sensors collect data that is sent to the microprocessor. A decision is then made by the code and sent to the motors to correctly manipulate movement.
- Line sensors collect data that is sent to the microprocessor. The decision to move away from the line is sent to the motors to avoid round loss.

Economic:

- The cost of the finalized robot must not exceed $250 as per the mini SumoBot rules.
- The total cost of the project should stay around $500 as per the guidelines for the senior design project.

Energy:

- Minimum output voltage from power supply is 6V.
- Minimum mAh battery’s rating should be enough to last for about three rounds.

Maintainability:

- Check all bolts, screws, and nuts before operation and between rounds.
- Batteries should be fully charged before use.
- Batteries should not be left plugged into robot for prolonged durations.
- The ECCS department would like to be able to keep the robots for display and demos so a user instructions will be included.

Operational:

- The robot must perform and interact with an opposing robot in a circular playing field with a diameter of 77 cm.
- The robot must detect the border of the arena to make sure it remains in play.
- The robot must be able to run for the entire length of the match, 3 minutes.

Reliability:

- The robot must operate for the entire length of the round, 3 minutes.
- The robot must operate for a minimum of 4 rounds.
- The robot should remain functional past the competition date for demos at ONU.

Availability:

- The robot must be capable of working on demand, failure could result in loss of round at the competition.

Alternative Solutions

To determine the best possible solution, three different designs are chosen for comparison – one of which is a kit, while the other two designs are custom. By building upon a kit’s design and tweaking different subsystems slightly (such as the motors or the batteries), the optimal design can be achieved. The determination of these optimal components is a direct result of the literature survey, since the information provided discussed the types of sensors that would be best for this competition. Because the aim of the manufacturers is to decrease the end cost of their product (while still making profit), they chose components that did not necessarily have the highest performance. Thus, by taking parts of these kits and adding in better components, a better design is achieved, which can be seen below in Table 7.

Table 1: Decision Matrix

Components	**Weight**	**Design1: Parallax Kit**			**Design2: Cobra**			**Design3: Vex Robot**		
		Component	**Rating**	**Score**	**Component**	**Rating**	**Score**	**Component**	**Rating**	**Score**
Edge Detection	15	2 QTI sensors	0.2	3	3 QTI sensors	0.4	6	3 QTI sensors	0.4	6
Motors	10	2 Cont. Rotation Servos	0.1	1	4 DC Motors (50:1)	0.45	4.5	2 Vex DC Motors	0.45	4.5
Opponent Detection	15	2 IR Rx/Tx	0.25	3.75	1 Sharp IR, 2 IR Rx/Tx	0.375	5.625	1 Sharp IR, 2 IR Rx/Tx	0.375	5.625
Battery	10	4 AA batteries	0.1	1	Rhino LiPo Battery, 360 mAh	0.4	4	2 Lithium Batteries	0.5	5
Mechanical Power	10	Average	0.1	1	Better	0.5	5	Better	0.4	4
Wheel Dimensions**		2.62in D, 0.3in W			3cm D, 2.16cm W			2.62in D, 0.3in W		
Microcontroller	10	BASIC Stamp 2	0.45	4.5	BASIC Stamp 2	0.45	4.5	Arduino	0.1	1
Motor Control**		None			Two Dual H-Bridge			None		
Price**		$129.99			$197.28			$175		
Weight	10	0.67241 lbs	0.1	1	0.9061 lbs	0.4	4	1.050 lbs	0.5	5
Dimensions**		Less than 3.93in x 3.93in			3.898in x 3.839in			3.90in x 3.90in		
Software Development	20	Low Complexity	0.5	10	Mid Complexity	0.4	8	High Complexity	0.1	2
Center of Gravity**		Mid			Low			Low		
		TOTAL	**25.25**		**TOTAL**	**41.625**		**TOTAL**	**33.125**	

**** denotes that these are areas that were NOT considered in the weighting and point determination of the design, as some are restrictions placed upon each design in order to be eligible for the competition (such as dimensions and price) while others are just other details used for comparison that do not affect the robot’s eligibility. These aspects do not necessarily affect the overall robot functionality, but are good for informational purpose.*

Design Solution

At this time, the current design that shall be entered into the competition is the Cobra design, which is presented as Design 2 in Table 1 (refer to Appendix A for a figure). The Components for this design are included in Table 2.

Table 2: Cobra Design

Component	Quantity
BASIC Stamp 2 Sumo PCB	1
IR LED with Receiver	2
Sharp IR Sensor	1
Cobra Chassis	1
Rhino 360mAh, 11.1V	1
Breadboard Wires	30

The BASIC Stamp 2 Sumo PCB is taken from a kit that is offered by Parallax, and the board includes components such as a voltage regulator, header pins (for adding extra accessories as well as quicker prototyping), breadboard space, terminal for the power supply, dedicated locations for the IR LEDs, and the BASIC Stamp 2 microcontroller (and the necessary components for its operation, such as the crystal for the clock as well as a memory module). This board is utilized in order to quickly prototype the overall design, as it offers many simple connection points for sensor interfacing.

Also, the Cobra chassis, sold by FingerTech Robotics, includes all of the necessary components to run four DC motors along with a microcontroller. Parts include: two dual H-bridge modules for motor control, four 50:1 DC motors, three QTI line sensors, and four polyurethane wheels. This particular configuration was chosen in order to have the best possible parts needed for success – as an example, the four DC motors ensures that there is enough torque to be able to push another robot out of the ring, even if the opponent is pushing against the Cobra head on. In addition to this, the H-bridge motor control interfaces easily with the microcontroller, as these components need to only have 5V applied for forward (a standard HI output level for a microcontroller pin, especially the BASIC Stamp 2 module) and 0V applied for backward movement (along with a PWM input signal, which the BASIC Stamp 2 module is capable of doing). Finally, the line sensors allow the robot to detect the border, so again, the chassis is convenient in that it allows for these components to already be factored into the design. The entire design is powered by a 360mAh, 11.1V Li-Po battery, which allows for the robot to last several rounds.

Finally, the different IR sensors are utilized for opponent detection. The IR LEDs return a 1 or 0 depending on whether or not the opponent is seen, while the Sharp IR sensor returns a continuous voltage range dependent upon how far away the detected object is (which is highlighted in the Literature Survey section). Ultrasonic sensors are not utilized due to possible interference – if the opponent also uses ultrasonic, the sensors on the Cobra design would pick up those signals, and thus be confused.

Design Integration

This project involves the implementation of two different designs, therefore this section will discuss the process of designing and working on these prototypes. The first of the two designs, the Cobra, is nearly complete at this stage. This design uses the cobra chassis kit and a Basic Stamp 2 processor. At this moment the vision sensors used are included with the Basic Stamp but will be changed out to a more reliable alternative. To begin, building the Cobra chassis was quite straight forward, piecing together the components until the base was complete. Then the basic stamp 2 was attached above the motors of the chassis using posts to leave room for the battery compartment of the design. The most difficult part was wiring up the chassis connections to the processor as there was a lack of clear documentation on the web. This was only a minor setback and it was squared away and testing began. Finally, moving forward, the vision sensors will be replaced and the processor will need to be attached in a different manner to accommodate a slightly larger sensor.

The second design, the Vex bot, is not as far along in the design process as issues with the size constraint are showing difficulty to work around. This design involves a small aluminum chassis with two motors catty-corner to each other and four wheels to stabilize the base. This design is still being tweaked but this will be the general layout of the robot. To see an initial physical design of the Vex design, refer to Appendix A.

Design Testing and Verification

To test the Cobra design, it is being run against a standard Parallax kit that is used to give a baseline for both designs. As only one design is currently available for testing this is what is being focused on. The two robots are placed into the sumo arena and a round is played between the two. At this stage, it is important to look at the big details such as tracking the opposing robot and detecting the border. The Cobra robot still needs some work as it does not always detect the edge, this is likely because of the test code that was taken from the FingerTech website as it uses, by nature, very sequential programming (meaning that while the robot could be turning to avoid running off the border, it will not care where the opponent is; it will simply finish its motion no matter what). Moving forward changes will be made to the code to fix these issues. By modifying different values and subroutines, the robot will be more likely to detect the border and the component, allowing for better operation.

Perhaps the most important test is determining if the robot is within the weight restrictions, the Cobra weighs in about 40 grams lighter than the weight limit which gives some wiggle room when making any modifications. Equally as important is the size restrictions the robot must meet. This was measured and the design fits the criteria perfects maximizing its size.

The last test that was conducted was the Cobra’s ability to push another sumo bot out of the ring. The power difference between the Parallax kit and the Cobra design was quite noticeable and the Cobra had no problem out powering the Parallax robot even in direct head-to-head collisions. The overall test plan can be seen in the next section, which highlights the ongoing tests.

There are various tests that are to be done on the robot prior to the competition. By doing so, there is a greater chance that the robot will perform reliably at the competition, thus allowing for the highest possible chance of winning. The following list includes the necessary tests in order to check for proper functionality:

1. To simulate a real competition scenario, two mini SumoBots will be designed and built to test the strength of each design. The designs will be continuously modified based on their performance. Before the competition date, these two robots will compete to see which shall go to compete in the competition.
2. To check if the robot can push an opposing robot out of the ring, a 1.5 pound weight shall be placed in the center of the ring. The robot must be able to push this weight out of the ring.
3. In order to prove that the robot can effectively push out a 1.5 pound weight at any given location in the ring, that weight shall be placed at different locations, and the robot will be oriented in different positions, thus allowing the tracking system to find the mass and consequently push it out of the ring.
4. To ensure that the motors are moving properly, connect only the motors and power supply to the microcontroller and run a test program that will force the motors to run at various speeds.
5. To test how long the robot will function, the robot will be run continuously inside of the ring until the battery is fully drained. This will serve as a benchmark for determining how long the battery lasts under that rated condition. The voltage of the power supply will be monitored throughout this process, allowing for a better view into that particular operating condition.
6. To test how long the robot will function in a competition setting, the robot will be subjected to a stress test, in which the robot will be pushing up against an inanimate object. By doing this, this forces the motors to stall, consequently increasing the amount of current flowing from the power supply. In this scenario, the amount of time that the robot can last while pushing a load heavier than it is capable of will show the operating time of the robot if the maximum load is applied.
7. To test the line sensors, the microcontroller will be programmed such that it shall charge up the capacitor in parallel with the phototransistor for a brief duration, turn off, and consequently measure the time it takes for the capacitor to fully discharge. Since the phototransistor acts as a variable resistor, the discharge time will be affected by the amount of light that is sensed. For example, if the color white is detected by the phototransistor, the capacitor will discharge slower – the microcontroller is able to then measure and display that discharge time.
8. To ensure that the robot is within the mass limitations, weigh the robot with all components included on the robot.
9. To ensure that the robot is within the size constraints, measure the robot’s width and length.
10. To determine if the robot is ready for competition, test the fully built design by placing other robots into the ring and have a mock tournament.
11. To test all of the software subroutines, set up each scenario that the program could possibly go through, and test accordingly.
12. To ensure no crosstalk between sensors, ensure that the algorithm turns off all sensors except the sensor that is being utilized.

Lessons Learned

Throughout the testing process, it was found that the design possibly warranted the use of more sensors. Although software complexity is proportional to the number of sensors utilized, there is an inherent complexity level that needs to be reached for the robot to actually have a chance of being competitive during the competition.

The largest piece of information learned involved the engineering tradeoffs that were required to be made. In general, the largest factor in all of the decisions involved the budget – because a robot can only cost $250 total when competing, this constraint does not allow for many expensive components. One might like to buy a very nice sensor; however, that leaves less money for the motors, microcontroller, battery, and casing. Alternatively, one can purchase a very nice microcontroller/microprocessor (in order to better implement a more involved program, such as machine learning); however, that leaves less money for all of the other aspects of the design.

Specifically towards the Sumo design, by testing out the Parallax kits, it was found that the IR LEDs were not the best option, as their performance was not consistent. Due to this, the extra sensors found through the literature survey are to be utilized, resulting in a more robust design. This shows that different types of sensors are needed – both very simple and somewhat complex (all staying within the cost constraints). The old saying of "not putting all of one's eggs into the same basket" certainly holds true – multiple sensors are needed for both redundancy as well as for a competitive edge.

Design Budget

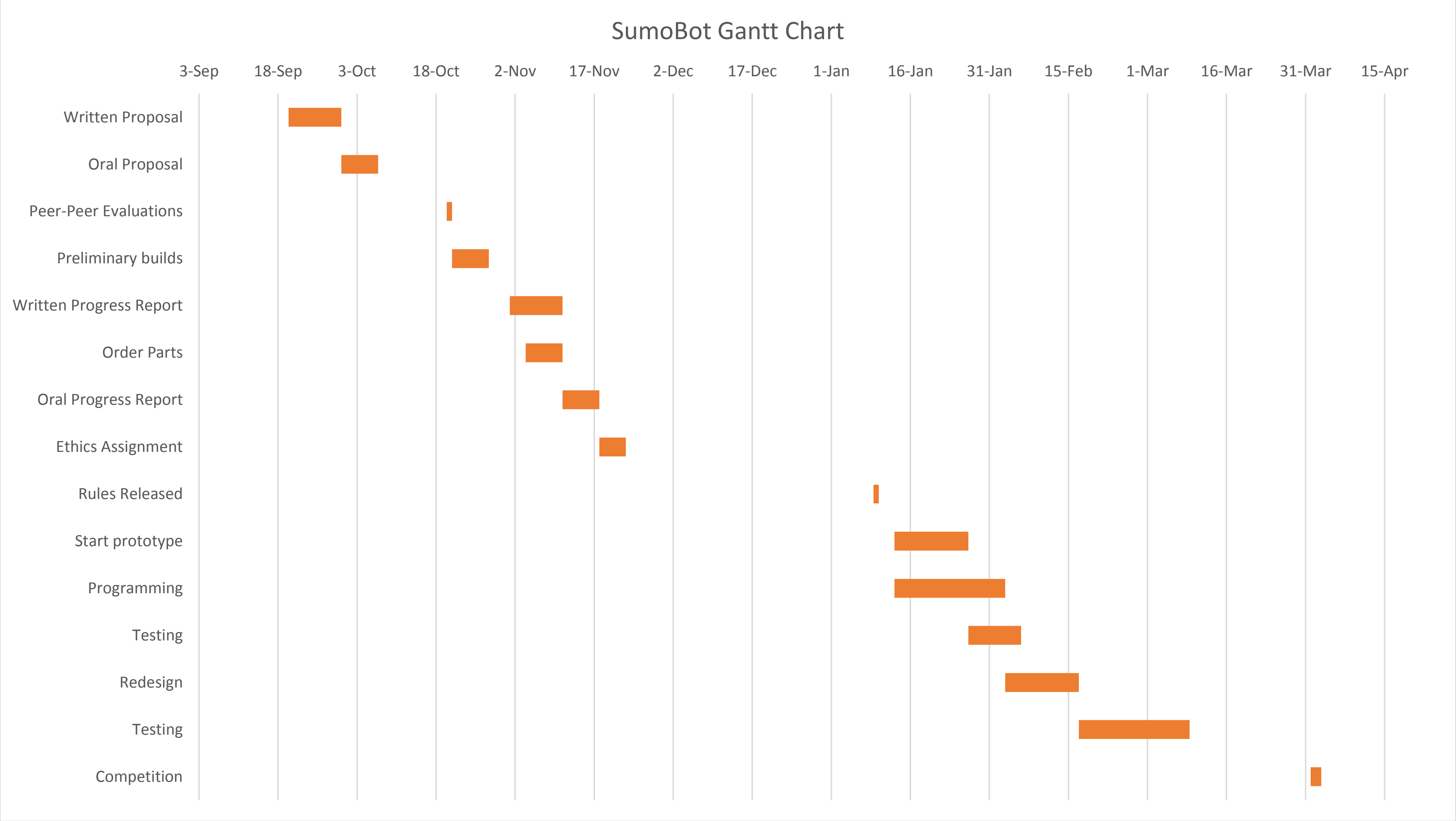
Assuming that the Cobra design is utilized per the decision matrix, the following table shows the cost breakdown for the components:

Table 3: Cost of Cobra SumoRobot Design

Component	**Price**
Cobra Chassis w/Sensors	**$ 108.24**
Rhino 3S Battery, 750mAh	**$ 9.79**
Cobra PCB Mount Chassis	**$ 4.47**
Parallax Sumo PCB	**$ 49.99**
Sharp IR Sensors x 1	**$ 19.99**
LED Rx/Tx	**$ 4.80**
TOTAL:	**$ 197.28**

As can be seen, the total cost for the Cobra design costs $188.28, which is less than the $250 budget. The total seen in the above table is the cost for one SumoRobot, however, two robots will be built for testing purposes as well as demonstrations at the university. For this reason the total cost of components will be around $400.

Design Schedule



Conclusion

Overall, as seen throughout this paper, the proposed design successfully meets the criteria needed for participating in the sumo robot competition. As such, the detailed process of research, choosing components, building, and testing the robot are included within this paper, which should serve as a guide for future students that would like to participate in this exciting event. By doing so, one does not need to go searching for material around the Internet in order to find resources on how to build a robot such as this – they need only to view this paper to gain the insight needed to build a sumo robot (and, hopefully make an even better design!).

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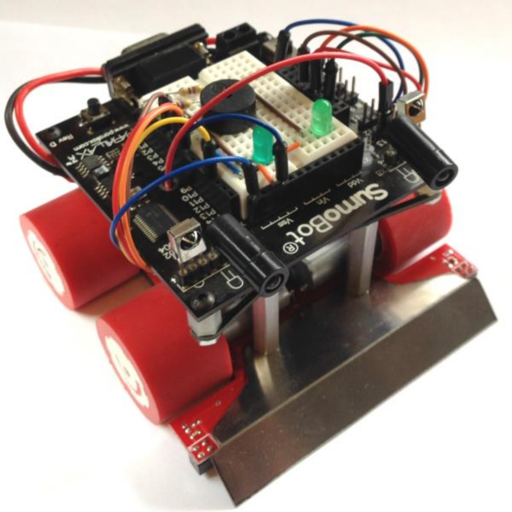
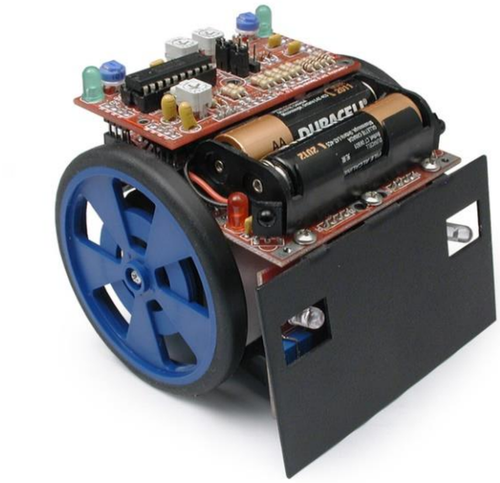
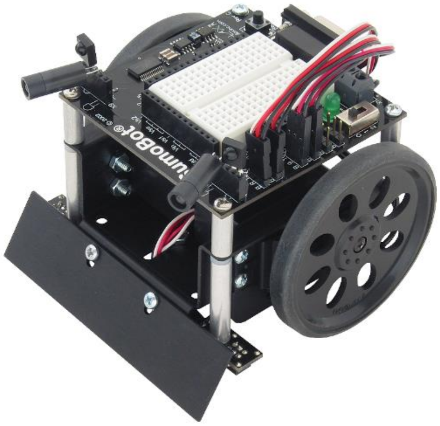
Appendix A: Diagrams of Different Designs



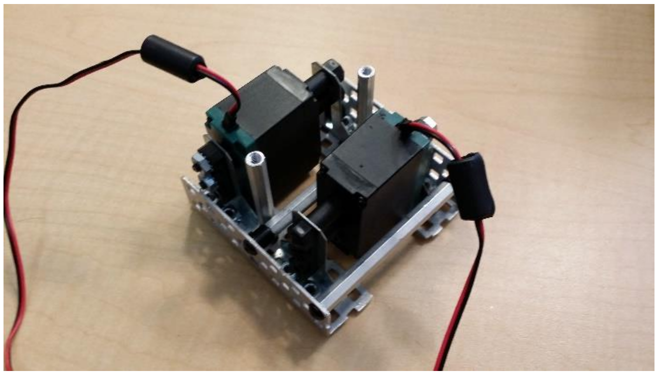
FingerTech Robotics Cobra Design[5]



Solarbotics Sumovore Kit[4]



Parallax SumoBot Kit[3]



Initial Vex Robot Design