Fall 2018

Pick and Place Bot: ASME Design Challenge

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Executive Summary

The purpose of this design project was to create a bot that could meet the requirements and compete in the 2019 ASME Student Design Competition. The contest involves creating a drivable bot with multiple functions meant to test the creativity and design skill of its participants. The bot must be able to navigate a 5 square meter course and collect balls on 20 cm tall podiums and return the balls to a designated starting area. Each action is scored differently and whatever bot scores the most points in a head to head competition wins the match.

Our approach was to design a bot that could grab and secure multiple ball before returning them to the starting area. It is believed that this strategy will give us the best chance of winning. To do this, a large, cubic bot was made with lots of room for storage. Two forward arms were used to grab the balls and funnel them into storage. Finally, a swinging gate in the back released the balls when desired.

The design described below was determined to be a success due to its ability to complete the required actions of the competition, along with the fact that the bot was made under the budget of $250 and completed on time. The complete breakdown of the cost, design, components, and evaluation is in the following report.

MEMS 411: MECHANICAL ENGINEERING DESIGN PROJECT
FALL 2018

Pick and Place Bot

Josh Clark

Stephan Meyer

Steven Mumford

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1 INTRODUCTION

Our team is tasked with designing a device that meets the rules and regulations of the 2019 ASME Student Design Competition. The 2019 competition is named *The Pick-and-Place Race.* Devices need to be able to retrieve balls of various size from the top of 20 cm tall columns. The balls can be captured for 2 points, and if they are placed in the starting location, an additional 3 points is attained. If a ball is knocked off a column and onto the course, 1 point is lost. The client has specified that the balls range in size from the diameter of a ping-pong ball to the diameter of a 16-inch-circumference softball. The device must be able to fit in a 50x50x50 cm box both before and after each round. Additionally, the client has specified that the device can be controlled by either a tethered remote control, or one that can connect wirelessly. After the completing the design of our device, our device will perform both a solo run of a course to retrieve balls and go head to head against another team's device.

2 PROBLEM UNDERSTANDING

2.1 BACKGROUND INFORMATION STUDY

Related Products

This section discusses products related to our product that have similar design goals and functions. These will be used as inspiration for our designs as well as benchmarks for knowing what functionality is needed to make our product competitive in the market.

The ping pong ball bot is a Purdue University student's design project. The final product is shown below.

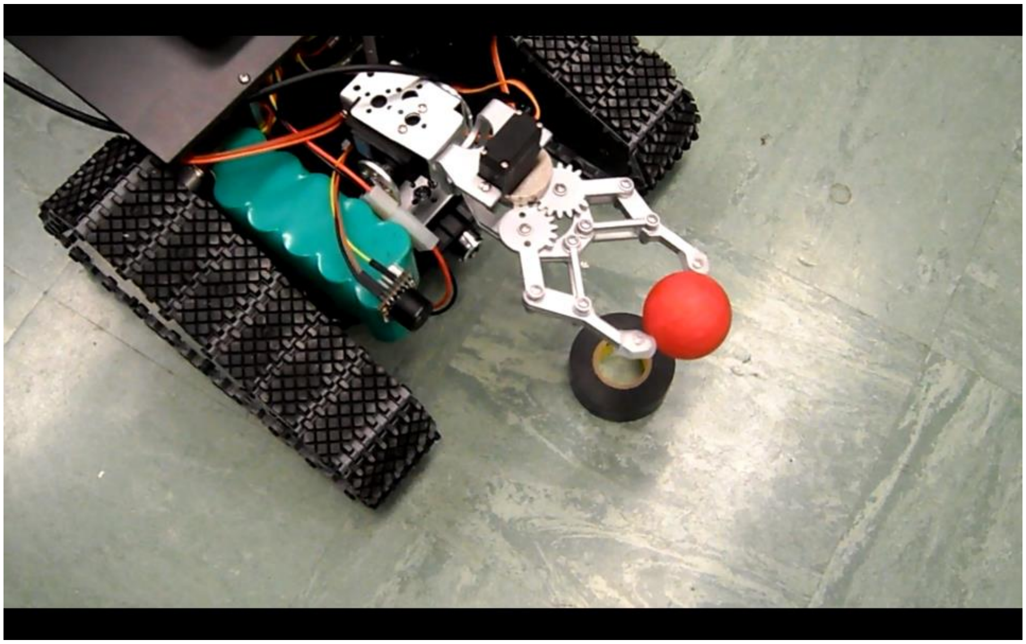


Fig. 2.1 The ping pong ball bot, showing the tank style driving system and a two fingered arm.

This bot was designed with the goal of being able to pick up a ping pong ball at a fixed height via wireless control. There were also sensors that could detect the ball as well as prevent collisions. It utilizes a tank-like wheel mechanism that makes for a smooth ride and simple turning. The arm is two prong and grips the ball from the sides. The product does not allow for the arm to adjust height or have a way to secure and hold multiple balls. Its successes with wireless control, ball grabbing, and detection make it an impressive product. Link: https://engineering.purdue.edu/ece477/Archive/2013/Spring/S13-Grp01/nb/jin52.html

The Tennibot, shown in Fig. 2, is an autonomous robot designed to pick up tennis balls scattered across a court to save tennis players the time it takes to pick up the ball. It utilizes computer vision and GPS tracking to find tennis balls and navigate the entire court. It has a bucket in the back that it can store up to 80 tennis balls in. It has a funnel shaped front that funnels balls into a shoot that sends the balls into the accumulator. It has four wheels for enhanced mobility. There is an app that comes with it that also allows for the bot to be driven manually from the user's phone. The bot has many different functions and is designed in an extremely user friendly way that should help it be successful in the market.

Fig. 2.2 The Tennibot that autonomously navigates a tennis court picking up and storing balls.
Link: https://www.kickstarter.com/projects/770435035/tennibot-the-worlds-first-robotic-tennis-ball-coll

The robotic ball sorter was a University of Florida student's design project. Its goal was to grab a bucket full of tennis balls and golf balls, dump them into its storage bin, sort them and put the golf balls back into the bucket. The final product is shown in Fig. 3. It utilized two fixed prongs that grabbed the bucket and then hinged up to dump the balls into the accumulator. The golf balls funneled through to a shoot that then dumped the balls back into the bucket. It had fixed wheels that worked rather effectively for maneuverability. Its hinging motion for dumping the bucket was effective and it sorted the balls with high success. It's consistent success with its design goals make it a good product.

Fig. 2.3 The robotic ball sorter with its two prong and hinging grabber. The grill in the bucket sorts the balls which are released through the door on the front.

Relevant Patents

<u>Patent 1</u>

Patent Number: US5989096A

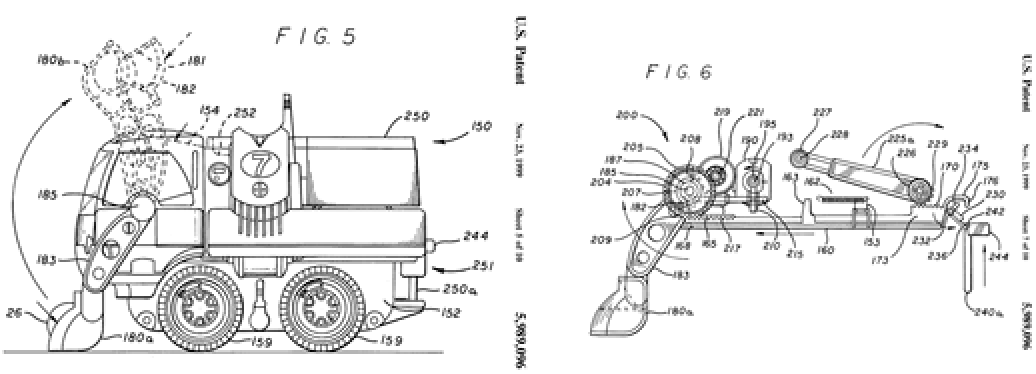


Fig. 2.4 Sketches of US5989096A

Patent **US5989096A** is a remote-controlled toy version of a skid steering system which resembles a front-end loader. This toy is capable of close quarter maneuverability and can raise and lower a bucket to transfer different elements into the rear of the vehicle. The patents relate to multiple versions of this concept including: bulldozers, dump trucks, trailers, and forklifts. This toy has a counterweight mounted on the rear of the vehicle to help stabilize when lifting different objects. The lifting mechanism uses actuators to elevate a lifting arm.

Patent 2
Patent Number: US5,921,843

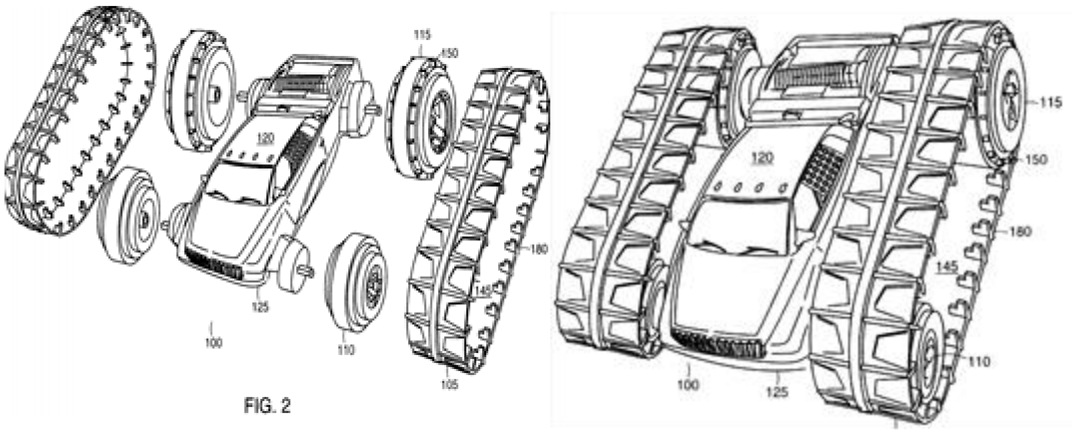


Fig. 2.5 Sketches of US5921843A

Patent US5921843A is a remote-controlled vehicle which has oversized treads on each side allowing for it to drive over almost any surface. This vehicle is directed by a handheld remote controller. This vehicle can be powered by one or two motors applied to the rear wheels allowing for close quarter maneuverability. The compact design of this patent in addition to the belt style wheel system allows for the vehicle to be operated while inverted.

Relevant Standards

A relevant standard to abide by for our product is the standard related to stepping motors, which will be used as the driving power allowing for power and precision. The standard we will address is titled “Control motors – Stepping motors” and its ID number is CLC/TS 60034-20-1:2004-09. It discusses different limits that a stepper motor can endure, such as voltage, temperature, and torque, which will be useful in ensuring that the motors operate within a range such as are safe and accepted in industry.

Another relevant standard to abide by will pertain to the power supply. The competition dictates the power supply must be rechargeable, so lithium reachable batteries will be used in a coupler to supply power to the motors of the bot. The standard for these batteries that we will use is BS EN 60086-4:2000 “Safety Standard for Lithium Batteries as Primary Power Supply”. It discusses the limits the batteries can be used for terms of mechanical us and the conditions at which they are best stored.

2.2 USER NEEDS

Table 1 A customer needs interview table summarizing the interview of the customer.

Product: Pick-and-Place Bot
Customer: Stephan Meyer, Josh Clark, Steven Mumford
Notes: Performed in my apartment, took turns asking one person questions while the others recorded answers.
Address: 6337 N Rosebury Ave. St. Louis, MO 63105
Date: 9.9.18

Question	Customer Statement	Interpreted Need	Importance
Which function is most important to you?	The ability to grab and hold on two the balls for 2 seconds is most important. This is the easiest way to score and we can still score well even if we don't secure them in the starting area.	A well functioning grabbing mechanism is a must.	5
Are there any functions that aren't as important?	Remote control via a wireless connection isn't a necessity, but would be a nice bonus.	The bot must be drivable	5
Are there strategies of the game that would influence the design?	A strategy could be to quickly grab and store as many balls as possible, then drop them in the starting area at the same time. Another could be to grab the balls and not worry about taking the balls back to the starting area, and try and get to the most balls before the other team.	The bot must be easy to maneuver The bot should be quick The bot should have a storage area for multiple balls	4 2 2
How important is minimizing size of the bot for the tie breaker criteria?	Similar to the wireless connection, if it can be done in a smaller volume that'd be great, but it's more important to have a well functioning grabbing mechanism	The bot should be as small as possible	1
What parameters should have a buffer to help ensure functions don't fail?	The batteries should have enough juice to last 5 minutes without any issues. The more consistent the securing feature is on the bot would be better to ensure balls aren't dropped and points lost.	Power needs shouldn't be more than the batteries can handle for the duration of the game The securing function should be consistently successful	5 4

Table 2 An interpreted customer needs table describing necessary functionality and the importance of each function.

Need Number	Need	Importance
1	A well-functioning grabbing mechanism is a must.	5
2	The bot must be drivable	5
3	The bot must be easy to maneuver	4
4	The bot should be as small as possible	1
5	Power needs shouldn't be more than the batteries can handle for the duration of the game	5
6	The bot should be quick	2
7	The bot should have a storage area for multiple balls	2
8	The securing function should be consistently successful	4

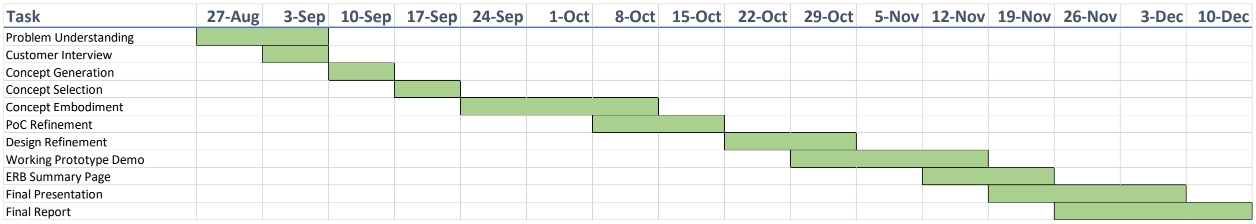
2.3 DESIGN METRICS

Table 3 A target specifications table describing the measurable goals of our product based on the customer interview.

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	4,7	Total volume	cm^3	<125,000	<43,000
2	3,6	Total weight	lb	<25	<15
3	5,6	Drive time before needing recharged	min	>5	>10
4	1,8	Successful 1st attempt grabs	percentage	>75	100
5	2	Turning radius	cm	<30 cm	<18 cm

2.4 PROJECT MANAGEMENT

Table 4 The Gantt chart used for scheduling our design process.



3 CONCEPT GENERATION

3.1 MOCKUP PROTOTYPE

A rough mockup was made of the product to visualize our ideas better and to expose any early issues in the ideas. The results of the construction are show in Fig. 1.

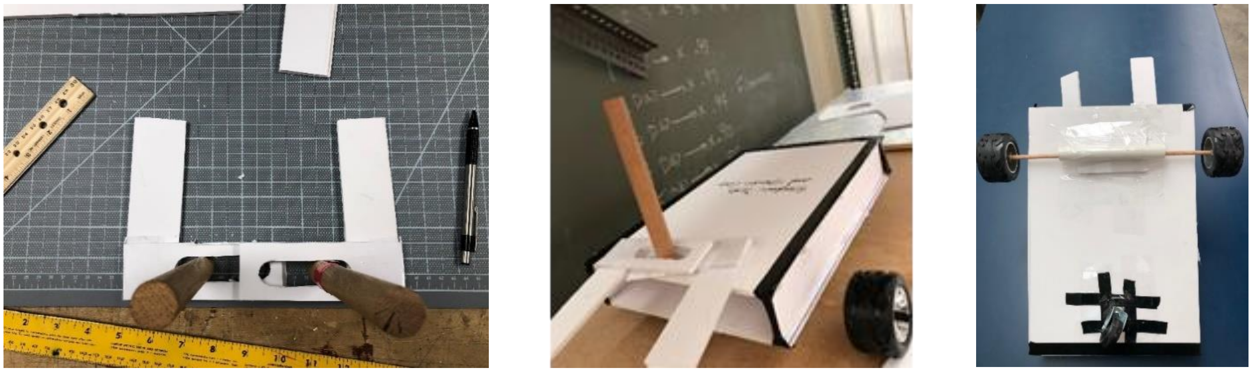


Fig. 3.1 The product produced from mockup construction.

The mockup helped visualize the size that we are limited to by the project guidelines as well as envision ways we can minimize size. We also explored a two-wheel high drive train with a single caster in the rear and were able to see the pros and cons of that approach. The ball securing mechanism was also modeled using the L-shaped cutouts with slots that a guide pole could fit through. We were able to see the range of widths we had with a two support versus one support method. We found that one support provided a much larger range of widths which is desirable for our finished product. These insights will be used as concepts are brainstormed for our first prototypes.

3.2 FUNCTIONAL DECOMPOSITION

To better understand the problems that need to be solved to create a final product, the bot was broken down into different functions, and multiple solutions were suggested for each function. The function tree is shown in Fig. 2 and the morphological chart showing the various ideas for each function is shown in Fig. 3.

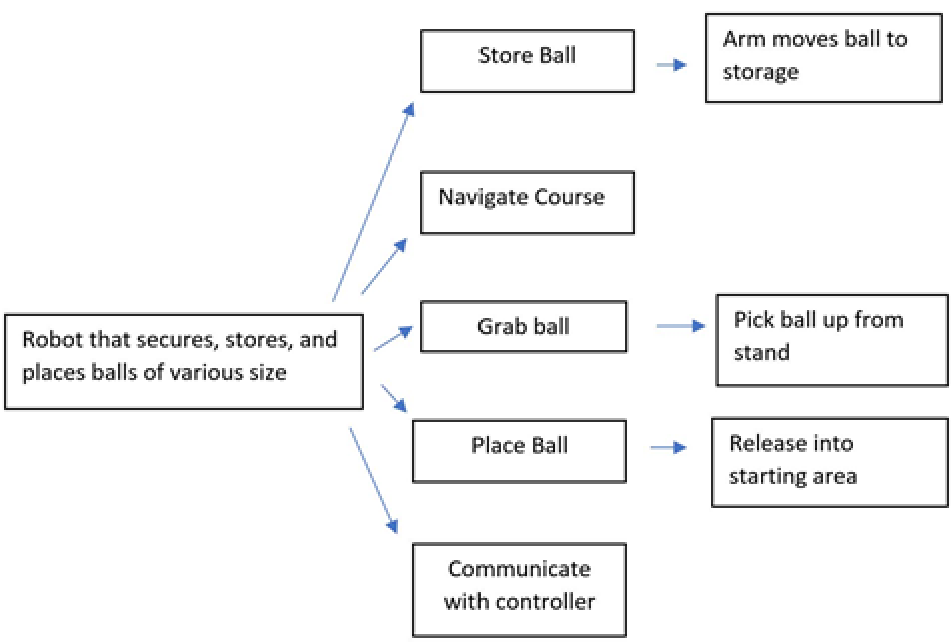


Fig. 3.2 The function tree for the pick and place robot.

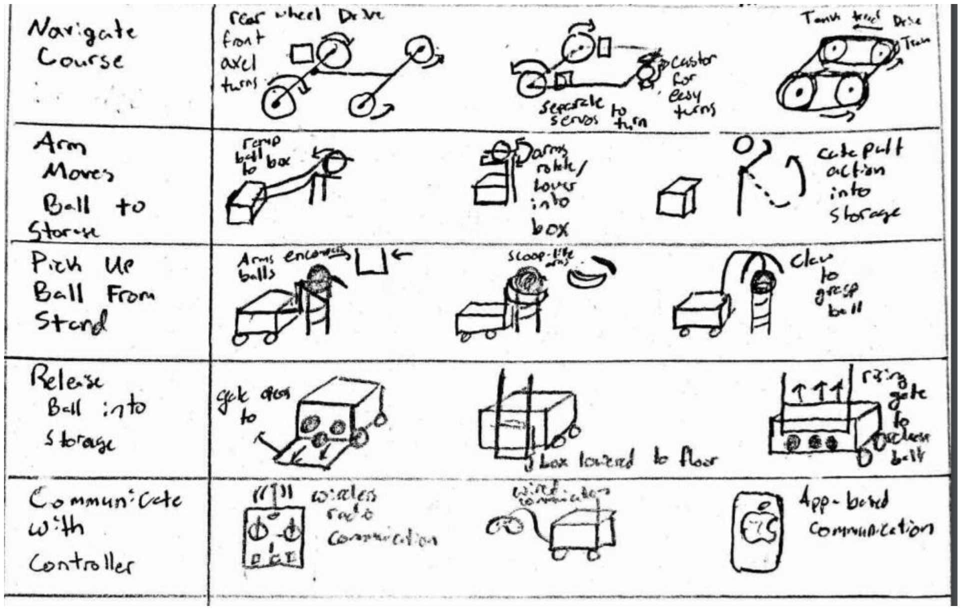
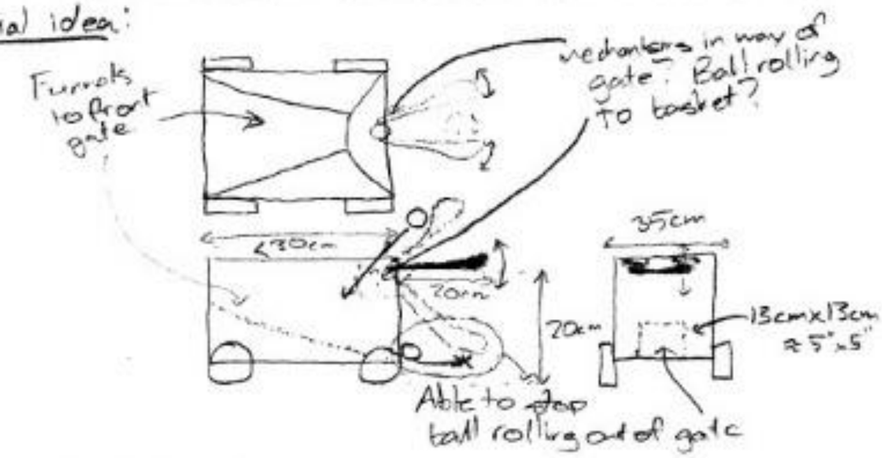


Fig. 3.3 The morphological chart showing different possibilities of how to perform the functions described in the function tree.

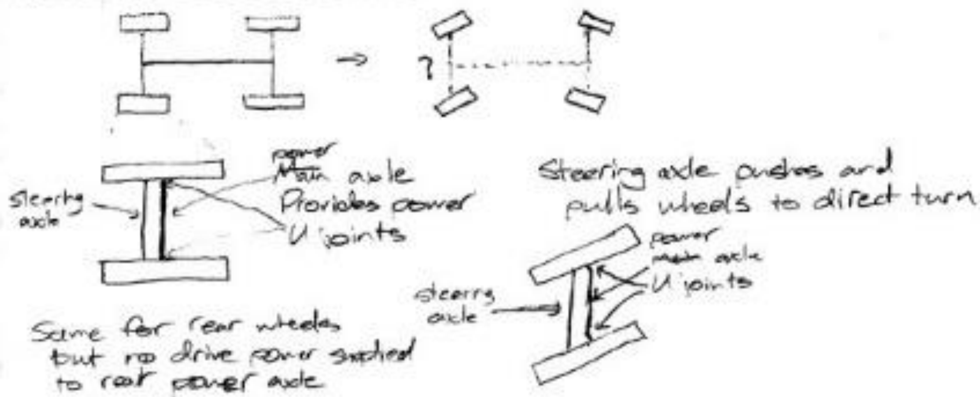
3.3 ALTERNATIVE DESIGN CONCEPTS

Each team member took this information from the function decomposition and came up with designs individually. The results are shown in the figures below. Steven Mumford’s is shown in Fig. 4, Josh Clark’s is in Fig. 5, and Stephan Meyer’s is shown in Fig. 6.

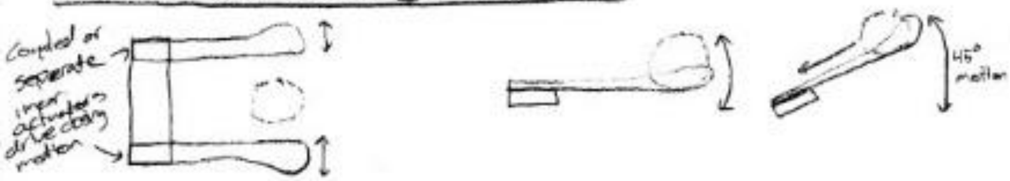
Initial idea:



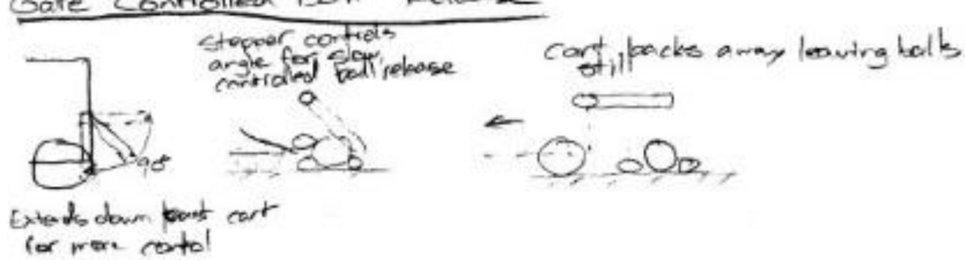
Steering and drive train



Alternative ball securing mechanism



Gate Controlled Ball Release



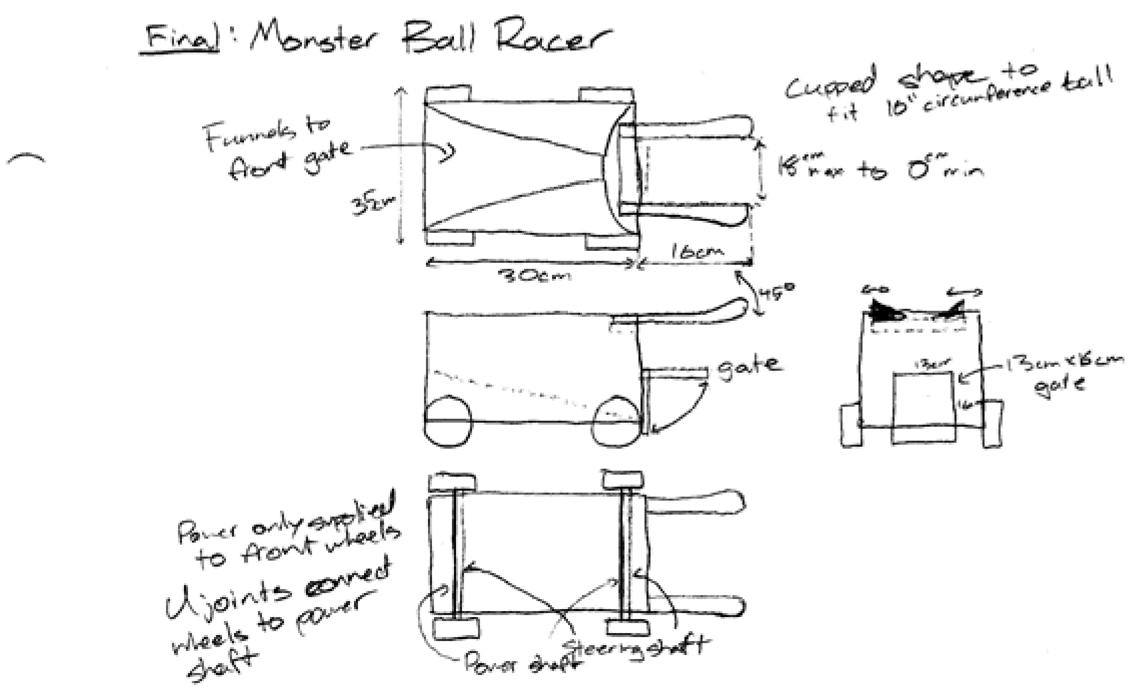


Fig. 3.4 The concept generated by Steven Mumford.

The monster ball racer uses the swinging arm with cupped prongs that grab the ball and then tilts up to roll the ball back into the storage container. It utilizes a four-wheel system with two-wheel high drive. It also uses the gate method for releasing the balls into the storage effort. This gate is slowly opened to release the balls in a controlled way that will help the balls remain stationary once placed.

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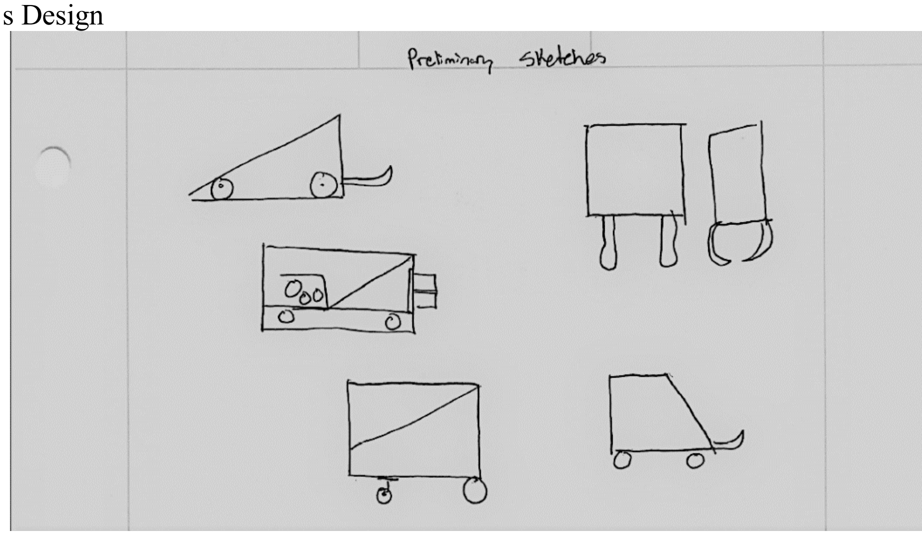
Josh Clark's Design



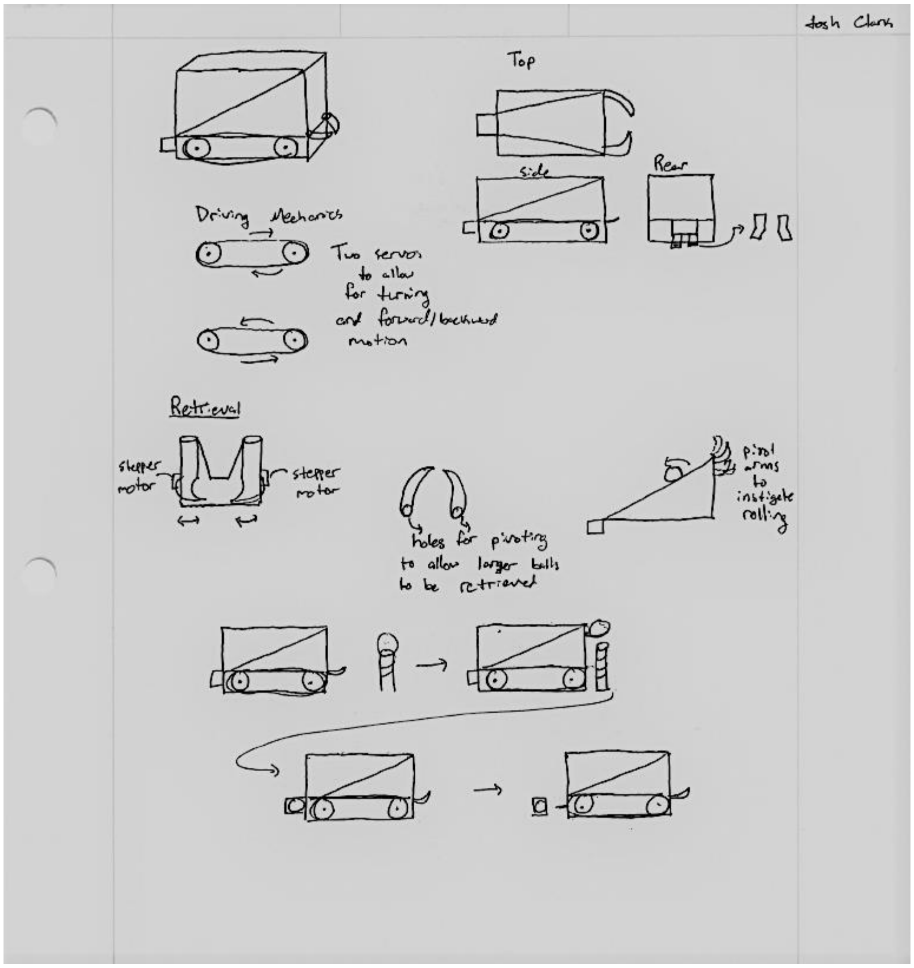


Fig. 3.5 The concept generated by Josh Clark.

The Clark design has a pair of pincers that can rotate about their vertical axes to adjust for ball size. The pincers also move vertically to retrieve the ball from the post. Once at its highest point, the pincers will tilt to roll the ball back into the detachable storage box. The bot uses a continuous track on each side to control movement. Servo motors will direct the rotation to allow the bot to move forwards, backwards, and turn. Once the storage box is full, it can be lowered to the starting area for maximum scoring.

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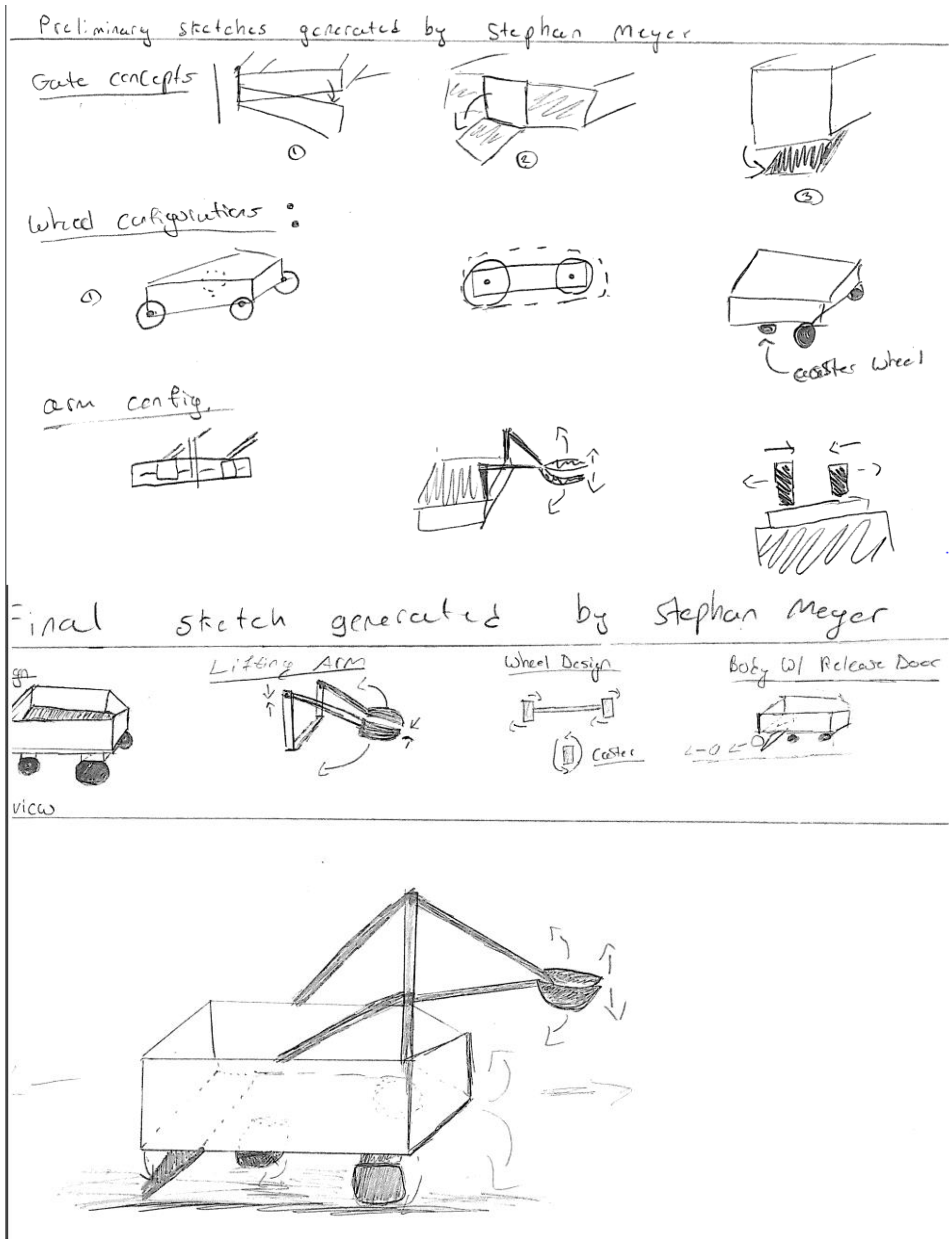


Fig. 3.6 The concept generated by Stephan Meyer.

The design by Meyer would include two long swinging arms that could swept in laterally to scoop balls of various size off their platforms. This design would allow for a large clearance between the ball platform and the body of the bot. Additionally the arms would be able to rotate in both azimuth and elevation allowing for the capture of balls placed at various heights. This bot with also be able to store several balls within the body of the bot itself to then be released later from the lowering latch door. The Meyer design includes a caster wheel in the rear and two driven will toward the front of the bot allowing for a tight turning radius.

4 CONCEPT SELECTION

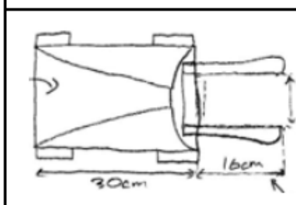
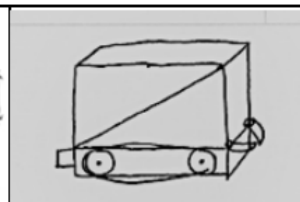
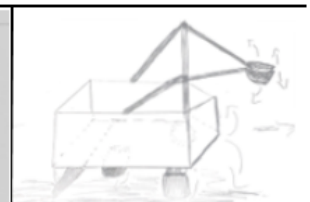
4.1 SELECTION CRITERIA

Table 5 The analytical hierarchy process table used for evaluating design concepts.

	Grabs Balls Consistently	Maneuverable	Can Store Many Balls	Small	Sufficient Battery Life	Easy to Control	Row Total	Weight Value	Weight (%)
Grabs Balls Consistently	**1.00**	3.00	5.00	9.00	1.00	3.00	22.00	0.27	26.86%
Maneuverable	0.33	**1.00**	5.00	7.00	0.33	1.00	14.67	0.18	17.90%
Can Store Many Balls	0.20	0.20	**1.00**	7.00	0.33	3.00	11.73	0.14	14.32%
Small	0.11	0.14	0.14	**1.00**	0.11	0.14	1.65	0.02	2.02%
Sufficient Battery Life	1.00	3.00	3.00	9.00	**1.00**	5.00	22.00	0.27	26.86%
Easy to Control	0.33	1.00	0.33	7.00	0.20	**1.00**	9.87	0.12	12.04%
	Column Total:						**81.92**	**1.00**	**100%**

4.2 CONCEPT EVALUATION

Table 6 Weighted scoring matrix used to pick the best design.

		Alternative Deisgn Concepts					
							
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Grabs Balls Consistently	26.9	4	1.07	5	1.34	2	0.54
Manueverable	17.9	2	0.36	1	0.18	5	0.90
Can Store Many Balls	14.3	4	0.57	3	0.43	3	0.43
Small	2.0	2	0.04	3	0.06	3	0.06
Sufficient Battery Life	26.9	3	0.81	3	0.81	3	0.81
Easy to Control	12.0	2	0.24	3	0.36	3	0.36
	Total score	**3.092**		**3.179**		**3.090**	
	Rank	**2**		**1**		**3**	

4.3 EVALUATION RESULTS

As shown above in the design analytical hierarchy matrix the two qualities which we deemed as most important are consistently grabbing the balls and sufficient battery life. As all three design concepts ranked equally in battery life, consistency grabbing the balls proved to be the deciding factor. Design concept two ranked the highest in is this quality at

5. Design concept two performed the worst in maneuverability, however, given its limited weight, it did not significantly affect the high performance of this design concept. Design concept two scored highly due to its high ranking in two highly weighted criteria. Storing many balls, and grabbing the ball consistently. Design concept three scored poorly mainly due its low ranking in a highly weighted criteria, consistently grabbing the ball. Design concept two was ranked this highest at 3.179 followed by design concept 2 at 3.092 in second and then by design concept 3 at 3.090.

4.4 ENGINEERING MODELS/RELATIONSHIPS

To ensure that the bot will not run out of battery before the end of the round, the current load must be accounted for can compared to the capacity of the batteries used. For analysis, the bot will be broken down into the drive system, the grab and secure system, and the ball release system. These systems will not be in use the entire time, and therefore an estimated percentage will be used to approximate how much current each individual system will draw during the round. The equation becomes

$$fC>(P_D I_D+P_{GS} I_{GS}+P_R I_R)t$$

where P_D, P_{GS}, and P_R are the estimated percentage of time in use for the drive system, grab and secure system, and release system, respectively [3]. Similarly, I_D, I_{GS}, and I_R are the given load ratings in mA for the drive system, grab and secure system, and release system, respectively, and t is the length of the round. If the sum of current loads is less than the battery capacity C [mAh] multiplied by an adjustment factor f, accounting for unforeseen issues affecting battery life, then the system should have sufficient power to run for the duration of the round.

For optimal scoring, it is imperative that the bot maneuvers the course both quickly and precisely. If the bot is unable to do so, it could knock into some of the pillars, causing balls to fall and hurt the teams score. One effective way to ensure precise maneuvering is to calculate the turning radius of the bot. The key information from the bot needed to calculate the turning radius are the wheel base, w, which is the distance between the front and the rear wheel of the bot, and α, the turning angle of the front wheel [2]. With these two knowns, the equation for the turning radius of the front wheel, or the outer turning radius, becomes

$$R=w*\sin(\alpha)$$

where R is the outer turning radius [m], and w and α are the knowns described above. Because the rear wheel remains stationary, different trigonometry is required to calculate the rear, or the inner turning radius [2]. The following equation shows this

$$r=w*\tan(\alpha)$$

Where r is the inner turning radius [m], and w and α are the same knows from the outer turning radius. If these radii are minimized in our design, precise turns can be executed to avoid losing points.

In order to successfully navigate the course, it is crucial that the bot is well balanced allowing it to add and remove mass without tipping. One way to ensure the bot is well balanced is to perform a moment balance of a free body diagram representing the weight distribution of the bot. This model is cited from Hibbeler's Engineering mechanics: Statics text. This model is most applicable if you consider a moment around the front wheel. Where the ball/lifting apparatus exerts a negative force (F1) about the front wheel at a distance (L1) which is the distance between the axis of rotation and the applied force. The body of the bot itself would exert a positive force (F1) at its center of gravity which is (L2) from the axis of rotation. Taking a sum of these moments will indicate the stability of our bot.

$$\text{Resulting Balance} = \sum F(y): \big(F2*(L2)\big) - ((F1*L1))$$

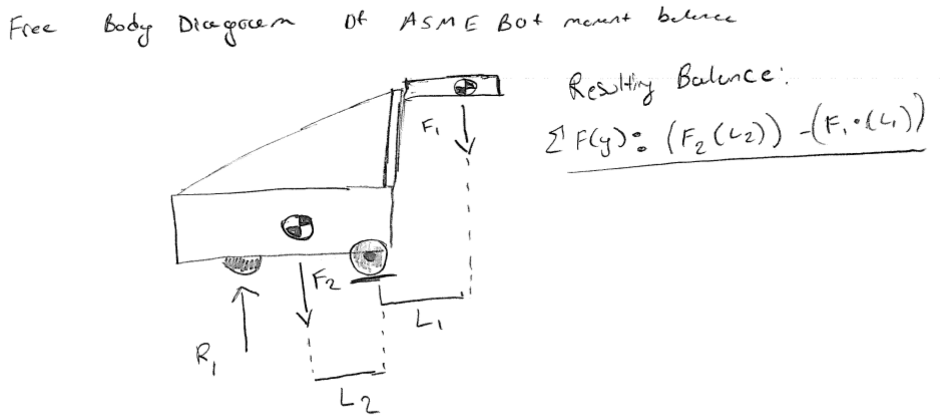


Fig. 4.1 Free body diagram of moment balance model

Optimally the resulting balance will be a positive moment. In this case the bot would want to rotate counter clockwise about the front wheel. This can be easily overcome with the incorporation of a reactionary force given by the rear caster wheel which was not considered in the previous model. The accuracy of this model will be dependent on where we are assuming the center of gravity of each component acts. Improving this assumption will lead to a higher degree of confidence in the stability of our bot. Additionally, we are assuming that that there is no acceleration while conducting this moment balance. If accelerating the bot would tip more or less depending on the direction of the acceleration

5 CONCEPT EMBODIMENT

5.1 INITIAL EMBODIMENT .

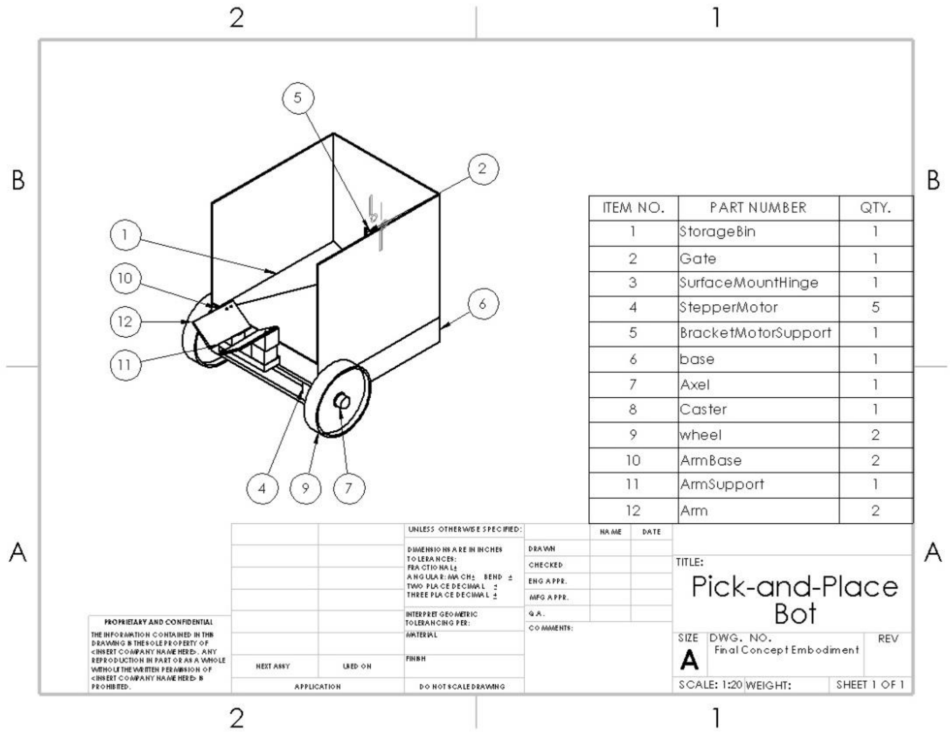


Fig. 5.1 The model of our design including a bill of materials.

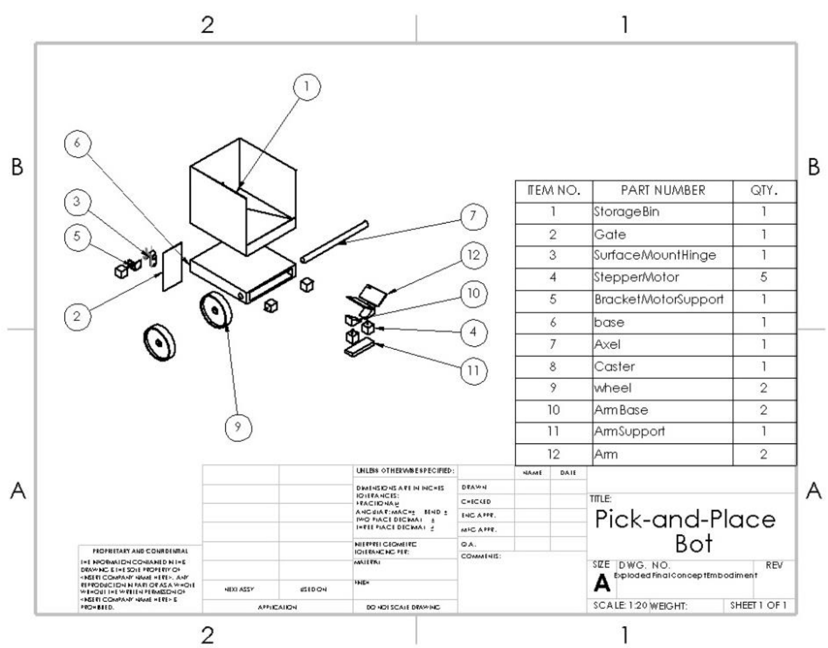


Fig. 5.2 The exploded model of our design including a bill of materials.

Table 1 The parts list needed for the design shown in Fig. 1 and 2.

Source Link	Supplier Part Number	Color, TPI, other IDs	Unit Price	Quantity
Amazon		Official with Booklet	$ 70.20	1
Amazon	K-KJ17MCA4BA		$ 17.99	1
Amazon	B0777DR3T6		$ 15.99	1
Amazon	B00FAS1WDG		$ 17.98	1
Custom			$ -	1
Custom			$ -	1
Custom			$ -	1
Custom			$ -	1
Home Depot	2908	Plywood	$ 6.00	1
Home Depot		Wood	$ 33.01	1
Home Depot	841102	Swivel, Rubber	$ 3.44	1
McMaster-Carr	115A95	Dull, Zinc-Plated Steel	$ 6.45	1
OSEPP	MTD-01	L298 Dual H Bridge	$ 9.99	1
Solarbotics		143:1 Offset	$ 16.99	1
		Total Cost	$ 198.04	

5.2 PROOF-OF-CONCEPT

Our three performance goals for the prototype are as follows

1. Collect ¾ balls (ping pong, golf, tennis, plastic bowling ball) in 1 minute,
2. Drop ¾ balls into home base,
3. Drive 4 figure eights around cones that are 1 m apart in 1 minute without hitting any cones.

These parameters are ambitious but if these goals are achieved, we believe we would be well set up to do well in the competition.

To drop the balls into home base, a swinging gate controlled by a stepper motor is used to controllably release the balls from the storage bin onto the ground. The design rationale for the mass of the gate based on the holding torque of the stepper motor are shown below. The model is shown in Fig. 3.

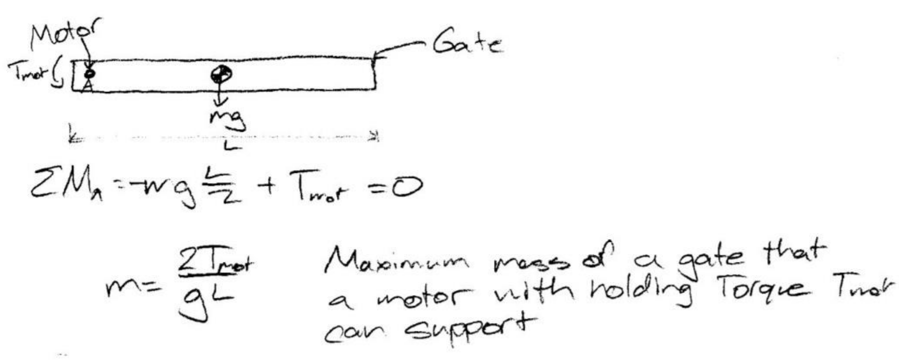


Fig. 5.3 The torque balance model used to find the mass of the gate a given motor can support.

With the above goals in mind, our group designed three separate prototypes. The driving prototype is shown in Figure 4, the collection prototype is shown in Figure 5, and the gate release prototype is shown in Figure 6.

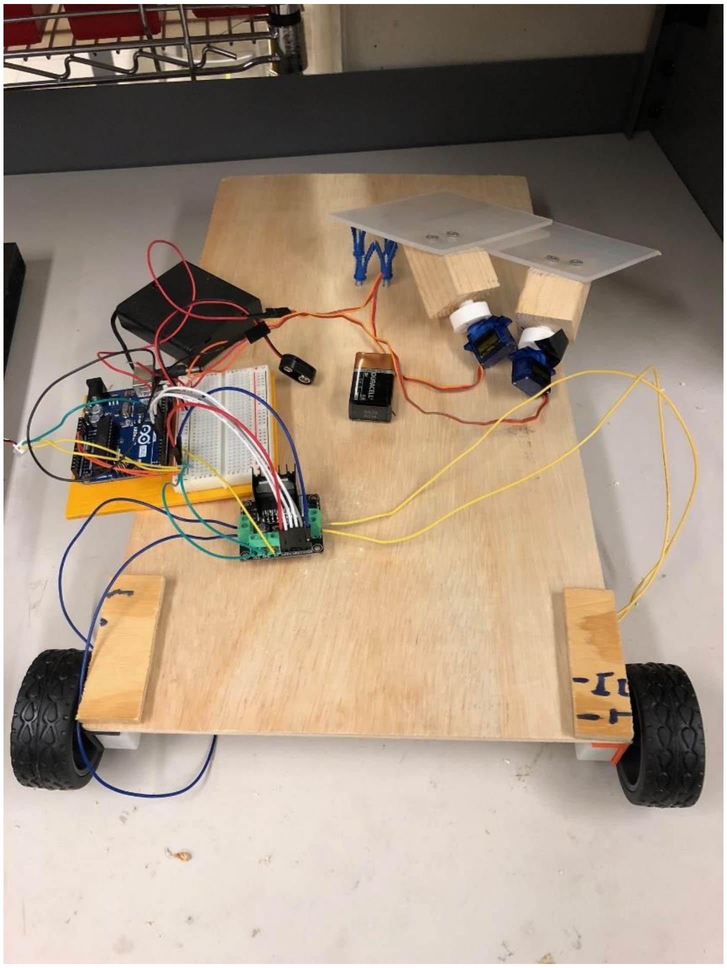


Fig. 5.4 Two driving motors were attached to the molded body for forward, backwards, and turning movement

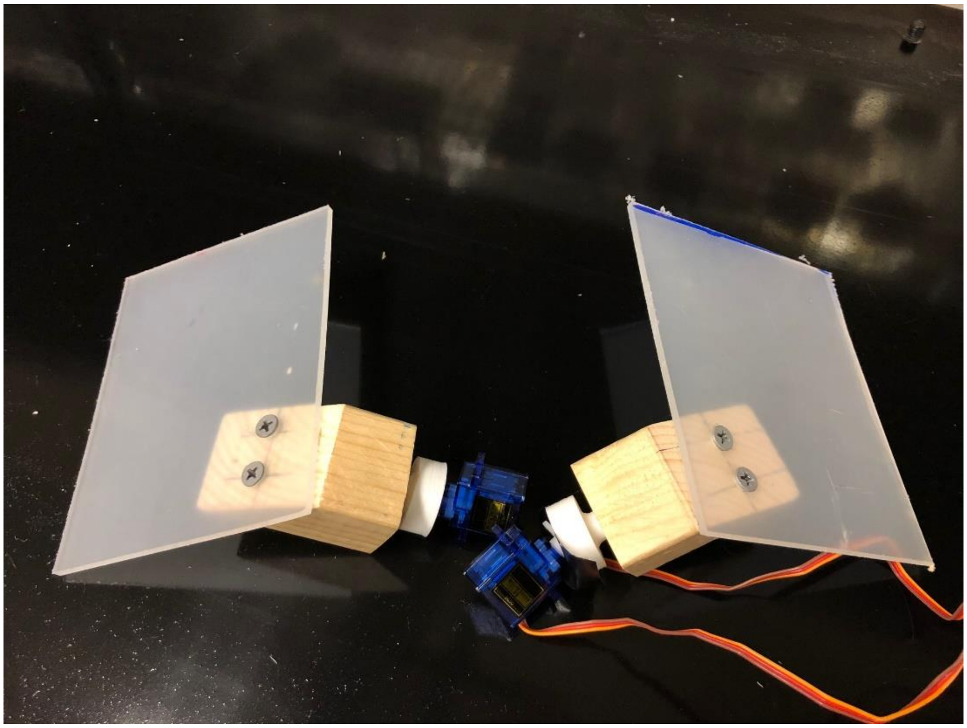


Fig. 5.5 A servo motor was attached to each arm so they can rotate to adjust for varying ball diameter

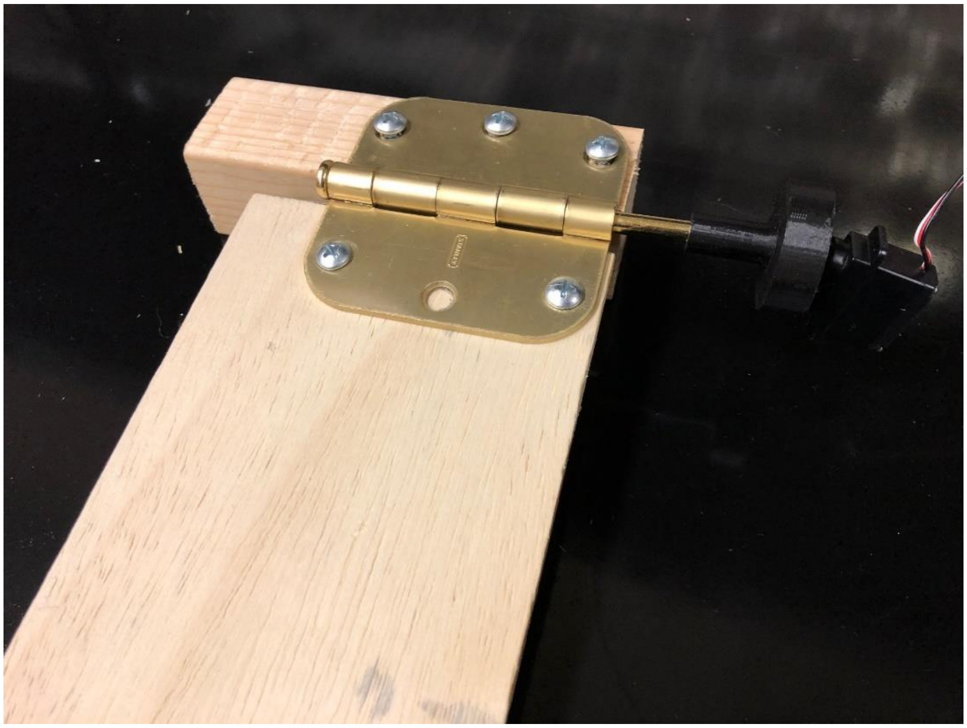


Fig. 5.6 A servo motor was attached to lift the gate so that collected balls can be deposited in the starting zone

6 WORKING PROTOTYPE

6.1 OVERVIEW

Transitioning from the POC to the working prototype included simplification of design in order to make feasible to implement. The designs of the arms were simplified to one servo driving one swinging arm with the second arm fixed. This helped improve repeatability and consistency of the securing mechanism. The driving motors were provided more power, increasing the voltage from 5 V to 9 V. The bot was then able to drive at an acceptable rate as opposed to barely able to move at 5 V. The gate mechanism remained unchanged, but was mounted in a necessary way to ensure it would hold the balls in the bot until it was time to release them.

6.2 DEMONSTRATION DOCUMENTATION

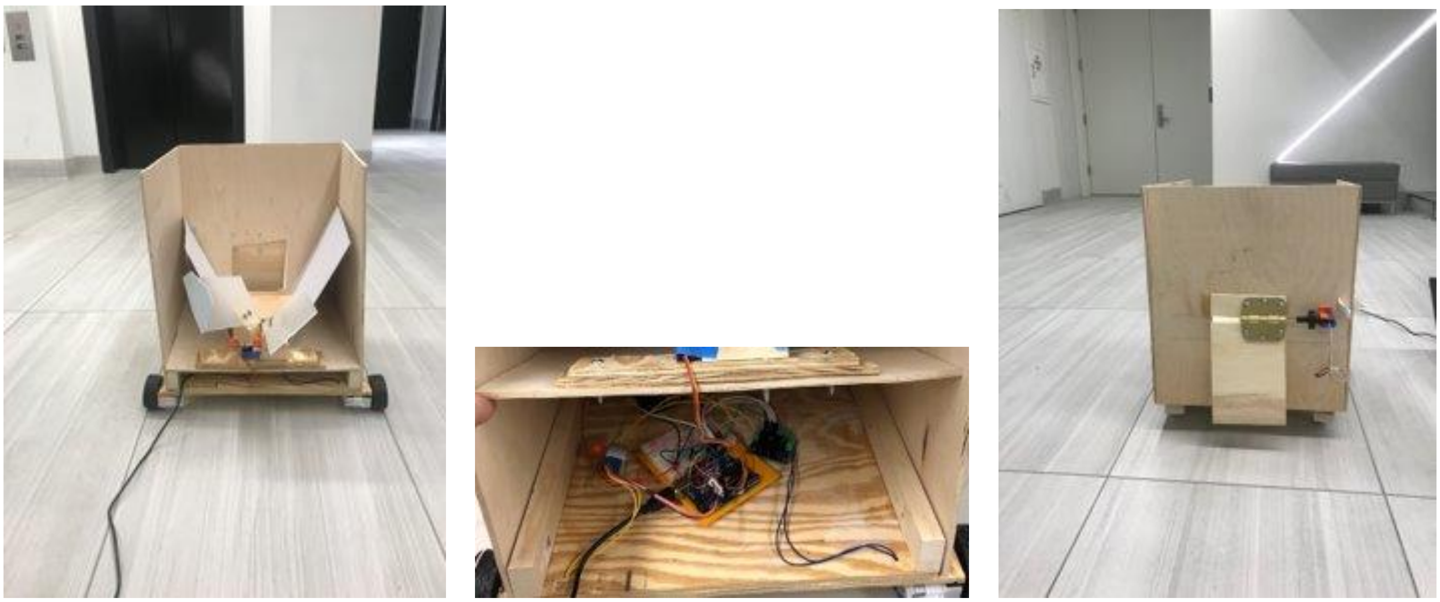


Fig. 6.1 Front, circuit, and rear-views of the working prototype

6.3 EXPERIMENTAL RESULTS

Testing our prototype to our first performance goal showed that our bot was able to grab ¾ balls we sought to grab. The bot struggled to grab the plastic bowling ball due to the servo not being strong enough to push the ball off of the stand. This was countered by increasing the speed of the closing action and we observed that this solution worked but not 100% of the time. Therefore, we concluded out bot was successful in meeting this performance goal because we were successful in grabbing 3 ball consistently and the 4th ball semi-consistently.

Similarly, with our second performance goal of dropping ¾ balls into the starting area were successful despite some inconsistencies. For most trials, ¾ of the balls would fall out, with 1 ball being stuck or left every so often. Despite this, we conclude that we are successful despite inconsistencies. Future work would redesign the interior ramp to help increase the success rate for all balls during release.

Our last performance goal was to drive 4 figure eights around cones 1 m apart in a minute, which our bot was not successful in doing. This failure was due to insufficient power being supplied to our driving motors. With a 5 V battery supply, the bot could barely move. With 9 V hooked directly to the motors, the bot could move but not with sufficient speed to complete the goal. The clunkiness of the controller also made maneuvering difficult and contributed to failing this goal. Future work would be to implement a DC to DC boost converter to provide more power to the driving motors and implementing a more user-friendly controller that would allow the bot to meet this goal.

7 DESIGN REFINEMENT

7.1 FEM STRESS/DEFLECTION ANALYSIS

For the finite element analysis, we chose to isolate the rear lifting gate. In order to accurate analyze the rear gate, several assumptions and boundary conditions were applied. First, we were particularly interested to the gate's behavior at maximum loading. As shown in Figure 1 this occurs when the gate is positioned perpendicular to the ground at maximum elevation. In this case there are two sources of loading. (1) is the force of gravity which acts on the entire body of the gate. (2) is the applied force which acts on the area where the mounting bracket makes contact with the gate. The only boundary conditions for the gate are fixtures located on the bracket mounting holes. We believe that this accurately models the real would stress that the gate will experience during maximum loading, Due to the gates relatively simple geometry we selected a fine mesh for high accuracy.

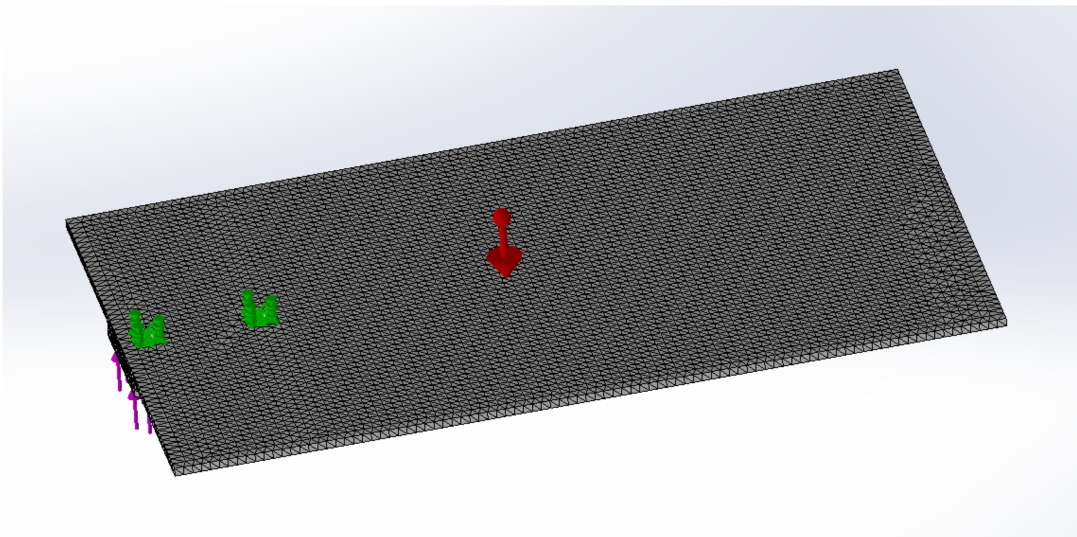


Fig. 7.1 Unloaded model with mesh, loads and boundary conditions shown

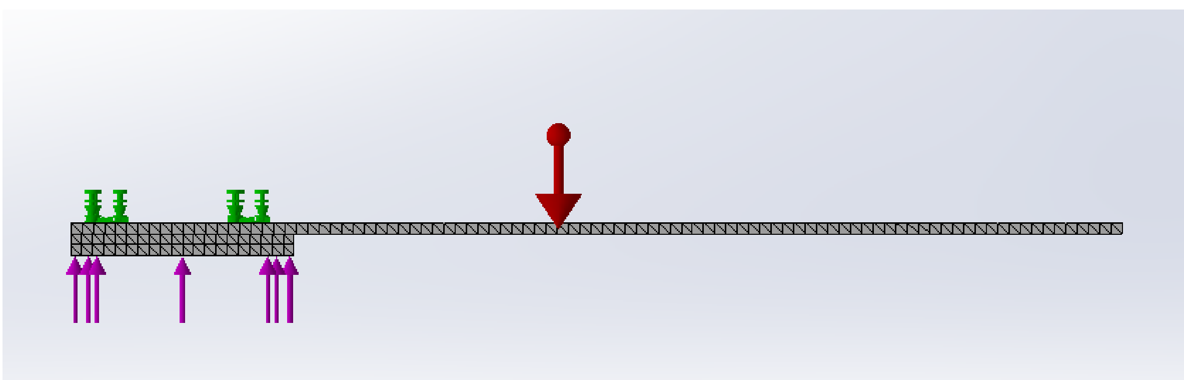


Fig. 7.2 Another angle of the unloaded model with mesh, loads and boundary conditions shown.

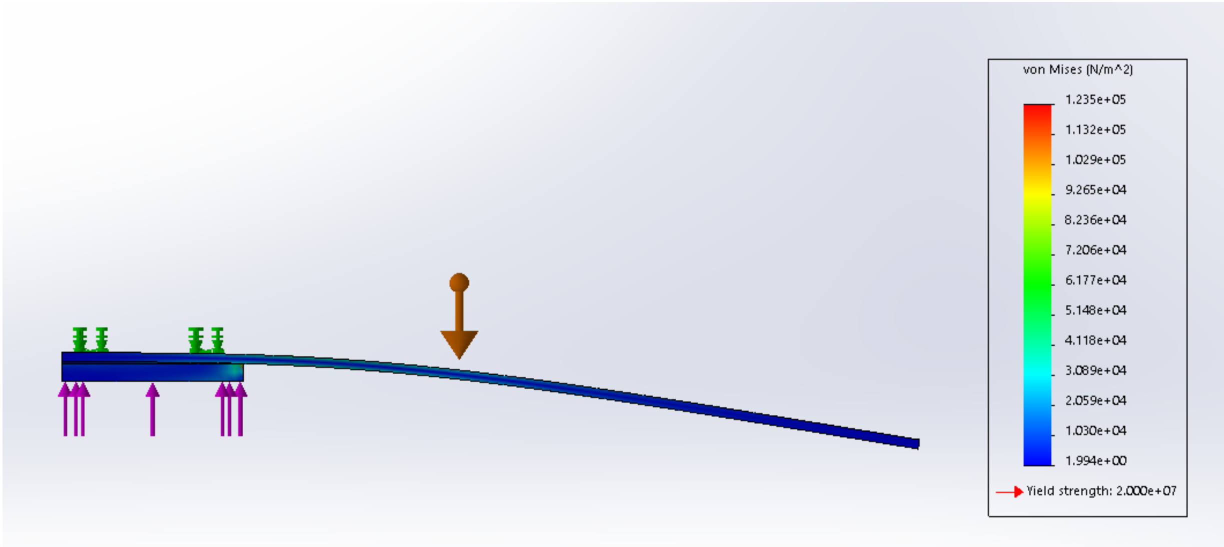


Fig. 7.3 The von Mises stresses in the loaded gate.

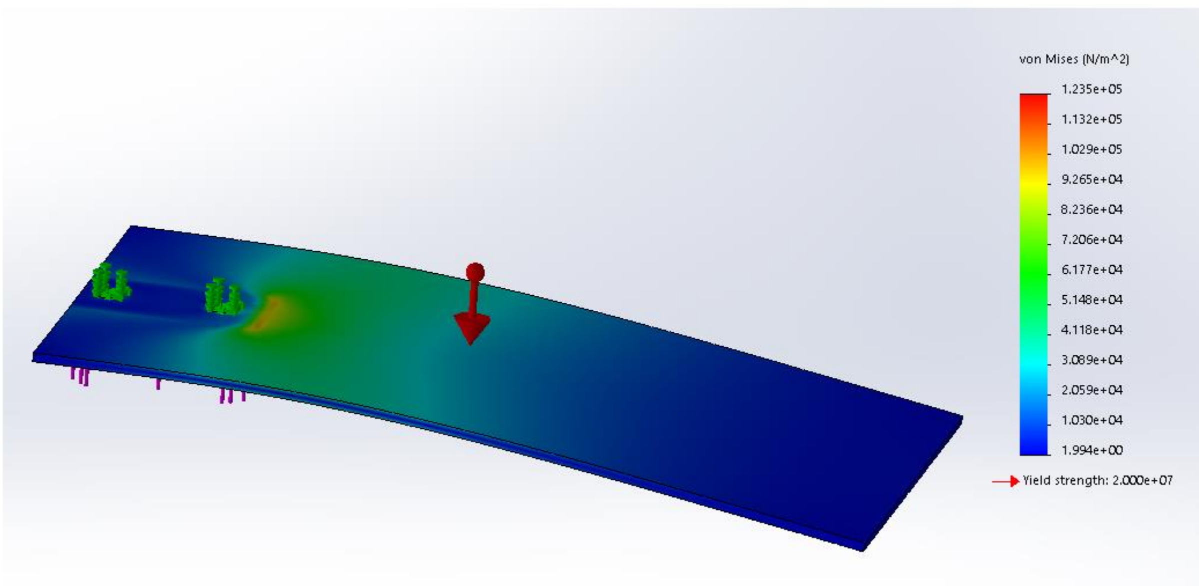


Fig. 7.4 Another angle of the von Mises stresses in the loaded gate.

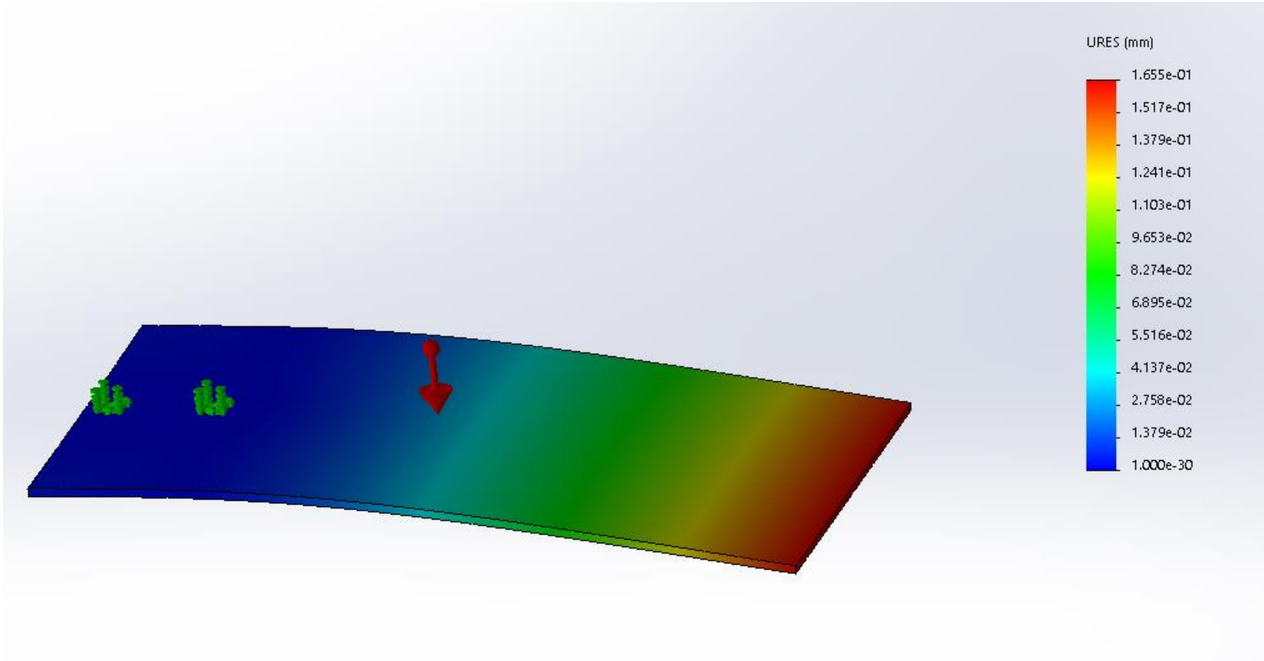


Fig. 7.5 The deflection of the gate under load.

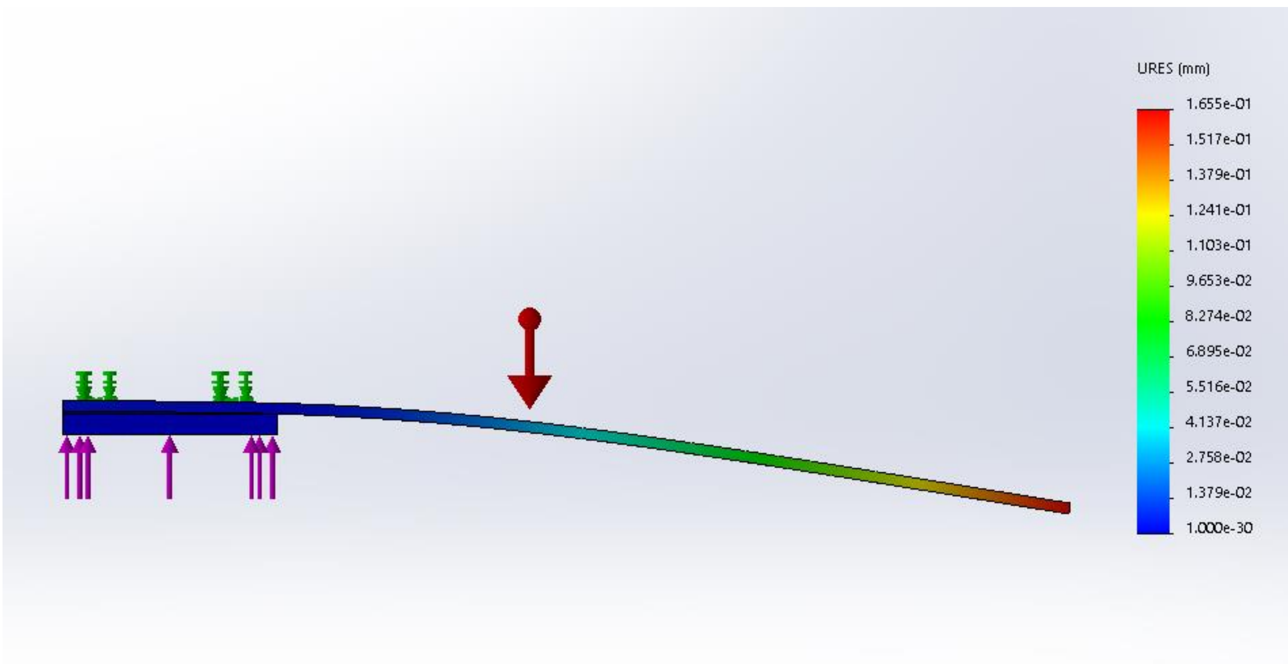


Fig. 7.6 Another angle of the deflection of the gate under load.

The factor of safety was evaluated in Solidworks to be 162. This was found using factor of safety analysis on Solidworks simulation. When evaluating deflection, we found that deflection of the gate at maximum was less than 2 mm. Given the extremely small deflection we have determined that deflection will not be an area of concern in out design of the rear gate. It may be necessary to perform this analysis again if the final design uses a material other than balsa wood. Balsa wood is very light which resulted in lower weight forces. In the case of a heavier material deflection may become an issue.

7.2 DESIGN FOR SAFETY

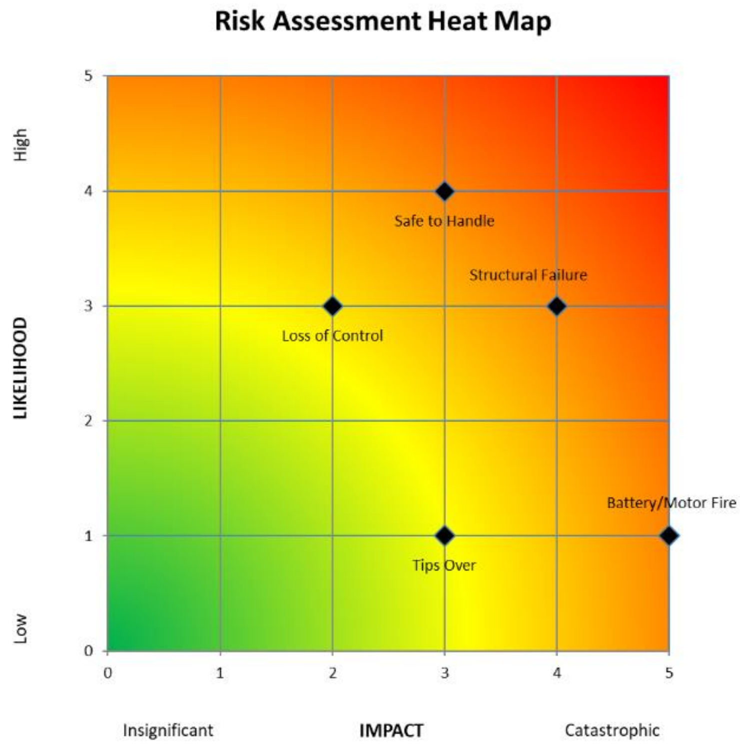


Fig. 7.7 A risk assessment heat map used to prioritize safety concerns while designing the bot.

Risk Name: Tip Over
Description: The bot would try to pick up a ball and fall over due to its weight.
Impact: 3: The bot wouldn't be able to get back up and it would end the round.
Likelihood: 1: The bot is heavy enough that it's unlikely, but it's possible.

Risk Name: Battery/Motor Fire
Description: The bot overheats and catches fire.
Impact: 5: The bot would be permanently damaged and hard to repair.
Likelihood: 1: The bot doesn't use that much power and the risk of reaching that kind of heat is low.

Risk Name: Loss of Control
Description: The bot could run uncontrollable and cause damage to itself or bystanders.
Impact: 2: Though a problem, the consequences wouldn't be that harmful.
Likelihood: 3: If using wireless, it's possible that the connection could be dropped.

Risk Name: Structural Failure
Description: A component of the arm breaks during competition.
Impact: 4: The bot could be broken and the lack of a spare part would make it no longer run.
Likelihood: 3: Somewhat likely due to the cyclic stress and use of the bot.

Risk Name: Safe to Handle
Description: The bot would injure a human handler while transporting.
Impact: 3: Would make it hard use safely.
Likelihood: 4: There are a decent amount of components and the screws could poke through dangerously.

The risk assessment heat map suggests that structural failure a safe handling are the two highest priorities when considering the safety of our design. It will also be important will be making sure the batteries and electrical equipment operate in their specified range to prevent a catastrophic event like a fire. Less concerning are events like losing control of the bot. Though this is somewhat likely, it would not put anyone in serious danger. Tipping over is also not a major concern since it's unlikely. However, it would have a significant impact on the ability to succeed in the game.

7.3 DESIGN FOR MANUFACTURING

In order to adapt our design for mass manufacturing, draft analysis was performed on the ball containment section of the robot, for it was deemed the easiest to mass produce. Figure 8 below shows a before-and-after of the ball containment section. By increasing the thickness of the vertical sections, the container became easier to mass-produce.

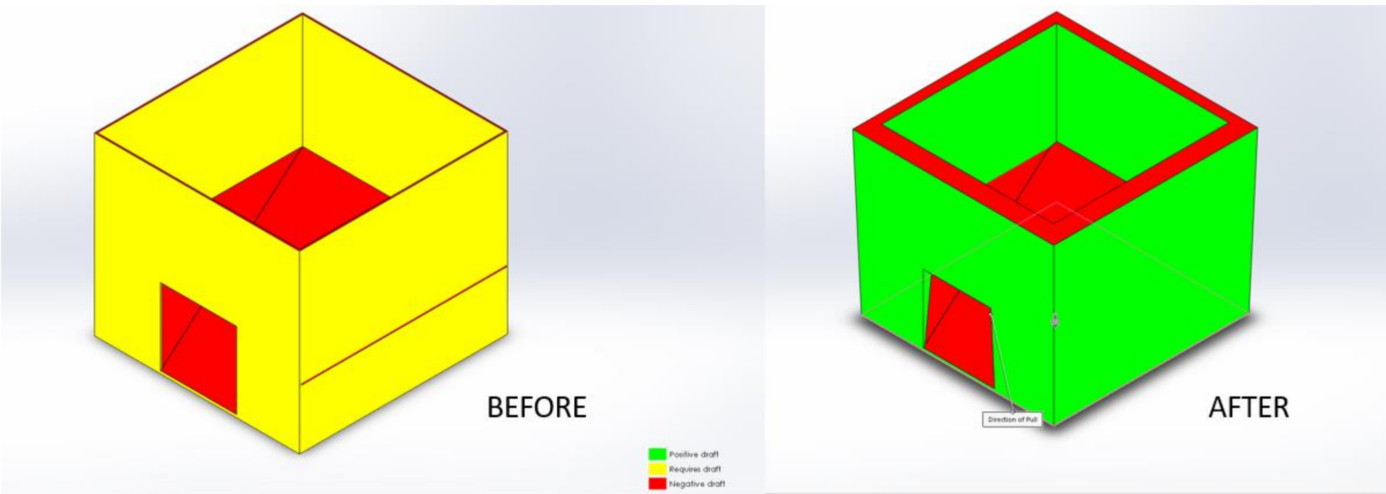


Fig. 7.8 Increasing the thickness of the vertical walls improved the manufacturability of our design

DMF analysis was also performed to improve the manufacturability of our bot. The wheel was selected, for it was determined to be the most complex, singular part of the bot. When DFM analysis was performed simulating a mill and drilling process, no errors were found. However, with costs in mind, it could be more feasible to have the wheels made of plastic, making injection modeling a process worth simulating. Figure 9 below shows the failure received when injection modeling was simulated.

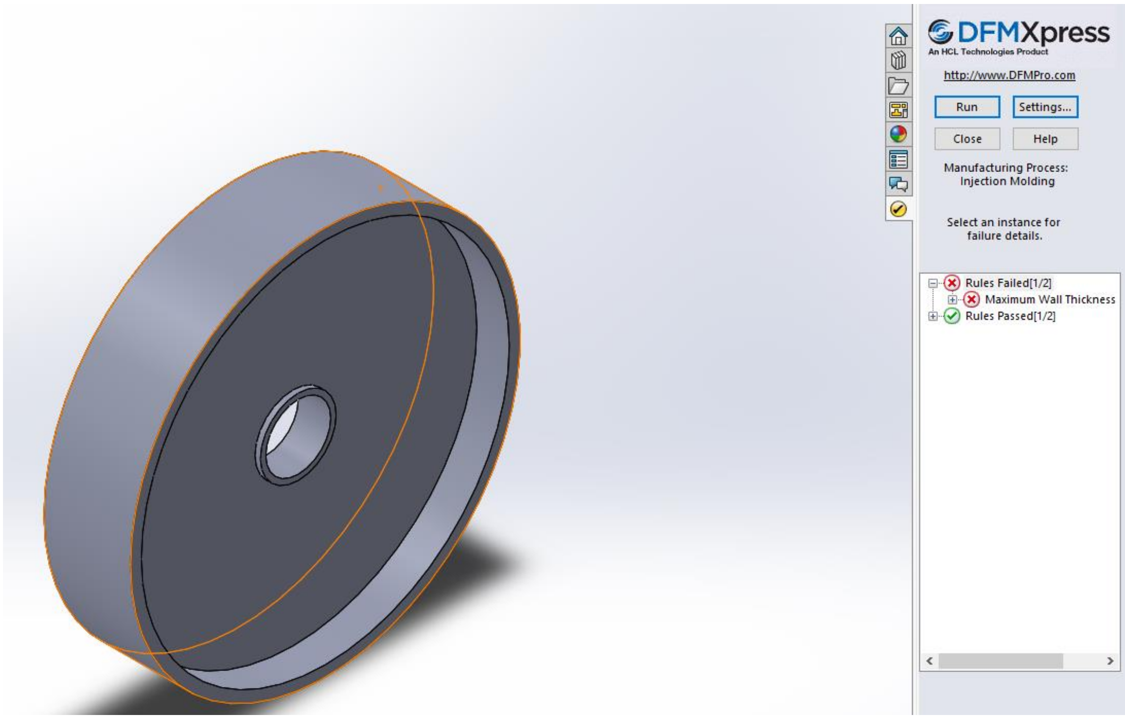


Fig. 7.9 The wall of the wheel was too thick and could cause cooling problems during injection molding

7.4 DESIGN FOR USABILITY

When considering the usability of our device, we evaluated how one with varying disabilities would be able to use the device. The five disabilities and an analysis of their interaction with our product is below.

1. **Vision:** A person with significant vision impairments would have a very difficult time guiding our bot due to the lack of feedback other than optical. This could be countered with haptic or audio feedback if sensors were calibrated to detect collisions or other interferences. Therefore, the user would not have to rely on watching the bot to operate it.
2. **Hearing:** Hearing disabilities would not affect the user in our current design. However, if safety measures were used such as an alarm, or audio feedback as described above, they might be missed. Therefore, there could be signal lights used along with audio or haptic feedback to signal collision or interference.
3. **Physical:** Impairments that would limit the ability to use a controller would create difficulties for use of our product for people with physical difficulties. Multiple kinds of controllers would perhaps be a way for people to find a controller that works for them.
4. **Language:** Language would not affect the direct use of our bot, however, if directions or instructions were given in English, that would be a barrier for non-English speakers. Having instructions written in multiple languages would counter this and make use of the product more universal.
5. **Control:** Those who are easily distracted or are easily fatigued would perhaps cause collisions due to not paying enough attention to controlling the bot. Having sensors detecting collisions and perhaps detecting a loss of control and could stop itself would allow these people to use it without harming themselves or the product.

8 1 DISCUSSION

8.1 1.1 PROJECT DEVELOPMENT AND EVOLUTION

8.1.1 1.1.1 Does the final project result align with its initial project description?

Our final project does align with what we set out to do. We are able to navigate the course and grab balls of varying size and weight and release them at the desired time. We met the requirements we had of it fitting in a 50 cubic centimeter box and being able to control it. Given the strict requirements of the competition, we were forced to stay close to the original project description.

8.1.2 1.1.2 Was the project more or less difficult than expected?

It was more difficult than expected do the intricacies of the competition. There are multiple systems that all have to work together. Each system had its own challenges and complications and in the end had to come together effectively. Making sure all the pieces fit together and trying to troubleshoot them individually was a time intensive and complicated process that we underestimated.

8.1.3 1.1.3 On which part(s) of the design process should your group have spent more time? Which parts required less time?

We should have spent more time in the prototyping phase. Being able to explore different design options on a small scale would have helped make some better decisions about how to proceed in the design as we finalized the assembly. Having more hands on experimenting would have been beneficial. I think less time could have been spent on the concept generation and selection process. Though nice to brainstorm, doing things proved more helpful than brainstorming them.

8.1.4 1.1.4 Was there a component of the prototype that was significantly easier or harder to make/assemble than expected?

The arms proved more difficult to make due to the complicated task it had. Though we simplified our design considerably throughout the process, the arms still included a lot of custom parts that was difficult to manufacture and implement. Many of the parts took multiple iterations to make correctly and usable. Then assembling these parts proved difficult do to design issues. Though it proved difficult, it came together and worked, though aided with a little bit of duct tape.

8.1.5 1.1.5 In hindsight, was there another design concept that might have been more successful than the chosen concept?

In the ASME design challenge there are several viable strategies for navigating the course. Some other designs may decide to go for of speed of capture and release of each individual instead of capacity of storage. Our strategy for this project was to capture multiple balls and release them all together towards the end of the allowable time. This would allow us to navigate throughout the course without returning to the starting area after each capture. Given this strategy, we believe that we selected the best design concept for our strategy.

8.2 1.2 DESIGN RESOURCES

8.2.1 1.2.1 How did your group decide which codes and standards were most relevant? Did they influence your design concepts?

In order to decide which codes and standards were most relevant we made sure to consider the code/standard with regard to safety of the overall design. The most relevant standard that was used for our product is the standard related to stepper motors, which in our design is used as driving power for power and precision. The standard we addressed is titled Control motors – Stepping motors" and its ID number is CLC/TS 60034-20-1:2004-09. This standard discusses voltage limiting standard which are useful in to ensure that we operate in a safe range which is accepted in the industry.

8.2.2 1.2.2 Was your group missing any critical information when it generated and evaluated concepts?

Given that this project was in response to the ASME design challenge we were of all of our rules and regulations from the beginning of the project. Some critical information that we should have considered to a higher degree of detail when evaluating concepts is how exactly each individual component would integrate together. Typically, we evaluated concepts based and how we imaged each individual concept would perform. Later, it was discovering during the fabrication process that some design are better than other as far as performance and ease of assembly. It was for this reason that we changed from vertically actuating arms to angle rotating actuating arms.

8.2.3 1.2.3 Were there additional engineering analyses that could have helped guide your design?

Overall the engineering analysis for this projected proved to be substantial enough to produces a bot which could successfully capture several balls and compete in the ASME design challenge. One area in which the bot suffered is that it was somewhat slow and lacked fluidity. This was in large part due to the wheels slipping on the floor. A further analysis of the toque supplied by the motors to the wheel and its associated slip would prove to be useful increase the performance of our bot by improving wheel performance.

8.2.4 1.2.4 If you were able to redo the course, what would you have done differently the second time around?

If we were able to redo the course, we would address some of our time management. A lot of our decisions on material selection were based off of what we could easily find and construct with the tools available to us. With more time, and the experience gained from this project, we would take the time to calculate the best material to use for all of our performance needs. Additionally, finding a space that gave us access to more precise wood working tools, if wood was the material we chose, would greatly reduce the about of "trial and error" cuts we experienced.

8.2.5 1.2.5 Given more time and money, what upgrades could be made to the working prototype?

With more time and money, there are multiple improvements we would make to our design, Firstly, we would adapt our tether cable control to a wireless, remote control setup. Secondly, we would use different materials for the body and various components for a more aesthetically pleasing bot. With wood, we are limited to methods for fastening, but with varying metal materials at our disposal, we could select a light-weight and durable material that is less likely to fracture.

8.3 TEAM ORGANIZATION

8.3.1 1.3.1 Were team members' skills complementary? Are there additional skills that would have benefitted this project?

Our team had a variety of skills that complimented each other well. Because of this, we were able to delegate specific jobs to each individual that did not interfere with only another. Additionally, we were able to combine ur individual components well, because each of us had some experience in the others' expertise. Stephan Meyer and Josh Clark were the primary fabricators of the bot body and various moving components, and Steven Mumford handled a majority of the electrical work for the bot.

8.3.2 1.3.2 Does this design experience inspire your group to attempt other design projects? If so, what type of projects?

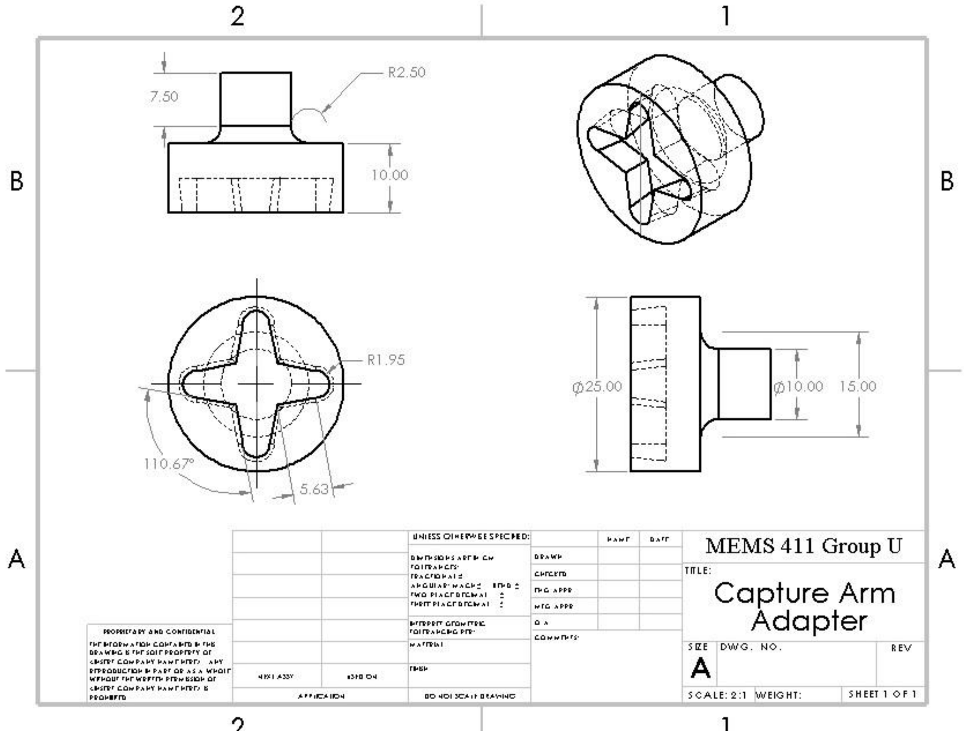
This project has inspired us to potentially pursue future ASME Student Design Challenges. Having done the process once, we feel as if future challenges would go smoothly in the beginning stages of product development. Additionally, we have also discussed the idea of pursuing a project that has a greater impact on the community. While this design challenge was both interesting and stimulating, we feel there are other projects we could develop that directly impact and benefit others around us.

APPENDIX A – COST ACCOUNTING WORKSHEET

Table A.1 The cost accounting table used to keep track of the cost of the bot.

Source Link	Supplier Part Number	Color, TPI, other IDs	Unit Price	Quantity
Amazon		Official with Booklet	$ 70.20	1
Amazon	K-KJ17MCA4BA		$ 17.99	1
Amazon	B0777DR3T6		$ 15.99	1
Amazon	B00FAS1WDG		$ 17.98	1
Custom			$ -	1
Custom			$ -	1
Custom			$ -	1
Custom			$ -	1
Home Depot	2908	Plywood	$ 6.00	1
Home Depot		Wood	$ 33.01	1
Home Depot	841102	Swivel, Rubber	$ 3.44	1
McMaster-Carr	115A95	Dull, Zinc-Plated Steel	$ 6.45	1
OSEPP	MTD-01	L298 Dual H Bridge	$ 9.99	1
Solarbotics		143:1 Offset	$ 16.99	1
		Total Cost	$ 198.04	

APPENDIX B – FINAL DESIGN DOCUMENTATION



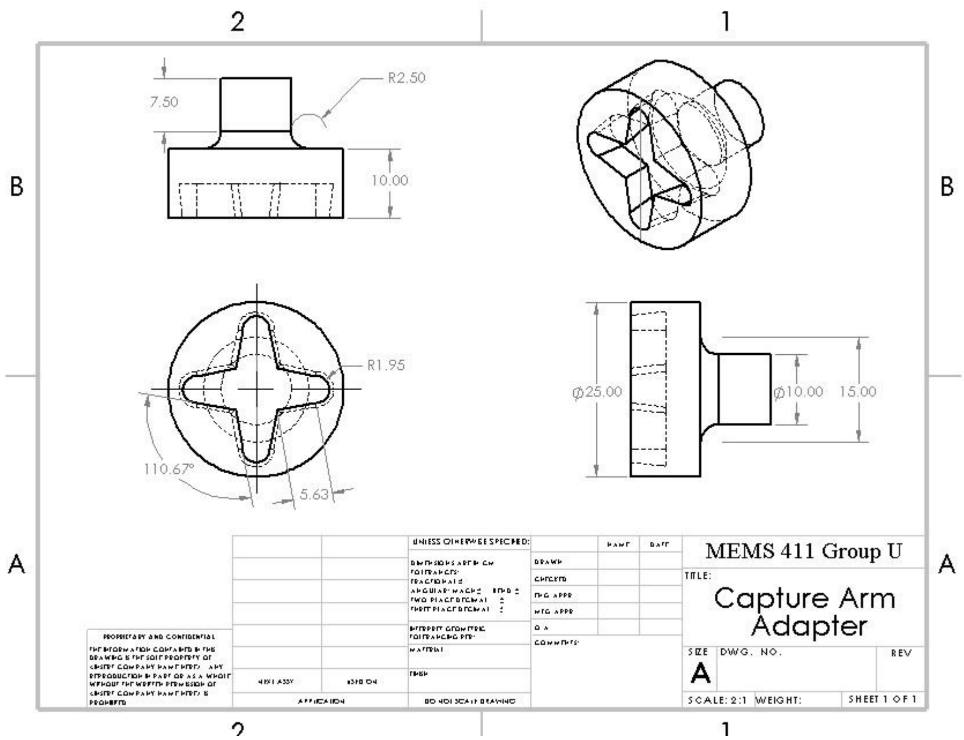
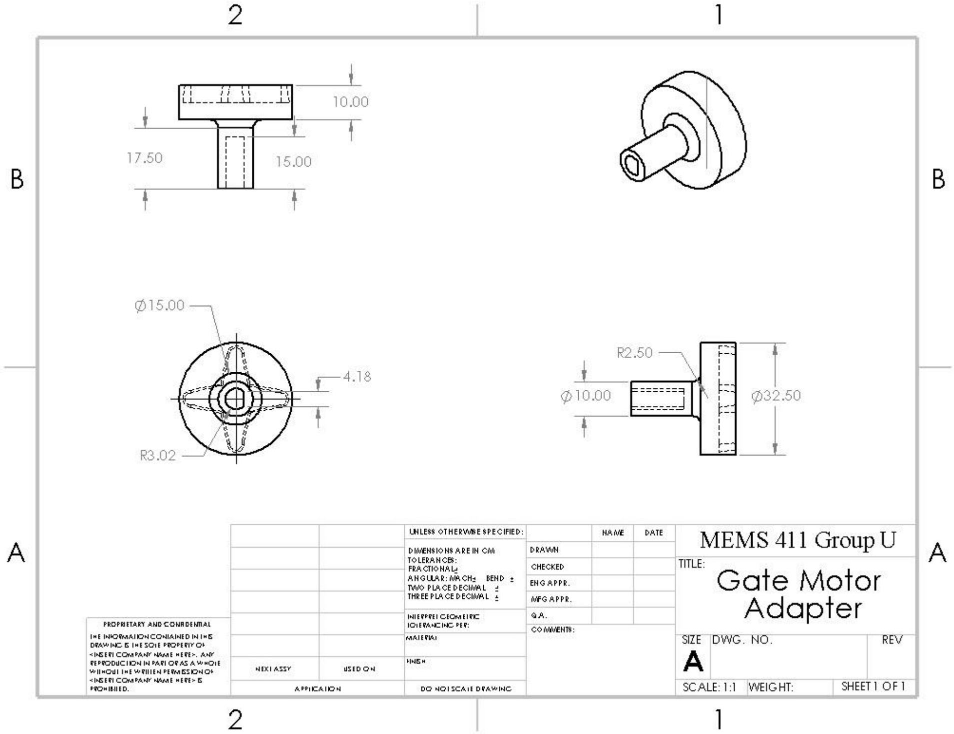


Fig. B.1 The capture arm adapter allowed the servo motor to easily connect with the capture arm



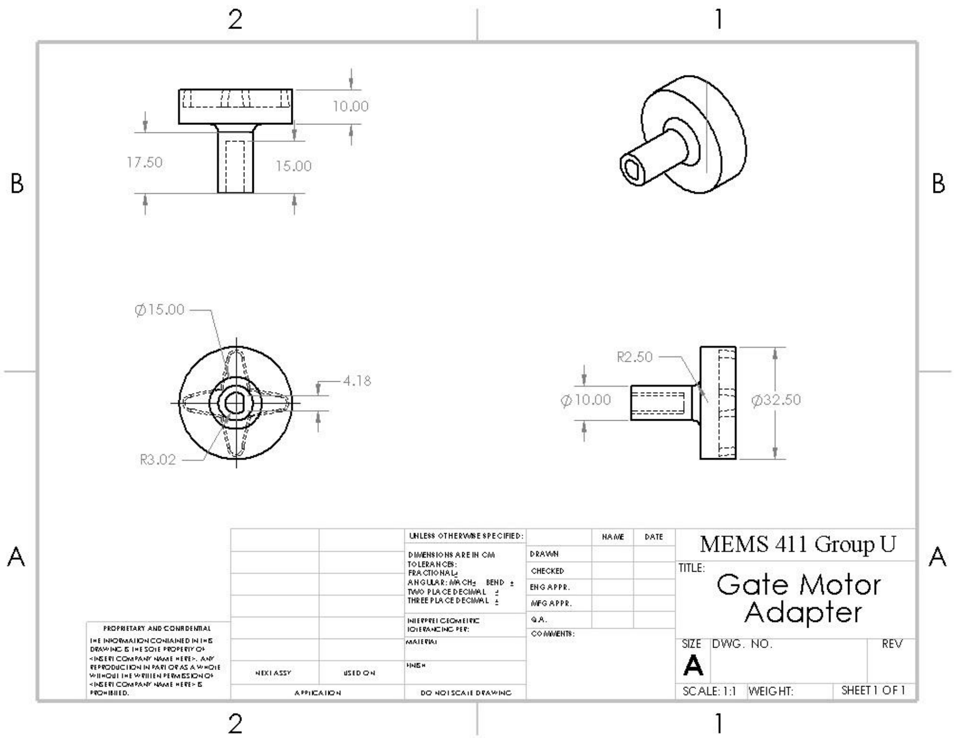
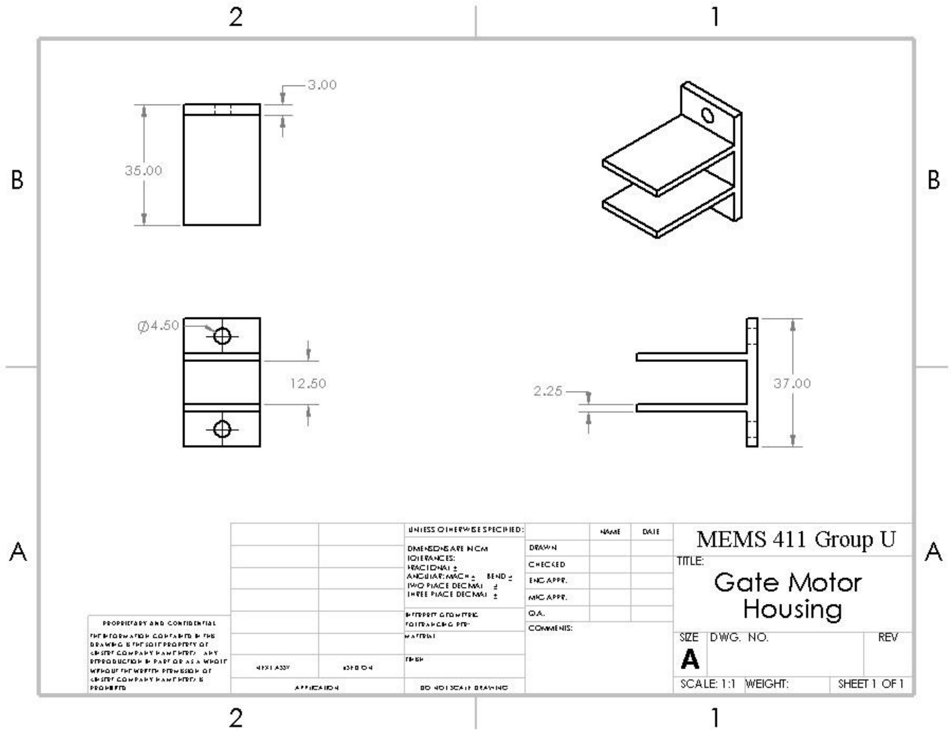


Fig. B.2 The gate motor adapter allowed the gate hinge to easily attached to the servo.



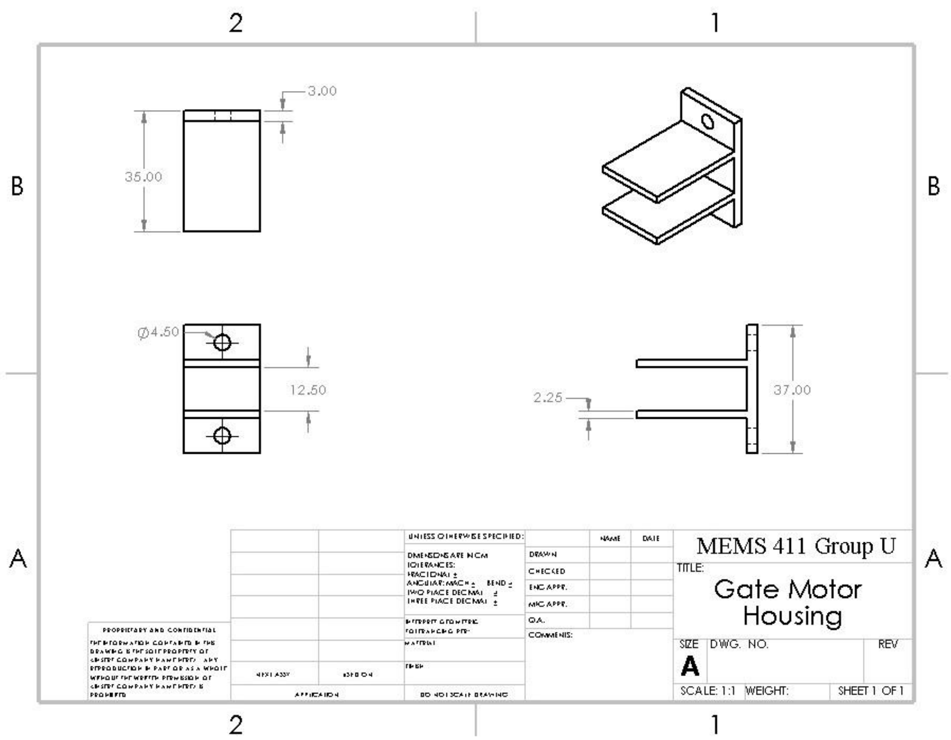
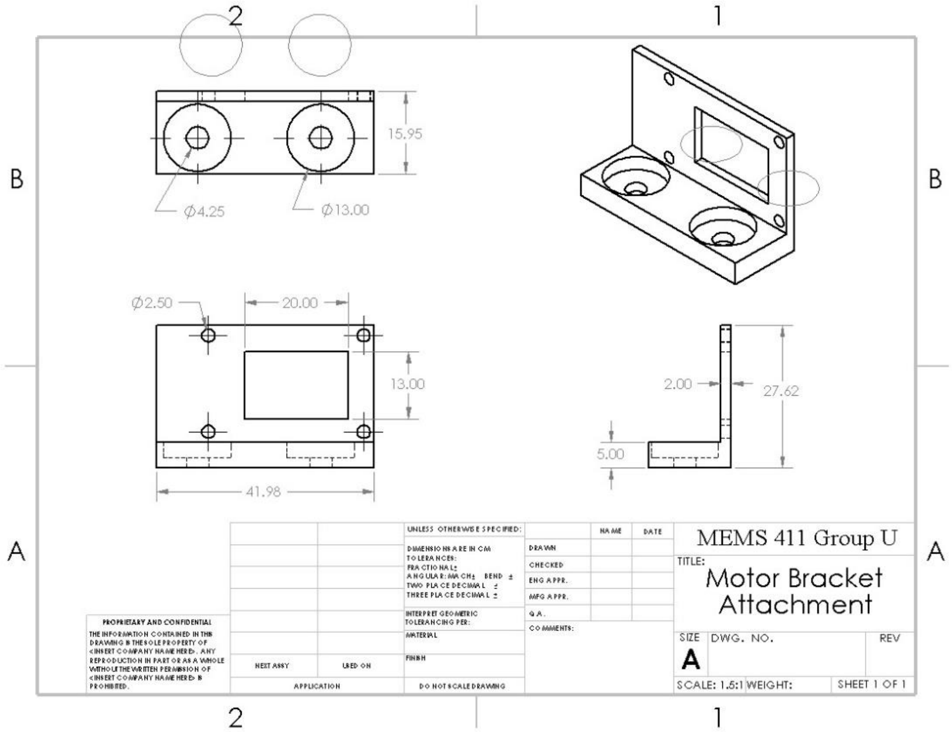


Fig. B.3 The gate motor housing attached the servo motor to the back of the bot



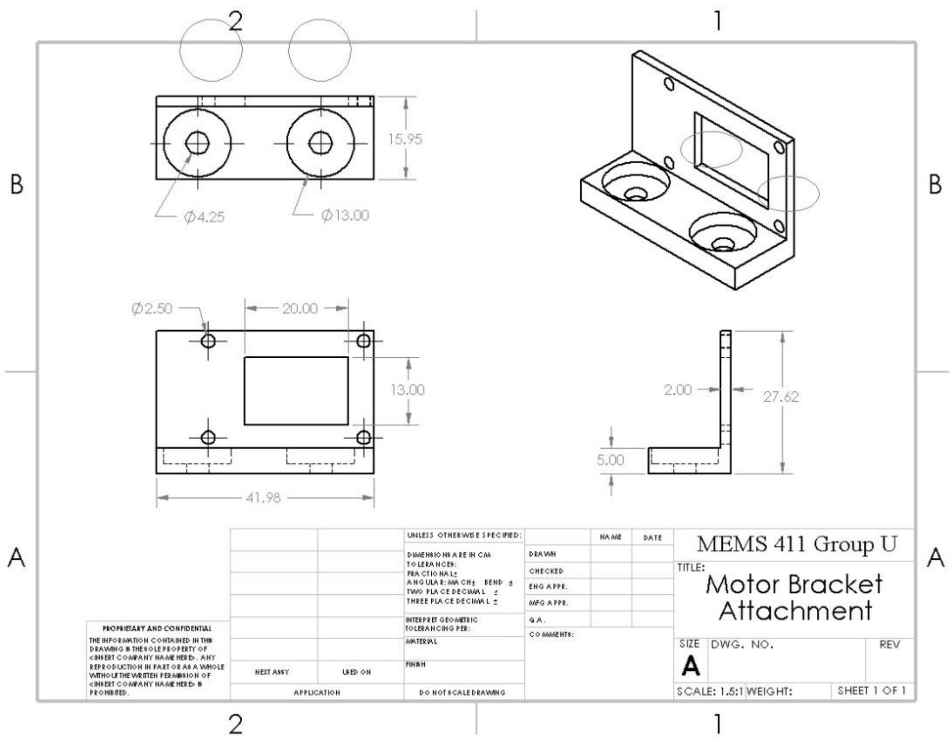


Fig. B.4 The motor bracket allowed the motors to be mounted to the base of the bot

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