Fall 2018

ASME Design Competition - Group H

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Executive Summary

This document presents our solution for the ASME pick-and-place design competition. In brief, the challenge is to collect balls from an arena and return them to a ‘home base’. The specifics of the competition are elaborated on within. The document walks through the design decisions that went into the prototype; the Goalkeeper concept that we ultimately landed on best solved the problems presented by the challenge statement as interpreted by our customer, Dr. James Jackson Potter. Several of the design choices were made by applying mathematical relationships, with the math and results included to illuminate our methods. We include a computer-aided design model that was used to plan construction, and an analysis of the device taking into account certain user impairments. We determine that the device is safe, and largely risk-free for even highly impaired users.

The final prototype is built out of plywood and PVC to minimize device weight. It has two drive motors and two servo actuators to enable the collection and deposition of the balls, powered by an Arduino Uno microcontroller. The operator uses a PlayStation 4 controller to remotely control the device, with a button assignment chosen to be intuitive to a first-time user. Photographs of the prototype are included.

MEMS 411: MECHANICAL ENGINEERING DESIGN PROJECT
FALL 2018

ASME Design Challenge

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1 INTRODUCTION

The ASME Design Competition for 2019 tasks the competitors to design and build a device that can pick up and place balls of various sizes. The designed mechanism must navigate a 5m x 5m area populated with 16 – 20cm tall poles, each of which has a ball at its top. Each team is given five minutes for their device to collect as many balls as possible and place them in the team's starting area. The device must be battery powered, wirelessly controlled, and be able to fit in a 50cm x 50cm x 50cm box which must also contain any replacement batteries and tools. The team's score during this first round will be used to seed them in a tournament for the knockout round during with the teams are given the same task as in round one, however in this round they must compete against another team on the same field. The team that scores higher will move on to the next match against another team while the losing team will be knocked out of the competition. The knockout rounds continue until there is only one team left who is then declared the winner.

2 PROBLEM UNDERSTANDING

2.1 BACKGROUND INFORMATION STUDY

2.1.1 Existing Designs Closely Related to Project Idea

1) Lego Mindstorms

Figure 2-1: Robot arm from Mindstorms Kit

Figure 2-2: LEGO Mindstorms Kit

   a. https://shop.lego.com/en-US/LEGO-MINDSTtoORMS-EV3-31313
   b. The LEGO Mindstorms kit is a customizable robotics set that allows the user to apply a mix of sensors, actuators, and support parts to make a robot that can do many things: including pick up spherical objects. It includes a programmable brick, which allows the user to 'teach' the robot the commands necessary to complete the desired task. This is applicable, because it could be used to create mock-ups of the design, as well as test out locomotion and collection methods. The most obvious applicable function is as a claw that picks up spherical objects. Also, the team already has access to an older edition of the product for prototyping.

2) The Spot Mini

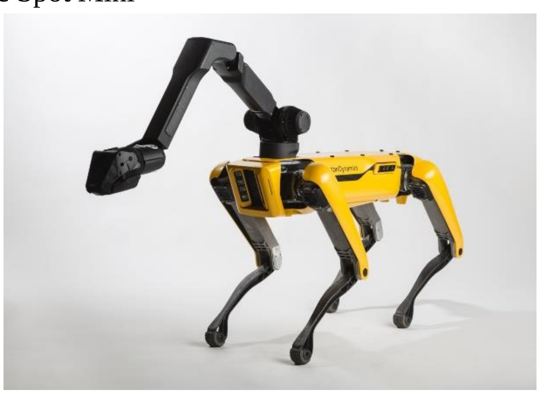


Figure 2-3: Spot Mini from Boston Dynamics

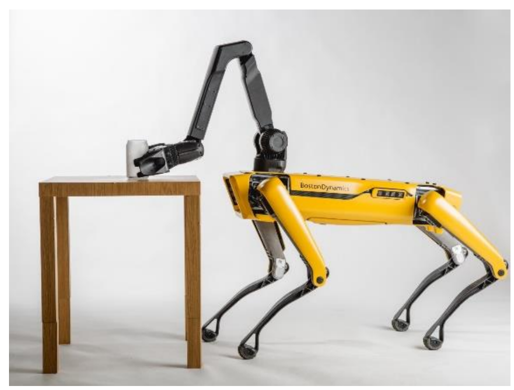


Figure 2-4: Spot Mini grasping a glass

   a. https://www.bostondynamics.com/spot-mini
   b. The Spot Mini is a small quadrupedal robot developed by Boston Dynamics. The robot is designed to navigate in confined areas around the home or office. The device is also equipped with and arm which allows the Spot Mini to pick up and handle small objects with relative ease. The sensors of the Spot Mini allow it to detect and avoid obstacles that it may run into on its given route. Its programming also allows it to attempt to stabilize itself in response to unforeseen collisions. The Spot Mini uses its legs to reposition and balance itself for a given task and allow it to maneuver obstacles such as low ceilings or even stairs.

3) Endeavor Robotics SUGV

Figure 2-5: Endeavor Robotics' SUGV

Figure 2-6: SUGV reaching into a car

a. http://endeavorrobotics.com/products#310-sugv
b. The SUGV is a highly portable bomb defusing robot that is used by the US military. It weighs 30 pounds and fits in a 22.9cm x 71.1cm container. A uPoint™ Multi-Robot Control system is used to control the robot and front cameras that are mounted on it. It runs for up to 6 hours at a time and has 2 rechargeable BB-2557 lithium batteries. The two-part tank tracks allow the SUGV to climb stairs and elevate itself to reach objects easier. The claw rotates and can reach objects of all sizes from any angle. SUGV has three variable speed selections and travels up to 6.2 mph depending on the surrounding conditions.

2.1.2 Patents Related to Design Idea

1) Extended Reach Device – PT NO US6315340B1 [1]

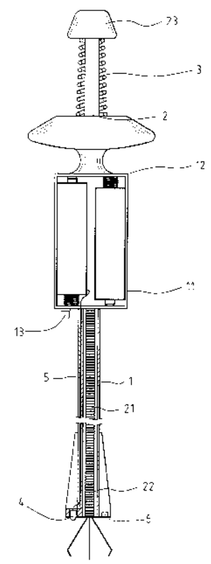


Figure 2-7: Multifunctional pick-up tool

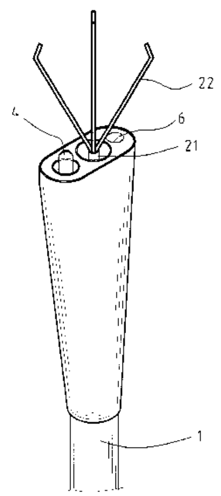


Figure 2-8: Partial view of the extended reach device

a. An extended device that uses push/pull actuation to open and close a claw. This claw is designed to be a versatile collector, able to pick up objects of myriad sizes and shapes. It is applicable as an example of how we could pick up the balls in competition.

2) Radio Controlled Car – PT NO US07929953 [2]

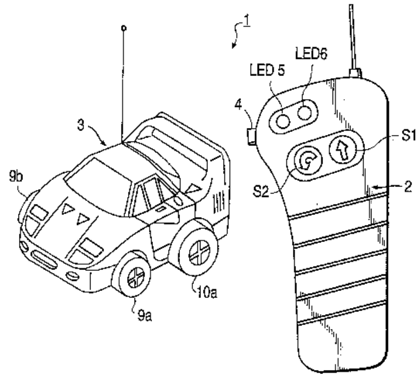


Figure 2-9: Radio-controlled car

a. A radio-controlled car created to make high-speed turns accurately. The controller and car use rechargeable batteries which charge using an internal charging circuit. This eliminates the need to remove the batteries to charge them or have a charging station. Different types of gears are used to control the shafts allowing the car to rotate efficiently.

2.1.3 Codes and Standards Relevant to Design Idea

1) Battery Travel Code
   a. United States Department of Transportation 49 CFR 175.10
   b. This code defines the specifications for hazardous materials and devices that may be carried on or be placed in checked baggage when traveling by plane. This includes the specifications for many types of batteries and how they must be stored when travelling. Since the device must be battery powered and must be transported from St. Louis MO to Michigan for the competition, the batteries we use must meet these specifications.
2) Electric Motor Standard
   a. ISO 18170:2017
   b. A standard which specifies the requirements for an electric motor with variable delivery. Applicable so that we select and use motors that are safe and will operate as intended. The device will require a motor to move the device, no matter how we choose to collect. Likewise, if we end up wanting a maneuverable collector, this standard will aid us in selecting a proper motor.

2.2 USER NEEDS

Product: Pick and Place Robot (PPR)

User: Dr. James Jackson Potter

Note: The customer was aware of the ASME Design Competition rules. He made adjustments to the design requirements from the competition so that it would be feasible to finish this project within the semester. The interview took about 30 minutes.

Address: Busch 100, Washington University Danforth Campus
Date: September 7, 2018

Table 2-1: Customer Needs Interview

Question	Customer Statement	Interpreted Need	Imp.
Collector capabilities	“I would say rule out basketballs” “I would say be able to pick up a volleyball, ping-pong ball, racquetball, lacrosse ball, and a 16” softball” “Be able to collect softballs and ping pong balls in equal number”	PPR needs to be able to collect many different sizes of ball	5
Control	“I want a nicely designed thing that works well whether or not its tethered or radio” “Is it smooth or too ‘jumpy’”	PPR can be controlled precisely	4
Appearance	“I want a nicely designed device”	PPR is aesthetically pleasing	1
Placing Capabilities	“I guess if you push the ball out of the start after it stops moving it still counts”	PPR can set balls down in controlled manner	2
Size	“The device can extend past the competition’s size requirement as long as it is able to reset to the size of the box by itself”	PPR is compact and portable	1
How long should the batteries last, ideally	“A few minutes. If the robot can score quickly, having the batteries last the whole round may not be necessary” “If feasible choose batteries that last the whole round (with intermittent loads on the motors).” “I assume you want to fly with it”	PPR uses rechargeable batteries	5
		PPR uses batteries with minimal energy capacity	4

Table 2-2: Interpreted Customer Needs

Need Number	Need	Importance
1	PPR needs to be able to collect many different sizes of ball	5
2	PPR can be controlled precisely	4
3	PPR is aesthetically pleasing	1
4	PPR can set balls down in controlled manner	2
5	PPR is compact and portable	1
6	PPR uses rechargeable batteries	5
7	PPR uses batteries with minimal energy capacity	4

2.3 DESIGN METRICS

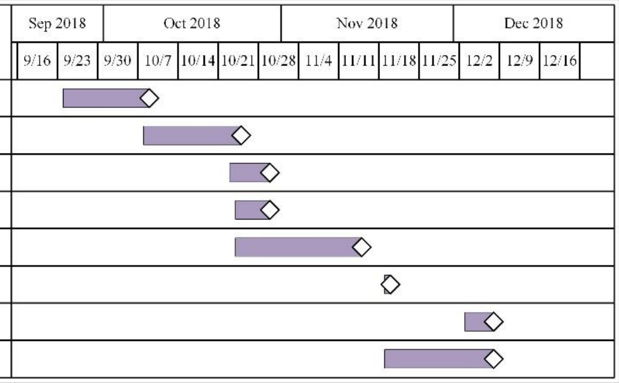
Table 2-3: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	5	Total Weight	kg	<5	<2
2	5	Total Size	cm	<50x50x50	<20(h)x25(d)x25(w)
3	2,3	Entertainment value	1-10	>4	>9
4	2	Smoothness of stop/go	Angle of jerk	2 degrees	0 degrees
5	1	Collectable ball sizes	mm	40-200	40-250
6	6	Maximum Speed	m/s	>0.5	>2
7	5,6	Battery travel code United States Department of Transportation 49 CFR 175.10	Binary	Pass	Pass
8	5	Electric motor standard, ISO 18170:2017	Binary	Pass	Pass
9	6	Battery life on full charge, constantly driving motors	min	>3	>5

2.4 PROJECT MANAGEMENT

Table 2-4 Gantt Chart for Goal Keeper Project Timeline

ID	*Task Name*	*Start*	*Finish*	*Duration*
1	Concept Embodiment	9/24/2018	10/8/2018	2w 1d
2	PoC Prototype Demo	10/8/2018	10/24/2018	2w 3d
3	Design Refinement	10/23/2018	10/29/2018	1w
4	Critical Design Review	10/24/2018	10/29/2018	4d
5	Working Prototype Demo	10/24/2018	11/14/2018	3w 1d
6	ERB Summary	11/19/2018	11/19/2018	1d
7	Final Presentation	12/3/2018	12/7/2018	1w
8	Final Report	11/19/2018	12/7/2018	3w



3 CONCEPT GENERATION

3.1 MOCKUP PROTOTYPE

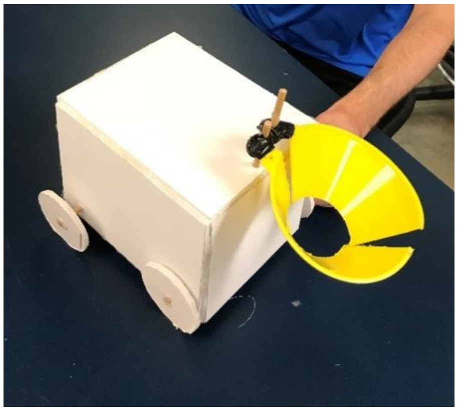


Figure 3-1: Mockup created in studio

Figure 3-2: Mockup dropping an object

Figure 3-3: Mockup holding an object

This mockup allowed us to visually notice problems the prototypes may face. The mockup arm informed us of a potentially large problem pertaining to the moment created by some of the larger balls. The mockup also brought up a concern that the device has a high chance of knocking the support poles over when trying to pick up the balls, this would create potential obstacles the device would then have to navigate around which could result in other support poles and their balls to be tipped over. The mockup let us see many of the variables we need to consider when designing the device.

3.2 FUNCTIONAL DECOMPOSITION

3.2.1 Function Tree

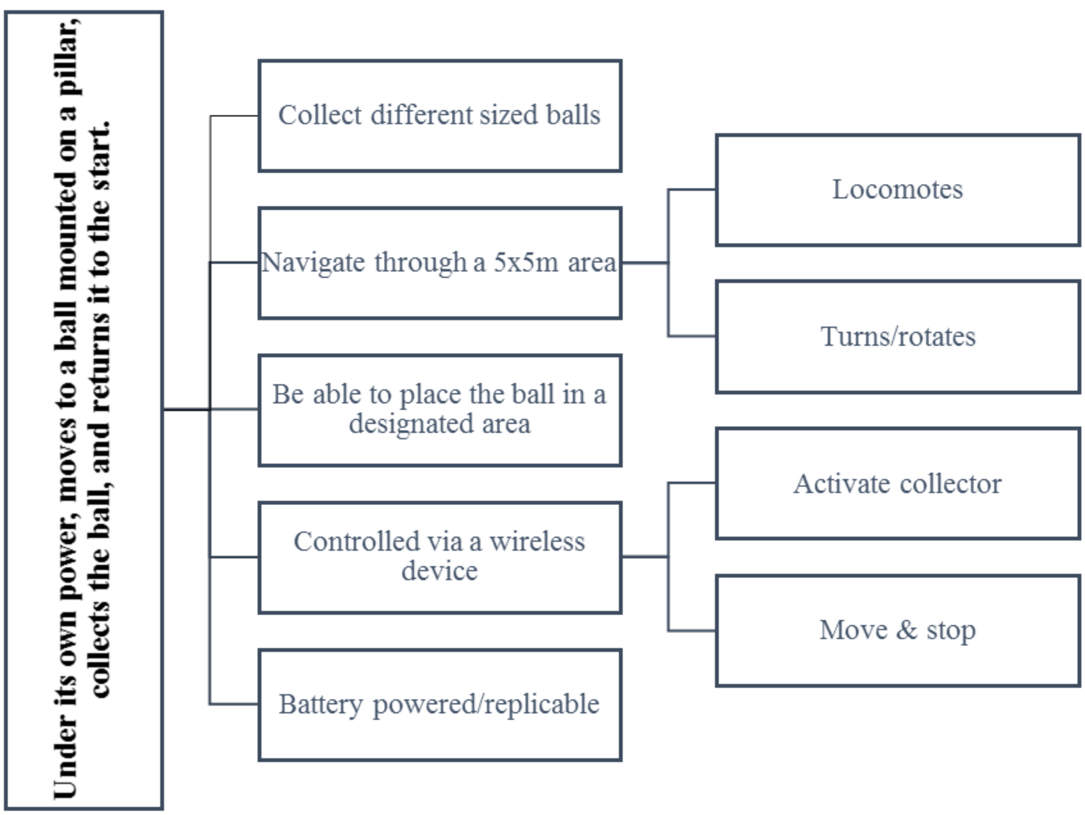
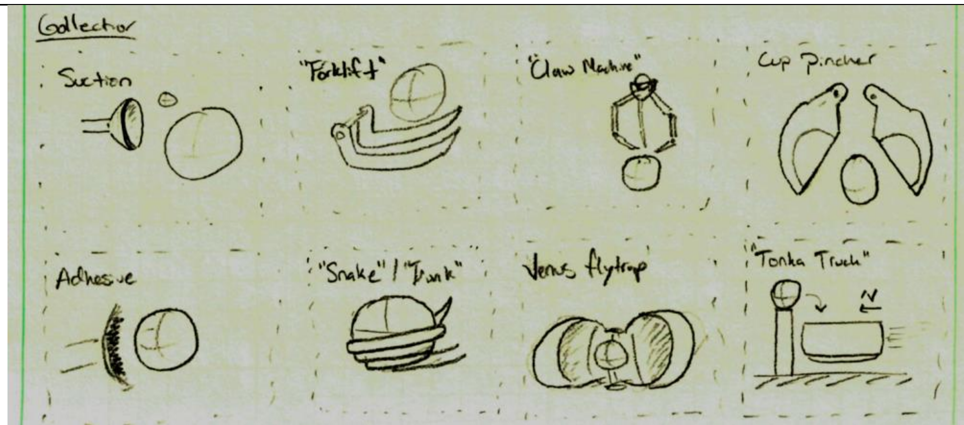
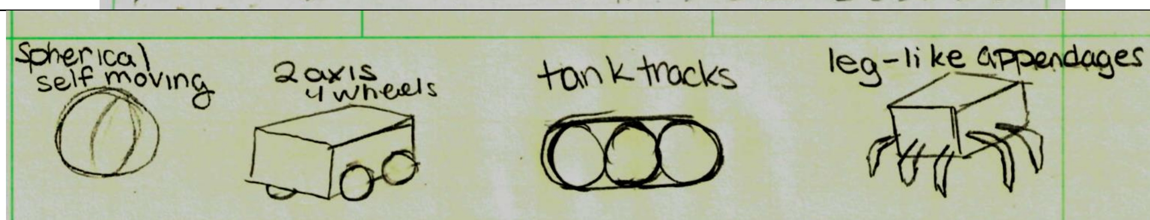
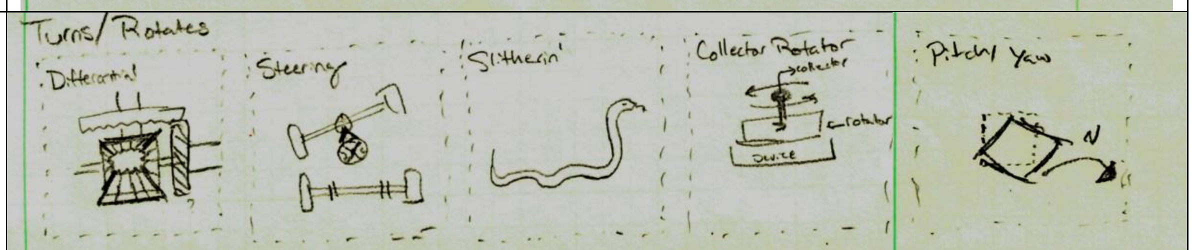
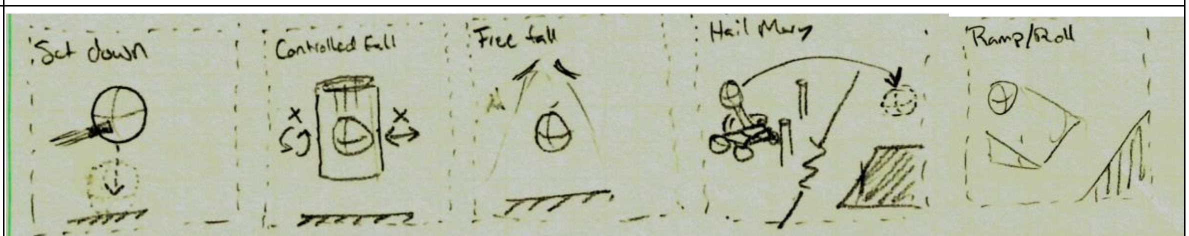
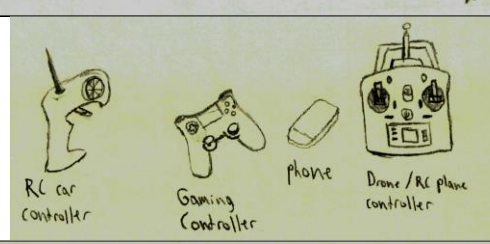
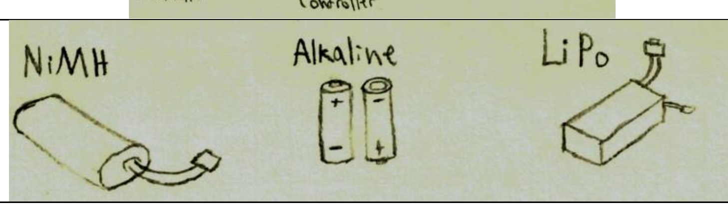


Figure 3-4: Function Tree for ASME Design Competition

3.2.2 Morphological Chart

Table 3-1: Morphological Chart

1- Collect different sized balls	
2- Movement	
3- Turns/rotates	
4-Be able to place the ball in a designated area	
5- Activate collector	
6-Move & stop	
7- Battery powered/ replicable	

3.3 ALTERNATIVE DESIGN CONCEPTS

3.3.1 Concept 1

Concept Name: “BB-Ate”

Group Member: Ben Tattersfield

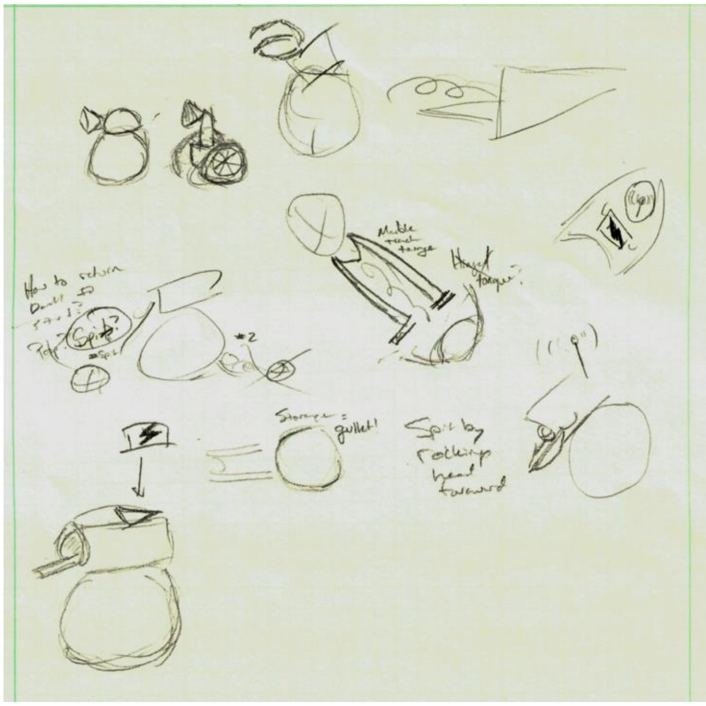


Figure 3-5: Preliminary sketches of BB-Ate

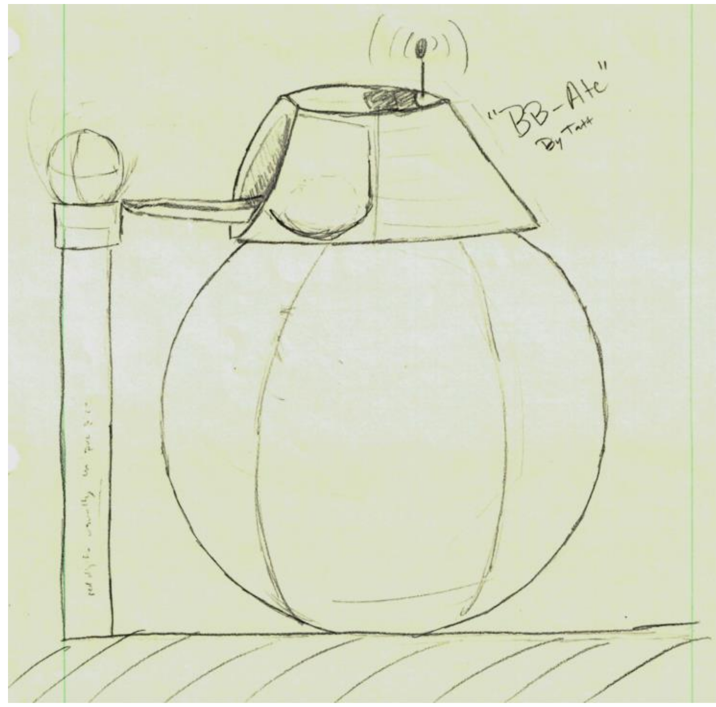


Figure 3-6: Final sketch of BB-Ate

Description: This design encompasses the rolling motion of the beloved new Star Wars droid and adds to it the eating-and-spitting-later strategy employed by emperor penguins. The idea is to stick the “tongue” right up under the ball, so that it rolls into the mouth of BB-Ate. Then, it is held in the mouth until it needs to be regurgitated for the young (deposited in the start zone). It is radio controlled, with an open slit in the head for easy battery replacement. All in all, this design concept would fit right in on Hoth.

Solutions:

1) Tonka Truck
2) Spherical self-moving
3) Collector rotator
4) Free fall
5) Joy stick
6) RC car controller
7) LiPo

3.3.2 Concept 2

Concept Name: "Widow's Fly Trap"

Group Member: Melanie Self

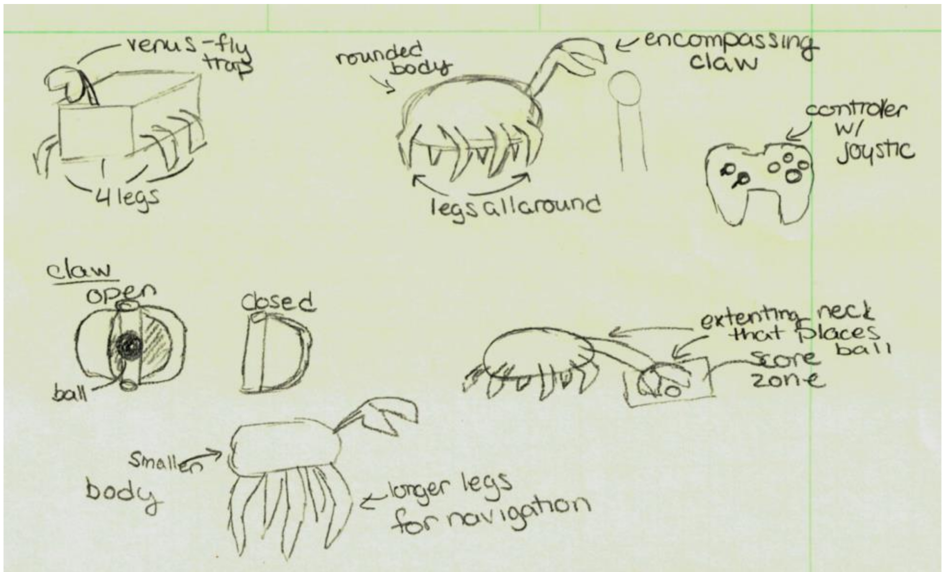


Figure 3-7: Preliminary sketches of Widow's Fly Trap

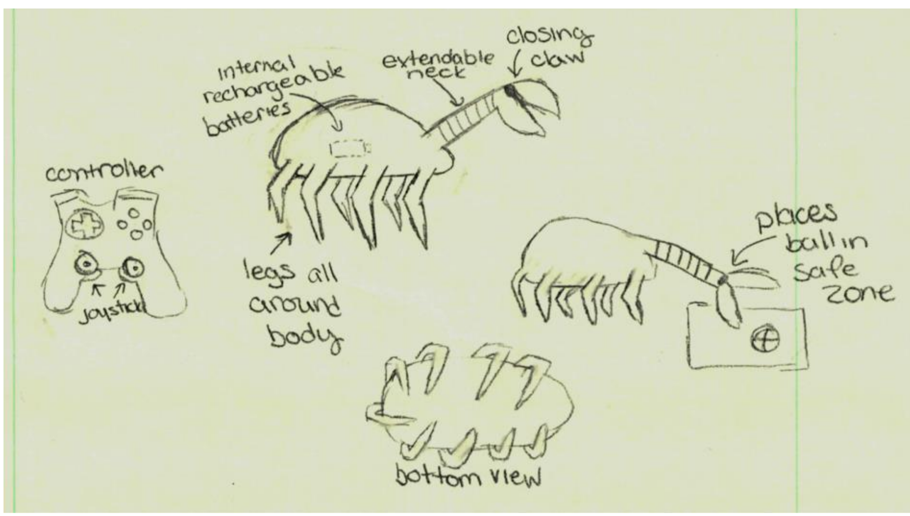


Figure 3-8: Final sketches of Widow's Fly Trap

Description: This design uses leg-like appendages to accurately navigate through the playing field. The body of the device has legs surrounding it and a neck apparatus attached on the top front section. The neck apparatus has three degrees of freedom allowing it to pick up a ball off a PVC pipe and place the ball on the ground. The component that picks up the ball is an all-encompassing sphere with a hinge to allow it to open and close. The neck apparatus can extend and return to a short length to fit the size restrictions. The legs also fold under the belly of the device to further reduce the size of the device when not in use. The Widow's Fly Trap is controlled by a standard gaming controller that has two joysticks and runs on rechargeable batteries.

Solutions:

1) Venus fly trap
2) Leg-like appendages
3) Pitch/yaw
4) Set down
5) Joystick
6) Game controller
7) Alkaline (rechargeable)

3.3.3 Concept 3

Concept Name: "Goalkeeper"

Group Member: Joshua Emde

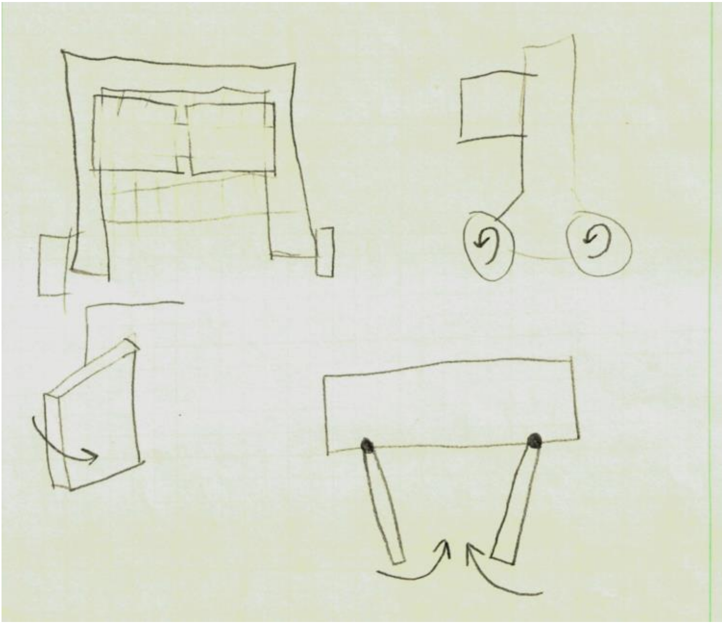


Figure 3-9: Preliminary sketches of Goalkeeper

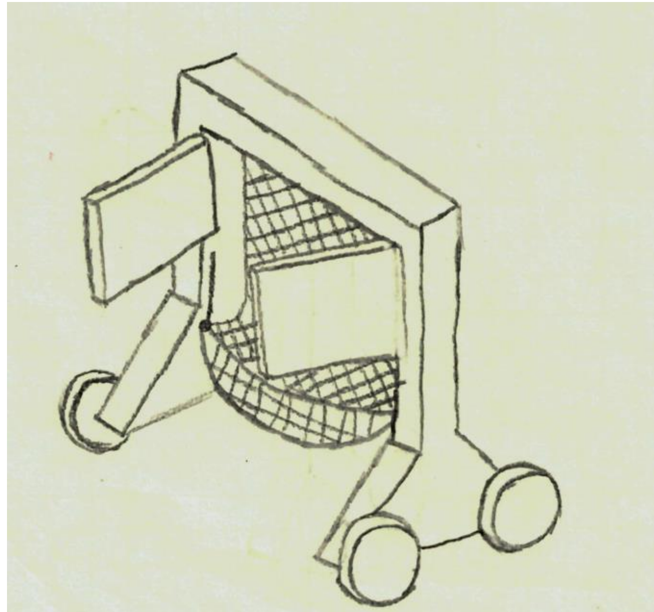


Figure 3-10: Final sketch of Goalkeeper

Description: This design moves using four driven wheels. It is able to turn via a difference in speed between the left and right sides. This device uses two rotatable arms to push the ball into a net which hangs along the frame of its body. The design approaches the ball with its arms open. Once the ball is in range the arms close placing the ball in the net below. The bottom support of the net can then be lowered allowing the collected balls to slowly roll out of the net. The bottom support can then be raised back into its upper, holding position to collect more balls. The device is controlled using a standard RC plane controller and is powered by a NiMH battery.

Solutions:

1) Tonka Truck
2) 4 wheels
3) Steering
4) Ramp
5) Joy Stick
6) RC plane controller
7) NiMH

4 CONCEPT SELECTION

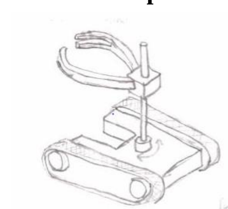
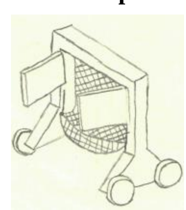
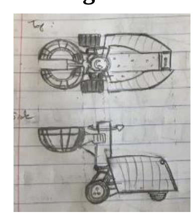
4.1 SELECTION CRITERIA

Table 4-1: Analytic hierarchy process for 6 selection criteria

	Battery Life	Simplicity of Construction	Diversity of Collectable Balls	Controllability	Course Execution	Size of device	Row Total	Weight Value	Weight (%)
Battery Life	**1.00**	3.00	0.25	0.14	0.14	5.00	9.54	0.12	11.72%
Simplicity of Construction	0.33	**1.00**	0.20	0.17	0.17	2.00	3.87	0.05	4.75%
Diversity of Collectable Balls	4.00	5.00	**1.00**	0.50	3.00	6.00	19.50	0.24	23.96%
Controllability	7.00	6.00	2.00	**1.00**	1.00	7.00	24.00	0.29	29.49%
Speed of Ball Collection	7.00	6.00	0.33	1.00	**1.00**	7.00	22.33	0.27	27.44%
Size of Device	0.20	0.50	0.17	0.14	0.14	**1.00**	2.15	0.03	2.64%
						Column Total:	**81.39**	**1.00**	**100%**

4.2 CONCEPT EVALUATION

Table 4-2: Weighted scoring matrix

		Alternative Deisgn Concepts					
		The Scorpion 		**Goalkeeper** 		**Stag Beetle** 	
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Battery Life	11.72	3	0.35	5	0.59	2	0.23
Simplicity of Constuction	4.75	3	0.14	5	0.24	1	0.05
Diversity of Collectable Ball Sizes	23.96	3	0.72	5	1.20	5	1.20
Contollability	29.49	3	0.88	3	0.88	3	0.88
Speed of Ball Collection	27.44	3	0.82	4	1.10	4	1.10
Size of Device	2.64	3	0.08	1	0.03	4	0.11
	Total score	**3.000**		**4.030**		**3.568**	
	Rank	**3**		**1**		**2**	

4.3 EVALUATION RESULTS

The battery draw criterion was evaluated based on the number of required actuators for each design, and for material that each used. For the Goalkeeper, this criterion was favored over the reference, because there were fewer required actuators and the locomotion wasn't conducted using treads. The Stag Beetle design has a similar number of actuators to the reference, but on the collector moves more material. The Goalkeeper has a simple construction, and the Stag Beetle has many inter-locking parts. Both alternate designs grant greater flexibility in ball collection than the reference design. The standard for controllability was whether the vehicle could do point turns, and all three designs met that criteria. Rapidity of course execution was a broad category which considered, among other things, turning radius, maximum speed, collection time, and carrying capacity. The Goalkeeper and Stag Beetle had greater capacity, if not obviously greater turning radius and maximum velocity. Both alternates can collect multiple balls before needing to deposit them, so received a better grade than the reference. The Goalkeeper required width and height greater than the other two devices, so was given a lower grade on size of the device. The Stag Beetle design could be shorter and less wide than the Goalkeeper, though longer. This isotropy of dimensions was granted a more favorable size rating.

The team has determined that the best design is the Goalkeeper. It offers the greatest ease of construction, and the simplicity of the design will be beneficial in prototyping. The lower power consumption is also notable. Its weakest criterion, 'size of device', is noted in the ASME guidelines as *only* a tie-breaker.

4.4 ENGINEERING MODELS/RELATIONSHIP

4.4.1 Battery Life

By modelling the device on battery life, we can select batteries that will power the device throughout the trials. The model considers three main energy consumers on the device: motors for moving around the arena, servos for actuating the gate and releasing the balls and the Arduino that is coded to control the device via a PS4 controller. Equation 1 models this relationship:

$$L = \sum_{motors} \left[\frac{I_m}{t_m}\right] \Big/ 60\ min + \sum_{servo} \left[\frac{I_s}{t_s}\right] \Big/ 60\ min + \sum_{Arduino} \left[\frac{I_A}{t_A}\right] \Big/ 60\ min \quad (1)$$

L is battery life [mAhr], t_m is time the motors run [min], I_m is current through the motor [mA], t_s time the servos run [min], I_s is current through the servos [mA], t_A is time the Arduino runs [min], and I_A is current through the Arduino [mA]. We're anticipating that we will only use two motors for controlling the motion, but those will most likely need to output the most work. Motors are generally classified by their torque and their power, the second of which is a term in the equation we're using with this model.

4.4.2 Moment Balance

Equation 2 and Fig. 4-1 is a model for the moment balance of the device is important to determine where we need to distribute the weight in the device such that it will not begin to tip about its front wheel.

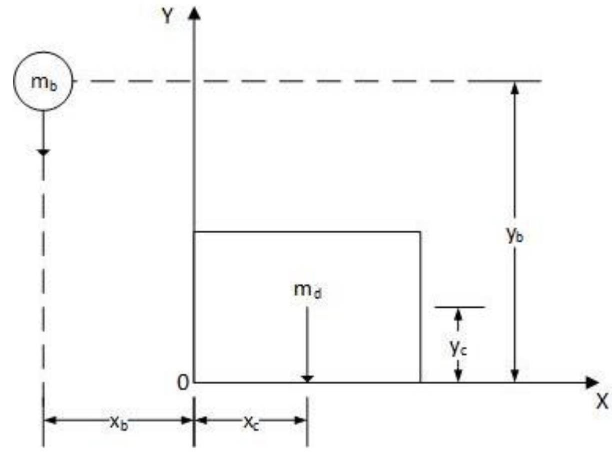


Figure 4-1 Schematic of theoretical moment balance (side view)

$$\sum M_0 = m_d g(x_c) - m_b g(-x_b) - m_d a(y_c) - m_b a(y_b) \tag{2}$$

M_0 is moment about point 0 [N*m], m_d is the mass of the device [kg], g is acceleration due to gravity [m/s^2], x_c is distance from point 0 to m_d in the x-direction [m], m_b is the mass of the ball [kg], x_b is distance from point m_b to 0 in the x-direction [m], y_c is distance from point 0 to m_d in the y-direction [m], a is acceleration of the device in the x-direction [m/s^2], and y_b is distance from point 0 to m_b in the y-direction [m]. This model considers lifting the heaviest possible ball and braking from a high speed. This model also helps determine how abruptly we can decelerate the device while it is holding a ball.

4.4.3 Motor Torque

This model outlines the torque that is necessary to drive the wheels and in turn moves the device. Figure 4-2 is a schematic of a motor and the mathematical model of the motor torque shown by Eq. 3 and Eq. 4:

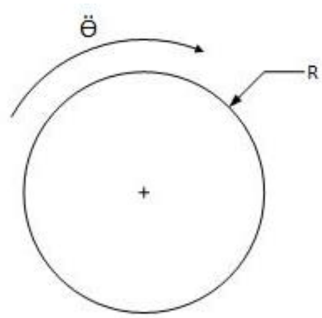


Figure 4-2 Schematic of theoretical motor

$$I\ddot{\theta} = T \tag{3}$$

$$\frac{1}{2} m R^2 \ddot{x} = T \tag{4}$$

I is rotational inertia of the motor [kg*m^2], $\ddot{\theta}$ is rotational acceleration [rad/sec^2], T is torque [N*m], m is mass of the motor [kg], R is radius of the motor [m], and $\ddot{x}$ is translational acceleration in the x-direction [m/sec^2]. This model helps specify the dimensions that are necessary for the wheels to achieve some acceleration given an applied torque. The model also helps in the decision for the specifications of the motors that the device needs.

5 CONCEPT EMBODIMENT

5.1 INITIAL EMBODIMENT

The concept embodiment was mapped out using the computer-aided design software, Solidworks. All the main functional parts of the device are included in Figs 5-1 thru 5-3. Excluded are the fasteners, wiring, and the net. These parts are excluded partially due to their difficulty to embody in Solidworks, and because they are not 'fixed' objects in the same way as all the included components.

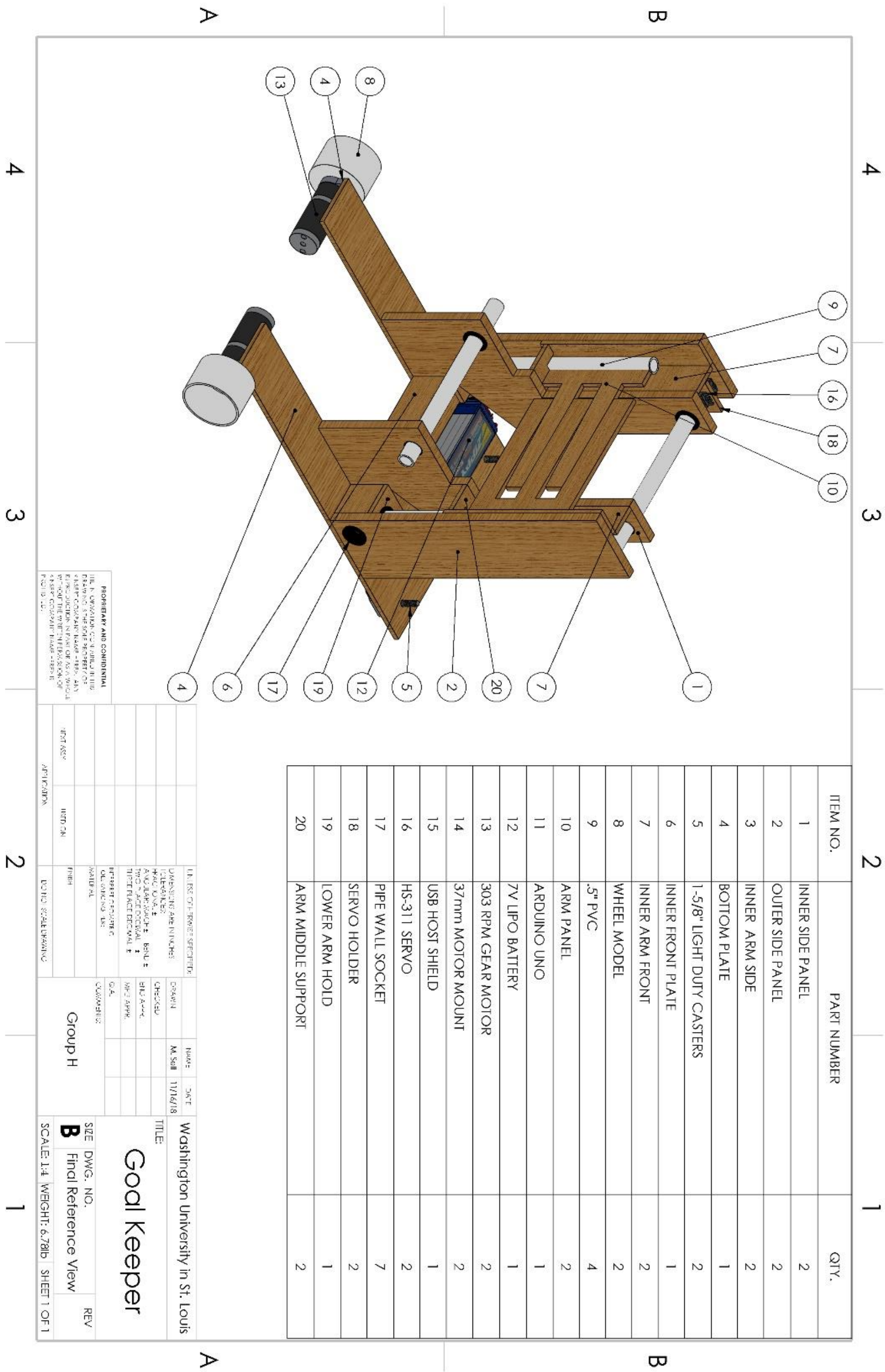


Figure 5-1 CAD embodiment of Goal Keeper project with BOM and balloons

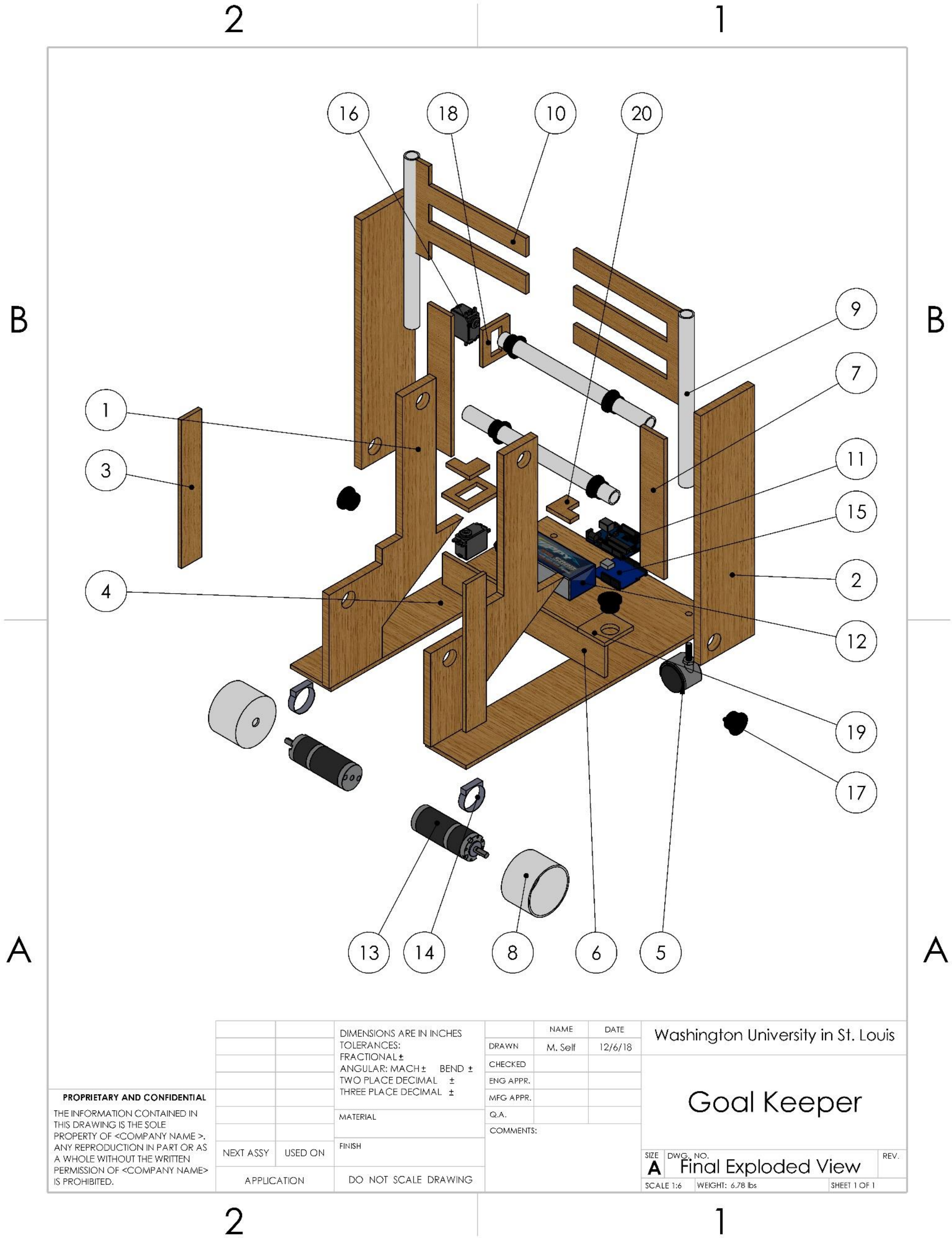


Figure 5-2 Exploded view of CAD embodiment of Goal Keeper project with balloon callouts

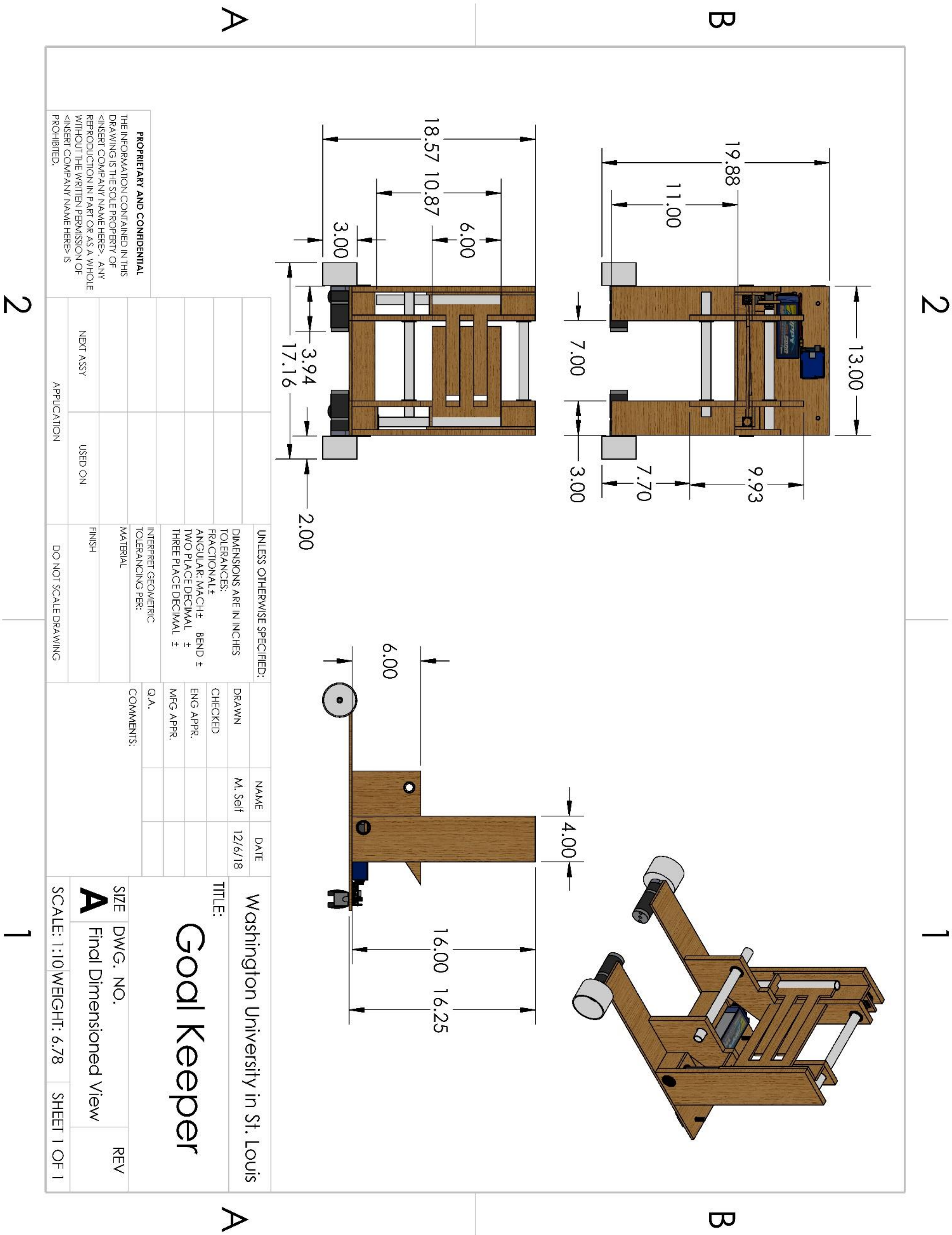


Figure 5-3 Dimensioned CAD embodiment of Goal Keeper

Table 7 is a final list of parts for the prototypes, with identifying features. Parts with an asterisk next to the name have the tax and shipping costs added to the total price column.

Table 5-1: Final Parts List

	Part	Source Link	Supplier Part Number	Color, TPI, other part IDs	Unit price	Quantity	Total price
1	303 RPM Gear Motor	Servo City	638202	Silver	$24.99	2	$49.98
2	Arduino Uno*	Mouser Electronics	782-A000066	Arduino	$22.00	1	$26.99
3	Arduino Uno host shield	Amazon	Mega2560	Keyes	$15.80	1	$15.80
4	Caster	McMaster-Carr	24215T31	black	$1.42	2	$2.84
5	Wheel	McMaster-Carr	2439T44	lightweight rubber with ball bearing	$14.83	2	$29.66
6	37mm Clamping Mount	Servo City	555116	Silver	$6.99	2	$13.98
7	.5in PVC	Home Depot	22015	253755	$1.17	3	$3.51
8	.25in Plywood	Home Depot	99167465289	BCX	$4.85	2	$9.70
9	.5in Plywood*	Home Depot	99167222912	BCX	$6.03	2	$14.49
10	HS-311 Servo*	Servo City	31311S00	Stock Rotation	$8.99	2	$24.97
12	7V battery*	Horizon Hobby	EFLB12502S	1250mAh	$16.99	1	$21.98
13	Miter Gears	McMaster-Carr	7297K18	16 TPI	$6.70	5	$33.50
14	Battery charger	Horizon Hobby	EFLUC1009	Celectra 2S	$33.29	1	$33.29
15	Power Supply*	Horizon Hobby	EFLC4000	AC to 12V DC	$19.99	1	$24.98
16	Motor Shield*	Mouser	485-1438	Adafruit	$19.95	1	$24.94
Total:							$330.61

5.2 PROOF-OF-CONCEPT

5.2.1 Prototype Performance Goals

The following list describes the performance goals the prototype should achieve:

1. Collect three out of four balls at one time (1 of each ping-pong, golf, tennis, black ball).
2. Drop three out of four balls into the home base.
3. Drive four figure-8 circuits around a pair of road cones separated by 1 minute without hitting the cones.

5.2.2 Design Rationale for POC Components

The back wheels (casters) were selected because they offered greatest freedom of movement for the front-wheel drive (elaborated on in a following paragraph). Rather than using a traditional steering mechanism, we have decided to independently actuate the drive wheels. This will allow for point turns, and the choice of casters prevents interference or skidding by the back wheels.

The front wheels were selected for their size, based on the height of the casters. Because they were selected dependently, the main chassis should be level.

The wheel motors were selected after the drive wheels. Once we had a diameter of the drive wheels, we could estimate the max speed of the device using simple radial mathematics:

$$v_{max} = r \times \omega = 1.5\ in \times 303\ rpm \xrightarrow{unit\ conversion} \sim 1.2\ m/s$$

r is the radius of the wheels, and *ω* is the rotations per minute (a specification for motors). For a 303-rpm motor as we have selected, the max speed, using 3" wheels, is roughly 1.2 m/s. The motor torque also played a role in the decision: it needs to be able to output enough torque to get the device moving in the first place. The stall torque on the selected wheel motors is 16.8 oz. in, translating to a maximum accelerating force of 9.34N. As of a recent estimate from the Solidworks drawing, the device weight is 7.144 kg; the stall-out acceleration is therefore 1.3 m/s^2, more than enough to reach top speed in a reasonable amount of time. Two things to note about using this model: first the given RPM is *unloaded*, so this is a drastically liberal speed estimate. Second, we do not plan on running the motors at stall capacity, but we wanted to have rough numbers for the device's capabilities.

Batteries were selected based on their operating time using Eq. 1. The required 12-volt battery life was determined using the following equation:

$$L_{12V} = \sum \frac{M \times t_m}{60} = 2 \times \frac{500\ mA \times 4\ min}{60\ min/hr} \approx 67\ mA \cdot hr$$

M is the drive motor operating current [mA], and t_m is the estimated operating time of the motor [min]. Similarly, the 6-volt battery life was determined using the following equation:

$$L_{6V} = \sum \frac{S \times t_s}{60} + \sum \frac{A \times t_A}{60} = 2 \times \frac{180\ mA \times 2\ min}{60\ min/hr} + \frac{50\ mA \times 5\ min}{60\ min/hr} \approx 16\ mA \cdot hr$$

S is the servo operating current [mA], t_s is the estimated operating time of the servo [min], *A* is the Arduino operating current [mA], and t_A is the maximum operating time of the Arduino [min] (which was assumed to be the whole competition time window of 5 minutes).

Other components were selected by cost or availability, as long as they met the desired function.

6 WORKING PROTOTYPE

6.1 OVERVIEW

The design of the working prototype changed drastically from the proof of concept design. We found that with the current configuration, the motors could not supply enough torque to turn the wheels and move the device. To correct for this we removed much of the nonstructural, nonessential material from the body in order to lighten the device. We also switched the positions of the motors & wheels with the casters so that less of the device's weight was supported by the motor shafts. We changed out the wheels with smaller, lighter wheels which required much less torque to turn. Because the new wheels were smaller, we moved the motors from on top of the device to underneath it.

The gear system that was going to be used to actuate the arms of the device was not precisely lined up with the arms themselves. This caused the gears to slip: making it difficult for the servo to actuate the arms effectively. To allow us to better control the arms, we removed the gear system and instead directly attached the right arm to the servo. The left arm was then secured to provide support for the ball as the right arm pushed it. Pieces of plywood were added to the bottom support of the net to help guide the ball into the net.

The motor shield that we were going to use to power the motors could not supply any power to its motor connections. We removed the motor shield and instead connected 9V batteries in series with the Arduino such that we could drive the motors between roughly 7-12V.

6.2 DEMONSTRATION DOCUMENTATION

With the changes mentioned in section 6.1 implemented, the final prototype appears as shown in the following figures. Figure 6-1 is a wide view of the final operating prototype which has the asymmetrical gate design for the final edition. Figure 6-2 is an image of the net filled with balls. The volume of the net is large: it is holding two golf balls, two baseballs, three lacrosse balls and a foam ball. Figure 6-3 is a back view of the net apparatus. This image shows the rotation arm that we added to increase the volume of the net. Finally Fig. 6-4 is a close up of one of the drive wheels. The rubber band wrapped around the PVC is to add traction.

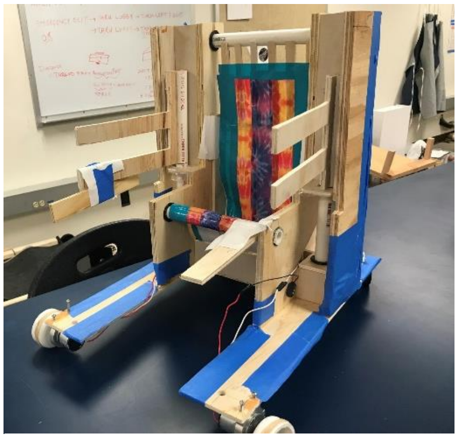


Figure 6-1 Full view of final Goal Keeper prototype

Figure 6-2 Net apparatus holding eight different balls

Figure 6-3 Rear view of net apparatus

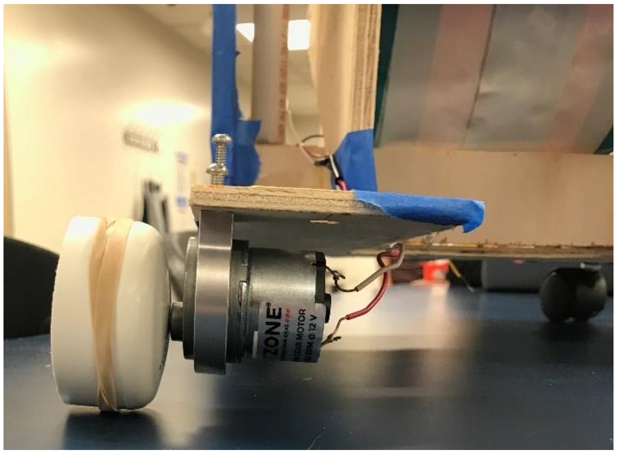


Figure 6-4 View of drive wheel and motor

6.3 EXPERIMENTAL RESULTS

Performance Goal 1:

We successfully completed the first performance goal to collect three of the four balls, one of each type. During the prototype demonstration the device was able to capture and secure all four types of balls separately without any major difficulty. The only ball that the device slightly struggled with was capturing the large, plastic bowling ball which took multiple sweeps of the arm to fully push the ball into the net. To improve this function we would connect an additional servo to the left arm so that we could actuate both to better secure the ball as it is being pushed into the net.

Performance Goal 2:

We successfully completed the second performance goal to be able to drop three out of the four balls into the home base. During the prototype demonstration, the device demonstrated its ability to successfully release each type of ball after it had been secured in net. While it was able to release the ball, it could not do so with much precision as the balls would roll away from the device in an uncontrolled direction. To improve this problem, we would add supports along the inside of the device to help guide the balls as they rolled out of the net. We also noticed that the device is much slower at releasing a heavier load, such as with the baseball. To help improve this we would add a counterweight to the top, driving support to reduce the torque needed to turn the support and release the load.

Performance Goal 3:

Unfortunately, we were not able to completely succeed in the third performance goal to complete four figure eights around road cones in one minute or less. While we were able to drive the device, we could not do so with the precision necessary to navigate the four figure eights. This was mainly due to the slight dissymmetry with the power being supplied to the motors as well as the weight differences that each motor experienced because the device was not perfectly symmetric. The series configuration did not provide us the proper control to account for these problems, so the control of the device was limited. To correct for this, we would ideally obtain a motor shield that could provide between 0-12V to give us better analog control of both motors and to allow us to drive the motors in reverse so that we could execute point turns.

7 DESIGN REFINEMENT

7.1 FEM STRESS/DEFLECTION ANALYSIS

The stress distribution in one of the PVC pipes under a maximum theoretical mode was analyzed. The analyzed piece is a pipe extending across the device and is used to support the collected balls. A maximum theoretical load of 10N was evenly distributed across the pipe for this analysis. 10N was chosen because it is roughly twice the weight of the largest possible ball, which, due to size constraints, the device can only carry one of at a time. For the simulation the pipe was fixed at both ends, simulating the walls the pipe is mounted to. This set up is shown in Fig. 7-1.

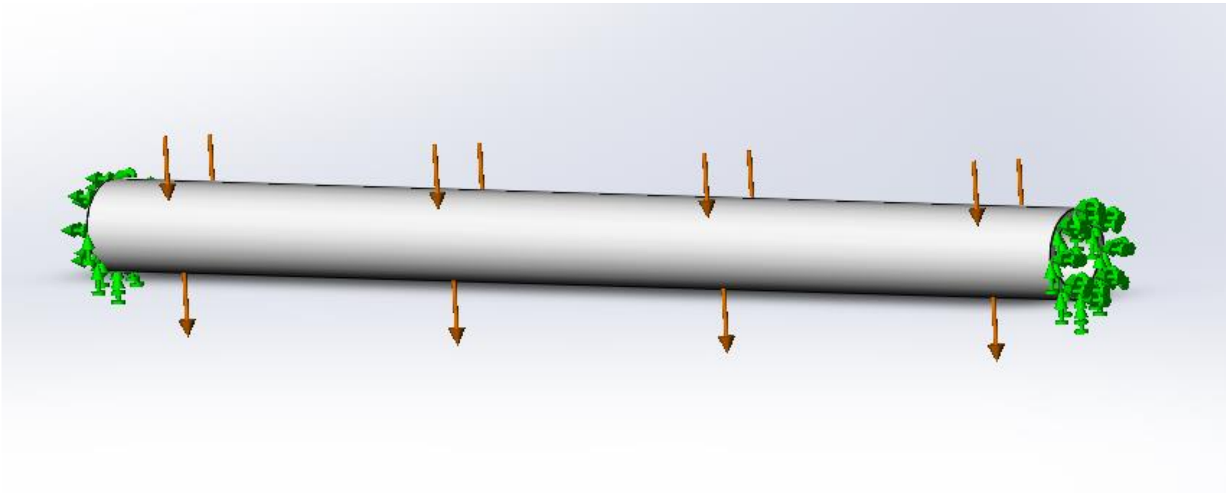


Figure 7-1 Setup of the unstressed pipe

In the actual device, .5in on each side rests in a bushing that is connected to the side of the device. The pipe is then hot glued into the bushing such that it is fixed and can no longer freely rotate. The load will not be evenly spread along the pipe: rather, most of the load will likely be applied to the middle section of the piece. The mesh used in the analysis was a standard mesh with 7608 elements in total.

From this analysis it was determined the maximum stress from such a load would be 0.405 MPa. The yield stress of standard PVC is 40.7 MPa meaning a factor of safety of 100.5 exists for the predicted stress. Given these results we do not believe any changes need to be made in order to reinforce this piece. The results are shown in Fig. 7-2.

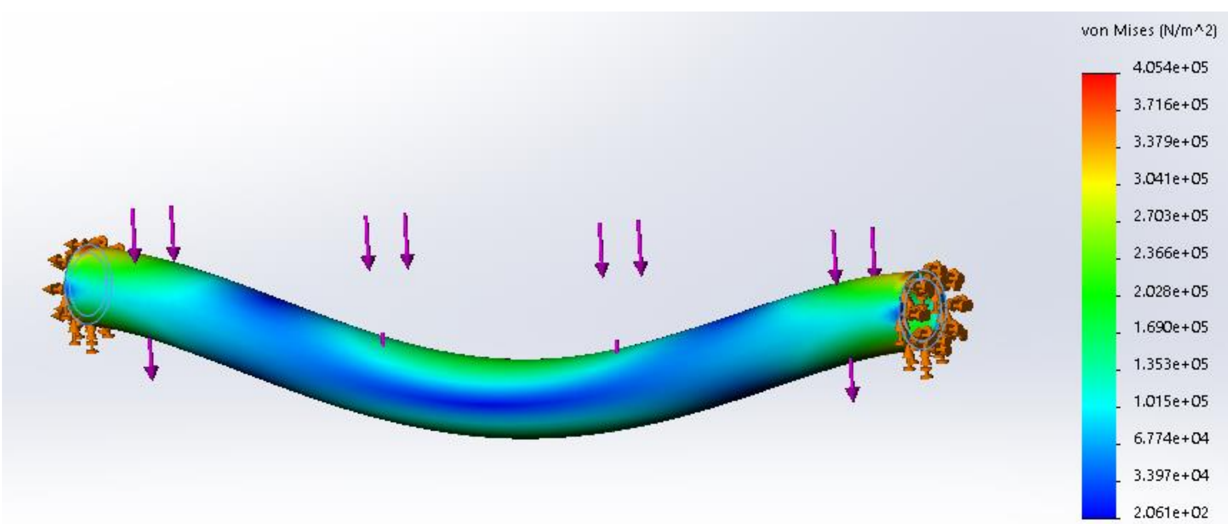


Figure 7-2 Von Mises stress map of analyzed part

7.2 DESIGN FOR SAFETY

7.2.1 Risks Associated with Goal Keeper

7.2.1.1 Risk 1

Risk Name: Batteries over heating

Description: If the battery is left charging for long periods of time, there is a risk that it could catch on fire. This would be extremely dangerous due to both the fire and the fumes released from the burning batteries; this must be avoided.

Impact: 5 (catastrophic)

Likelihood: 1 (extremely unlikely)

7.2.1.2 Risk 2

Risk Name: Gate Pinch point

Description: If an individual has their fingers close to the gates, with or without the motor running, they could get caught. If this does happen, there would not be any severe injury, only discomfort, since the gates do not move very quickly. Children should not play with the device for this reason.

Impact: 2 (mild)

Likelihood: 3 (moderately likely)

7.2.1.3 Risk 3

Risk Name: Dropping on person

Description: The device weighs approximately 15lbs and if dropped could cause minor injury an individual. For this reason, children should not carry or operate this device.

Impact: 3 (moderate)

Likelihood: 1 (extremely unlikely)

7.2.1.4 Risk 4

Risk Name: Splinters

Description: The chassis of the device is made from plywood; handling it presents a possibility of getting splinters in the hands. The plywood has sharp edges as well, so there is also a chance of mild lacerations.

Impact: 2 (mild)

Likelihood: 4 (fairly likely)

7.2.1.5 Risk 5

Risk Name: Loss of control

Description: If the motors lock into actuating, or the user is behaving haphazardly, the device could careen off course and ram into the feet or shins of an adult. Because of the device's weight and sharp edges, this could cause minor injuries upon impact.

Impact: 3 (moderate)

Likelihood: 3 (moderately likely)

7.2.1.6 Risk 6

Risk Name: Components overheating

Description: There are several components that could overheat. If the wires draw too much current and short-circuit, there is a fire risk. The device is made of wood, so device obliteration is possible, in addition to incidental property damage. The wheel motors spin at significant speed, which means that there is a possibility for internal friction or shaft-contact friction overheats. Both have the same fire risk as the short-circuit scenario.

Impact: 4 (significant)

Likelihood: 1 (extremely unlikely)

7.2.2 Risk Assessment

In Fig. 7-3 below, the risks are mapped based on likelihood of occurring and the impact that they would have.

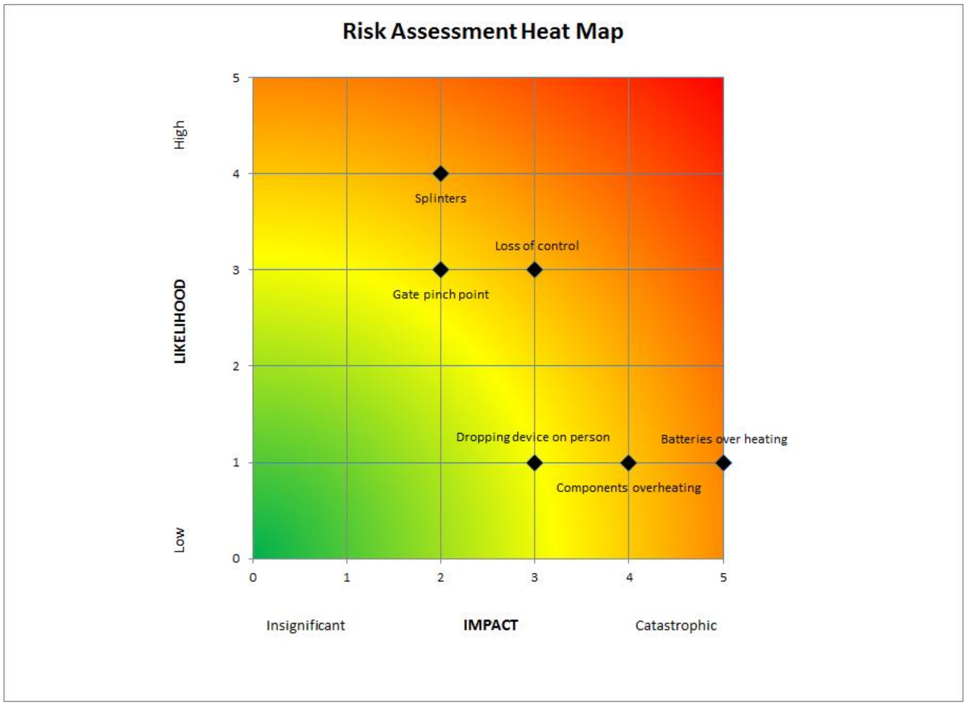


Figure 7-3 Risk assessment heat map

From the risk assessment heat map, it can be determined that the highest priority is to reduce the risk of splinters. To do this, all exposed sides will be sanded down. The next highest risk is loss of control of the device. To avoid this, only individuals that have been shown how to control the device should operate it. The third highest risk is the gate pinch point. If an individual's fingers get caught between the arms they can be pinched. To avoid this, hands should be kept away from the arms while it is running. The third lowest risk is that the batteries overheat. It is very unlikely that this will happen, but the impact would be catastrophic. To avoid this, the battery should not be left charging overnight or unattended for any extended period. The same goes for components overheating—the second lowest risk. If there is a sign of components overheating the power should be cut off. The lowest risk is dropping the device on a person. To avoid this, caution should be taken when carrying the device.

7.3 DESIGN FOR MANUFACTURING

7.3.1 Draft Analysis

In order to design the bushings for easy molding and manufacture, we had to alter the angle of the vertical walls of the piece. We applied a positive draft angle to the walls in the direction of the top face. This allows the piece to more easily be removed from the mold.

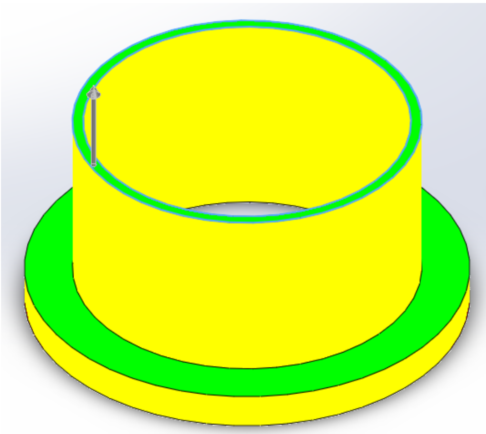


Figure 7-4 Positive draft angle applied to the bushing

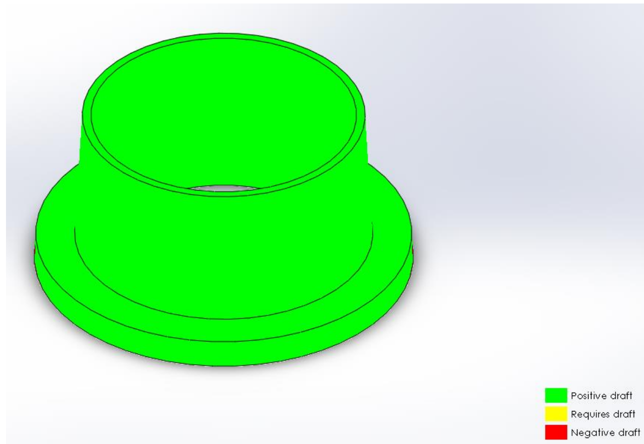


Figure 7-5 Results of draft analysis

7.3.2 DFM Analysis

A DFM analysis on the Miter gears that we use in the device was conducted. The device requires six of these pieces and thus must be easily manufactured. The first manufacturing process we analyzed was using only a Mill and Drill to construct and shape the piece. The only errors involved the dimensions on the chamfer at the top and bottom of the gear's central hole. The dimensions are not standard and thus could be difficult to create using standard sized tools. The error of the top hole and bottom hole are shown in Fig. 7-6 and 7-7 respectively.

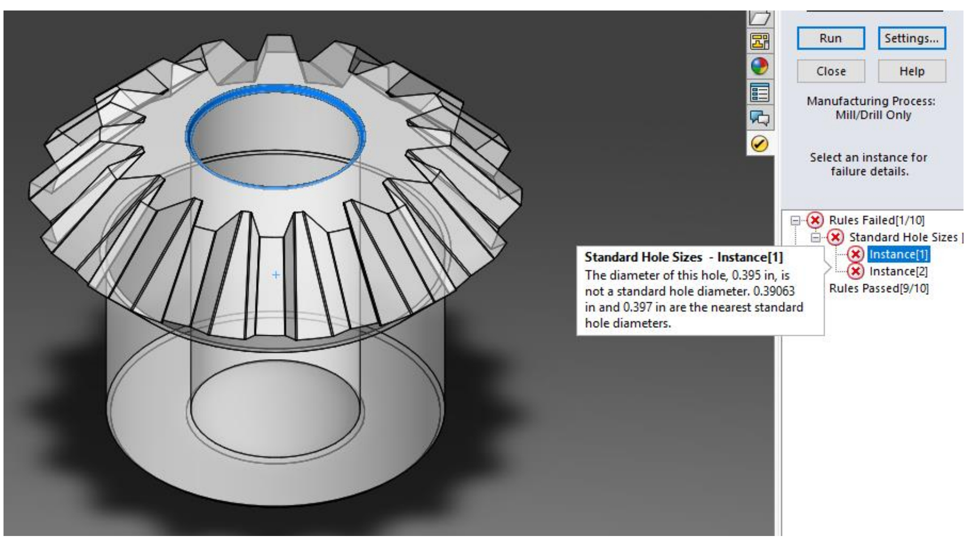


Figure 7-6 DFM analysis error for non-standard hole size (top location)

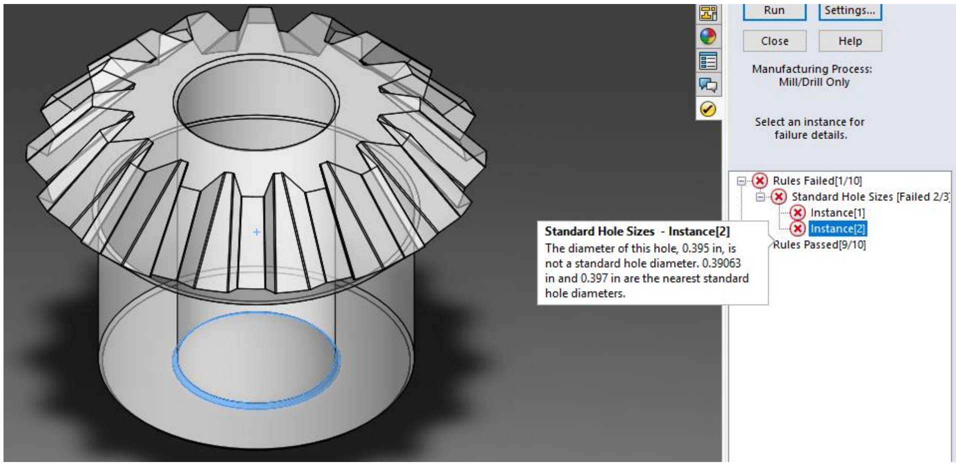


Figure 7-7 DFM analysis error for non-standard hole size (bottom location)

The second manufacturing process we looked at with the DFM analysis was injection molding. The analysis determined that many of the features of the device exceeded the maximum wall thickness required for injection molding to be a viable manufacturing option. The features of the part were too thick and would cause cooling problems during the molding process. An example of this is shown in Fig. 7-8. Many of the other features, mainly the teeth of the gear, were too thin and would cause high molding stresses during process. An example of this is shown in Fig. 7-9.

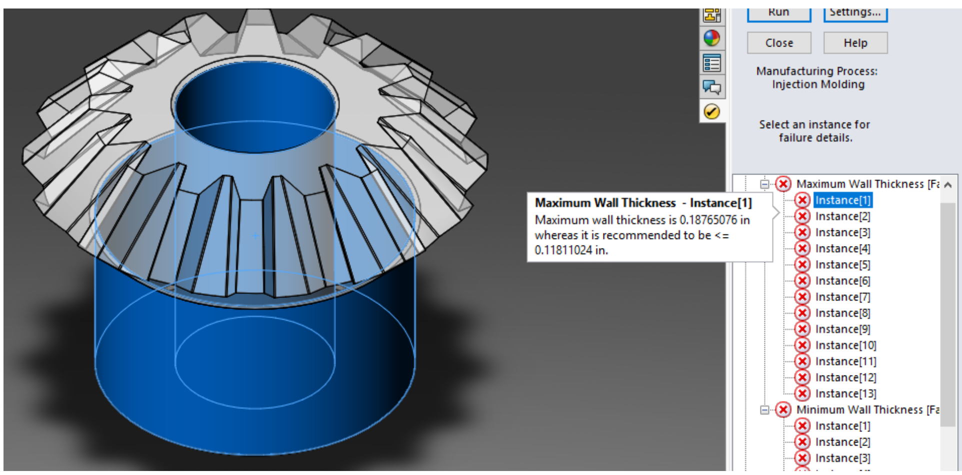


Figure 7-8 DFM analysis maximum wall thickness instance for injection molding

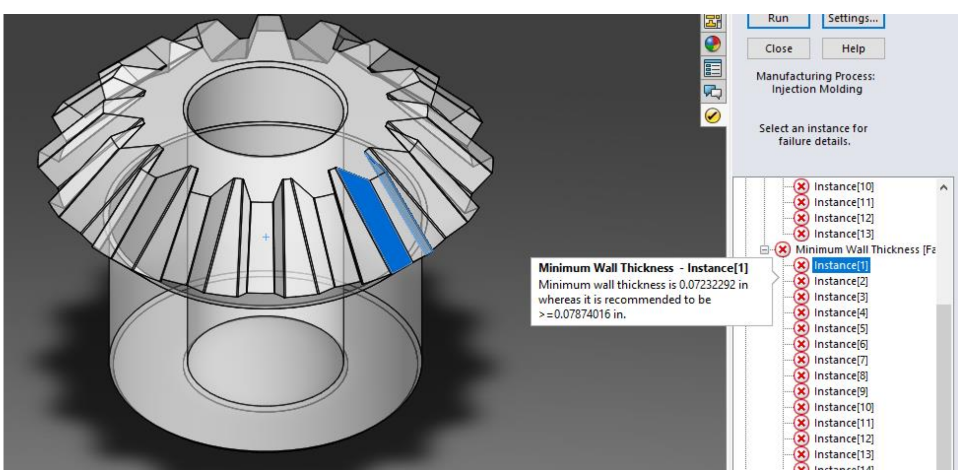


Figure 7-9 DFM analysis minimum wall thickness instance for injection molding

7.4 DESIGN FOR USABILITY

7.4.1 Vision Impairment

- Device is remotely controlled, so if a very nearsighted user is unable to see its location this could represent a hindrance to controlling its motor functions (e.g. moving in the right direction, knowing if the net is slack or taut).
- A possible improvement to increase usability for vision-impaired user would be to increase color contrast of certain parts. We could have the device itself be very black, and the net be red, for instance. This color contrast could increase visible signs from a distance.

7.4.2 Hearing Impairment

- Nothing on the device requires the user to listen. This impairment does not represent a hindrance to using the device. As a proof of this, one of the designers is quite hard of hearing and has not encountered any usability issues with the device.

7.4.3 Physical Impairment

- An arthritic user could find it difficult to manipulate the controller that we're using to maneuver the device. The user is required to perform fine motor functions in order to control the device, which may make controlling difficult if the user is unable to perform those fine motor functions.
- The controller is a product of many design iterations (and at least 4 generations of the product) that are aimed at improving usability. Initially we planned on using an Xbox controller, but after some thought we decided the PlayStation controller was more intuitive for the device. This is an improvement that we have already implemented. The usability of the device is left to designers at PlayStation.

7.4.4 Language Impairment

- There are no language skills necessary to use the device. If the user wished to change the Arduino code or look through this document on the device's manufacture, then there might be some issues with language accessibility. Unless the user wants to do either of those two things, there should not be an obvious language barrier to device usage.

7.4.5 Control Impairment

- The device is large and heavy, so a control impairment could make it a hazard for bystanders. If control is impaired enough, the user might run the device into the legs of said bystanders, potentially leading to minor injuries.
- Add some bumpers and softer edges to protect the legs or toes of bystanders.

8 DISCUSSION

8.1 PROJECT DEVELOPMENT AND EVOLUTION

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

The final design for the device does align with the initial project description. The final state of the device is well within the requirements to compete in the ASME design competition. It meets the size, power and functional specifications that are set up by the ASME rules for the competition. While it is unable to collect some of the larger balls described by the ASME rules, it is able to collect the balls specified by the customer interview.

8.1.2 Was the project more or less difficult than expected?

Many aspects of the projects were more difficult than expected. Some of the electrical components did not function in the way we thought they would which meant that we had to change the design at points to better match the unforeseen limitations of the components. We also had more difficulty with portions of the Arduino coding than we originally thought we would. Overall the fields that our members were not familiar with brought more trouble than we expected.

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

The proof of concept should have had a larger commitment. We ended up working towards the CAD target too soon, without adequately testing the actuators to see if they could tolerate the loads to which we would be subjecting them.

We spent a long time working on the chassis, which ultimately was wasted because we didn't anticipate how much the motor operation would be dictated by the weight of the device. There was a phase in construction where we engaged in what we called 'drastic weight reduction measures,' which basically meant ripping all of the walls apart and removing as much material as we could without compromising the functional structure. In summary, we spent more time on building the chassis than we needed to, since most of the chassis was a hindrance to movement.

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

The body of the device had a large number of independent and interlocking parts, which made construction flow somewhat challenging. One specific example of this was a case where we needed to screw down the motor mounts into a corner of the device that was already bounded by two walls; it was impossible to use any of the available drills and very difficult to use a screwdriver. An improved work flow would have been to prepare all of the holes and features on every wall before gluing the chassis components together.

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

All other design concepts that we brainstormed—including many that are unlisted in the document—had a greater number of actuators and complex motor tasks than the goalkeeper concept. Since the actuators presented the largest time commitment in debugging, we predict that the goalkeeper would stand as the most successful design concept that we considered.

8.2 DESIGN RESOURCES

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

The codes and standards we thought were most relevant came from some of the requirements dictated by the rules as well as codes and standards similar devices generally adhere to. This mainly dealt with the electrical components that would be necessary to power and drive the device. Since a rechargeable battery was required for the competition, we decided that codes dictating the limitations on batteries would relevant for our device. Since the device would have to be transported a long distance to compete in the competition, we thought that we must adhere to the travel regulations concerning batteries. We also knew that the most logical way to have the device move would be with motors, so we believed that the standards associated with dc motors would be relevant. These codes and standards did not influence the size of the battery; however, we did follow the standard for motors when picking which motor we wanted to drive our device with. When deciding which battery, we needed, the first priority was that it was able to power the control system as well as the motors. The battery did happen to fall within the code that allows us to bring it onto a plane, although, that was not the main priority when choosing it. When choosing the motor, we wanted to make sure that the motor would function properly so we did adhere to the standard when making that choice.

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

We do not believe that we were missing any critical information when we generated and evaluated concepts for this project. Since this project is for the ASME design competition, they had already provided an extensive list of rules and guidelines for our device and for the competition itself. Adding onto this information, the interview with Dr. Potter, cleared up any misconceptions about the rules and solidified the critical design requirements for our project. There was some small confusion about how some of the points would be scored in the competition, mainly concerning returning the collected balls back into the team's home base. We were unsure on whether the balls had to come to rest for a certain amount of time once they were released into the home base, or if we merely had to drop them in the area and they could roll out. This confusion did not factor too much into our design decisions however we decided that precisely placing the balls would not be a necessity for this project. We did not believe that this rule was critical information when generating and evaluating concepts. Other than this slight misconception, we thought that the rules and guidelines set up for this project were clear and allowed us to properly generate and evaluate concepts.

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

The gear system that we had originally designed to actuate the arms turned out to not be precisely placed enough to be viable for our device. It would have been helpful to do more analysis on the forces that would be associated with the gear to gear interface and the potential for slipping between the gears. This may have helped us decide against the design given precision was something we were not sure we could achieve. We could have decided on a less precision dependent design such as the solution we used in the final design. It would have also been helpful to do an analysis on the strength of bonding methods when attaching parts to one another. During testing we found that sometimes the glue used to hold components together could not withstand the forces applied to it and thus would come undone. We originally assumed that the bonds would be relatively solid fixtures and were more focused on whether the parts could take or supply the torques rather than if the bonds between them could. If we had looked at the shear strength of the glue prior to attaching to it we may have decided on a different bonding method for some of the parts that experience a large amount of torsion.

8.2.4 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 have taken more consideration into the components that we would use in our design. When we were deciding which components to decide on, none of us had much experience dealing with the control systems or with the electrical components. Going back with a better understanding of the capabilities and limitations of the control systems and electrical components would help in the decision in what components we would need to acquire and allow us to obtain and configure these components much sooner than we did for this course. This would give us more time to mitigate the potential problems we would face and end up with a better functioning device than we did for this project. A second time around would allow us to use design concepts we had not initially considered during the design selection and refinement process. While I am not sure we would use many of the other design ideas, we would have a better understanding on how to implement them into a practical design that we would be able to construct. The knowledge we have gained in this course would be immensely helpful in choosing the proper path to take our design.

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

Fill Some of the components that we had bought could not meet the performance expectations they were advertised to have and thus made it difficult to design around their limitations. These mainly concern the Arduino motor shield, which we were planning to use to be able to control the motors, and the battery, which was used to power the entire device. The Arduino motor shield we were going to use should have been able to power the motors between 0-12V as well as run them in reverse. Unfortunately, for some reason the motor shield we received was unable to provide any power to its motor connections. Due to budget and time restrictions, we had to settle for a less precise control system that lacked any reverse capabilities. If given more time and money the first priority would be to acquire a working motor shield to better control our device. We would also want to get a more powerful battery to power our device. The battery that we have can power our device for a short time but if it drops below a certain voltage, the Arduino will lose its connection with the controller. Using a more powerful battery would allow us to operate the device for a much longer period of time without worry that the connection would be lost.

8.3 TEAM ORGANIZTION

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

The skill sets of our members complemented each other's rather well during this project. Most of the time we were able to work efficiently and solve the problems that arose. While we believe that we worked well throughout this project and we had the skills necessary to complete it, we think that we would have a much easier time if we had some additional skills prior to this class. At the beginning of the course, none of our members had any experience with using Arduinos or the various shields that can attached onto them. This provided an obstacle when configuring the control system for our device, so it would have been useful for someone to have at least some prior skill with these components. While constructing the actual device, we found some difficulty exactly shaping and configuring each part so that everything would line up as it did in our design. This meant we sometimes had to remake parts, reshape them, or change the design to work with the imperfections created during the construction process. It would have been beneficial to have someone with more experience and skill for precisely building these types of parts to make the building process easier.

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

The design experience we acquired during this course definitely has inspired us to attempt other design projects. The types of projects that we have become interested in are rather wide ranging, but are closely related to what we have seen throughout this course. With new knowledge about control systems as well as motor and servo control has opened up a wide interest in more mechatronics related projects, many of which are closely related to the device we designed during this course. We would like to possibly attempt to perfect or at least improve our own design however seeing the devices other groups created throughout their course has piqued our interests in how we would attempt to solve the same problem. Many of the problems presented to the other groups have vastly different requirements than those presented to our project. It would be interesting to try to adhere to these different rules and guidelines to attempt to solve the proposed problem. The knowledge that we have gained throughout this course provides us with a different mindset when approaching these problems so it would be interesting to see how our design decisions would change from the rudimentary designs when we first heard about these projects.

APPENDIX A – COST ACCOUNTING WORKSHEET

Table 0-1: Cost Accounting Worksheet

	Part	Source Link	Supplier Part Number	Color, TPI, other part IDs	Unit price	Quantity	Total price
1	303 RPM Gear Motor	Servo City	638202	Silver	$24.99	2	$49.98
2	Arduino Uno*	Mouser Electronics	782-A000066	Arduino	$22.00	1	$26.99
3	Arduino Uno host shield	Amazon	Mega2560	Keyes	$15.80	1	$15.80
4	Caster	McMaster-Carr	24215T31	black	$1.42	2	$2.84
5	Wheel	McMaster-Carr	2439T44	lightweight rubber with ball bearing	$14.83	2	$29.66
6	37mm Clamping Mount	Servo City	555116	Silver	$6.99	2	$13.98
7	.5in PVC	Home Depot	22015	253755	$1.17	3	$3.51
8	.25in Plywood	Home Depot	99167465289	BCX	$4.85	2	$9.70
9	.5in Plywood*	Home Depot	99167222912	BCX	$6.03	2	$14.49
10	HS-311 Servo*	Servo City	31311S00	Stock Rotation	$8.99	2	$24.97
12	7V battery*	Horizon Hobby	EFLB12502S	1250mAh	$16.99	1	$21.98
13	Miter Gears	McMaster-Carr	7297K18	16 TPI	$6.70	5	$33.50
14	Battery charger	Horizon Hobby	EFLUC1009	Celectra 2S	$33.29	1	$33.29
15	Power Supply*	Horizon Hobby	EFLC4000	AC to 12V DC	$19.99	1	$24.98
16	Motor Shield*	Mouser	485-1438	Adafruit	$19.95	1	$24.94
Total:							$330.61

* denotes parts that include tax/shipping in the total price

APPENDIX B – FINAL DESIGN DOCUMENTATION

The following figures are fabricated parts from the final prototype. Each is fully dimensioned so that they could be reproduced at any point. Figure 0-1 is the bottom plate of the Goal Keeper. Figure 0-2 is the lower arm holder which keeps the gates in place. Figure 0-3 is the pipe wall socket which serves as a frictionless surface for the PVC pipes to rotate in. Finally, Fig. 0-4 is the wheel model for the final prototype.

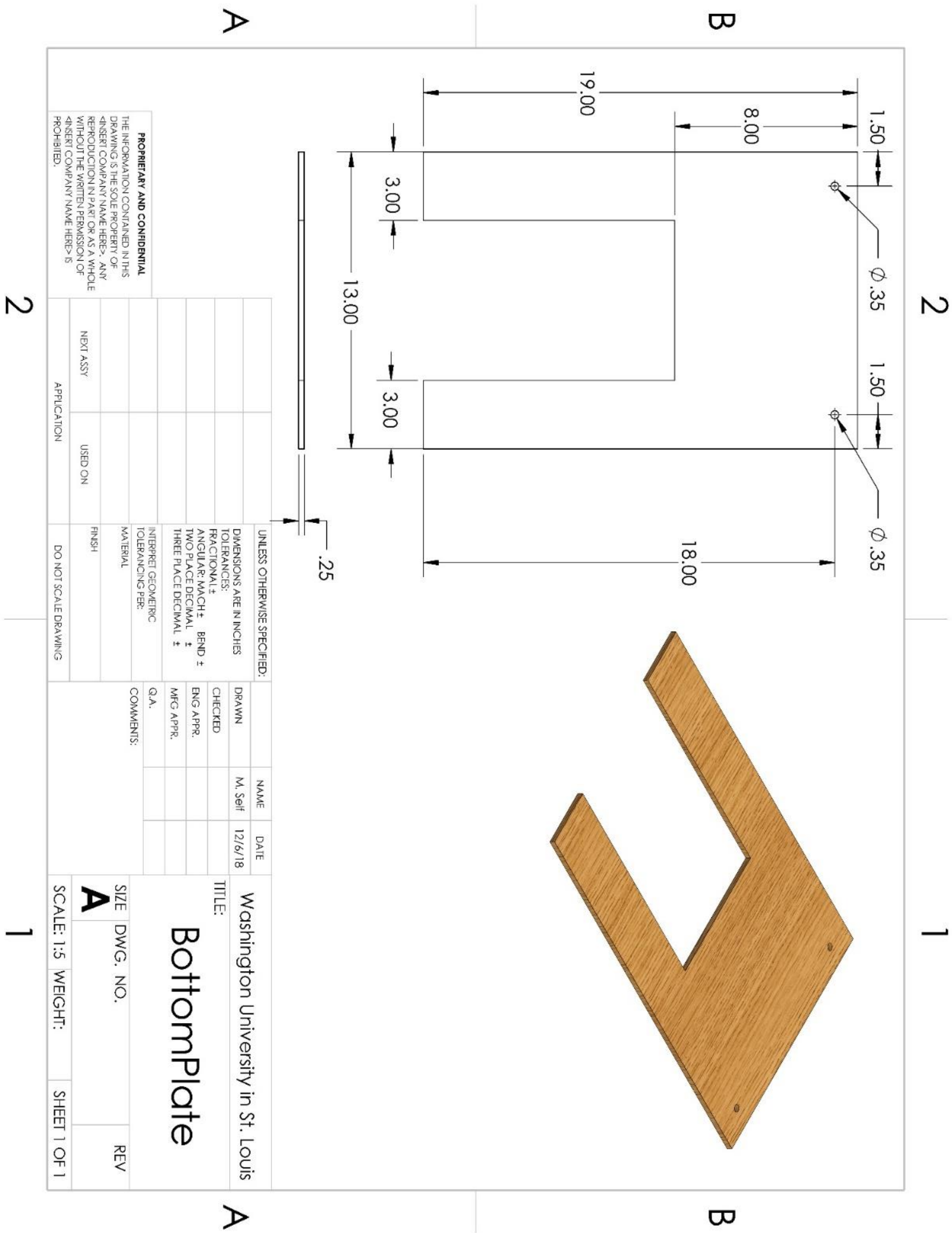


Figure 0-1 Dimensioned drawing of the bottom plate

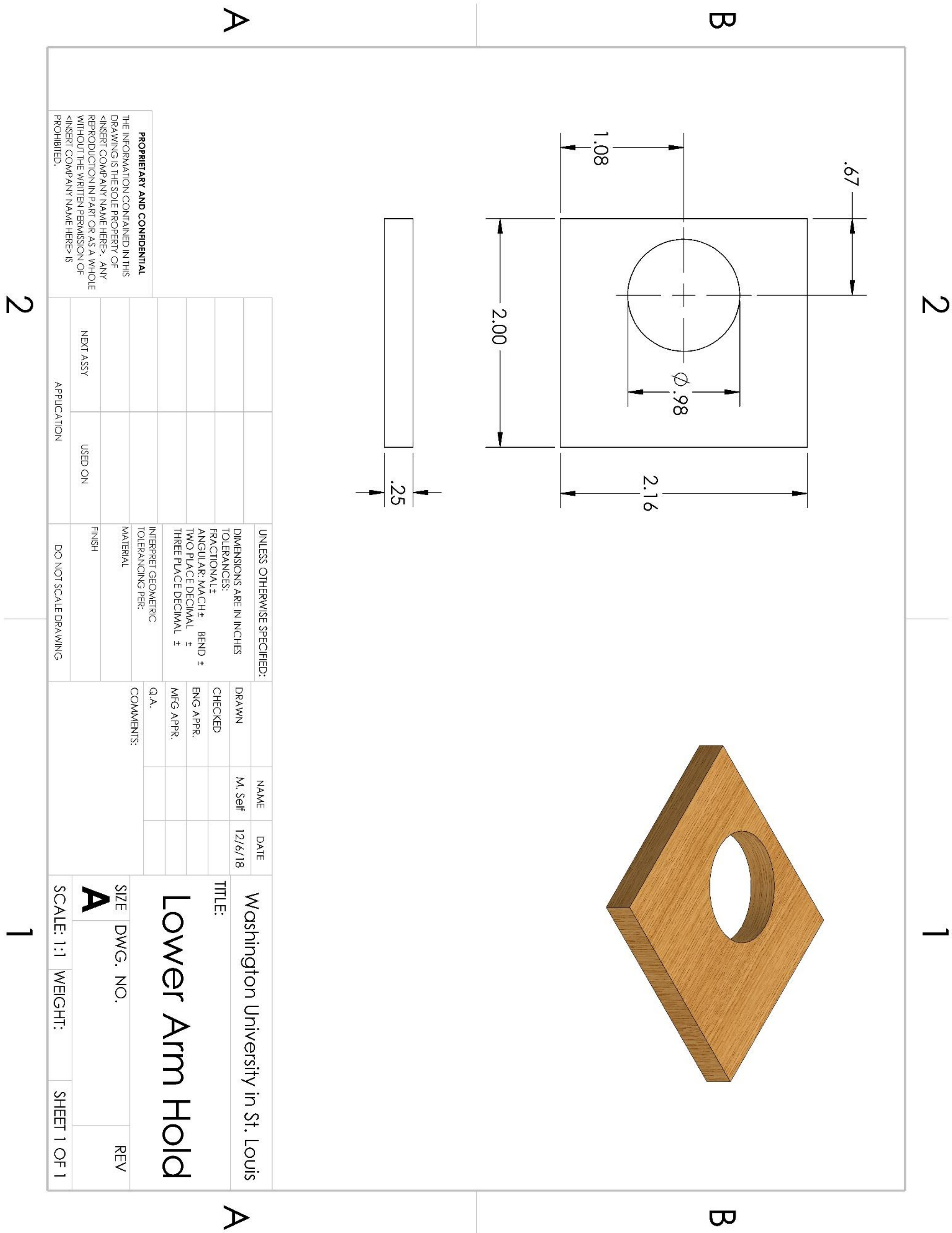


Figure 0-2 Dimensioned drawing of lower arm holder

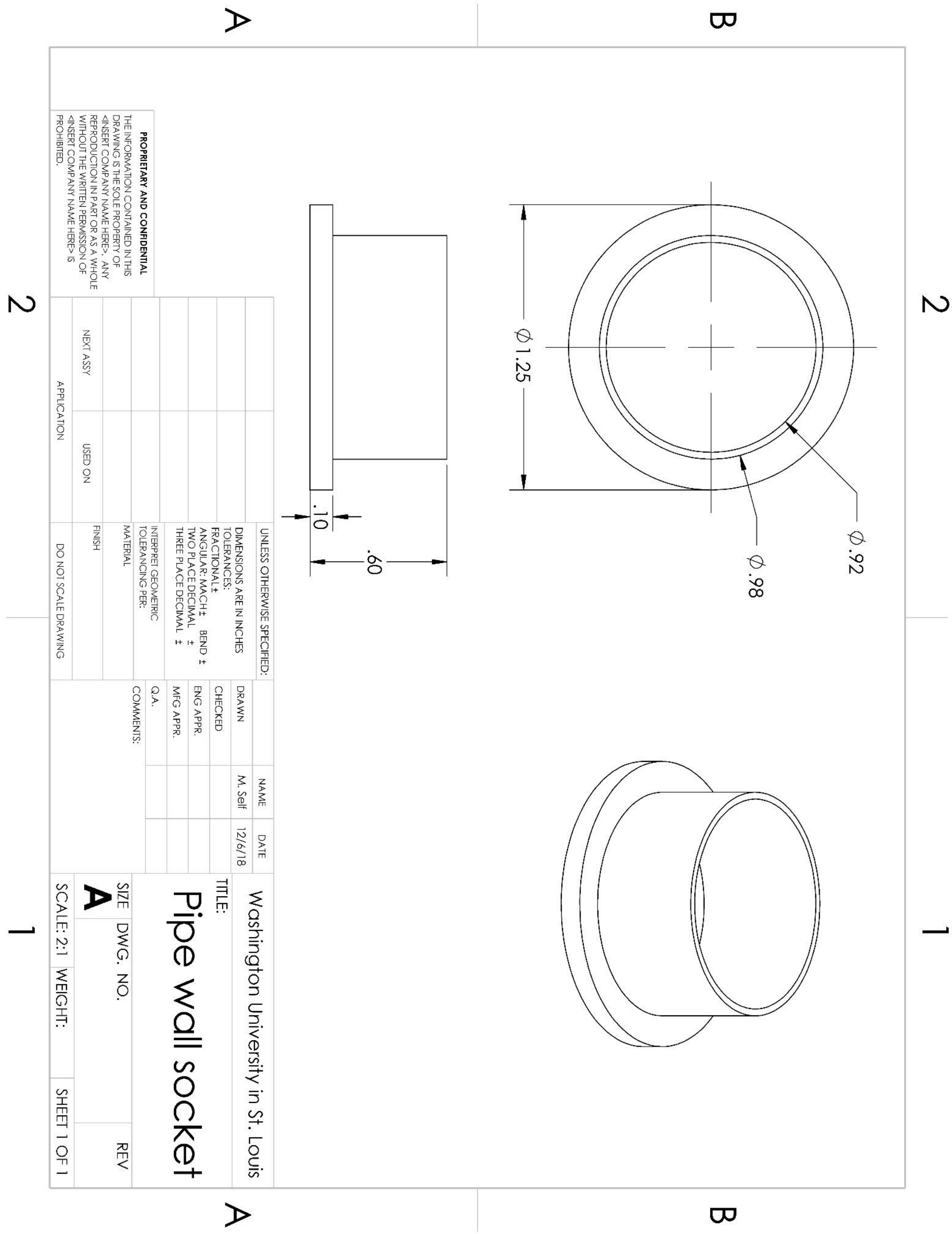


Figure 0-3 Dimensioned drawing of pipe wall socket

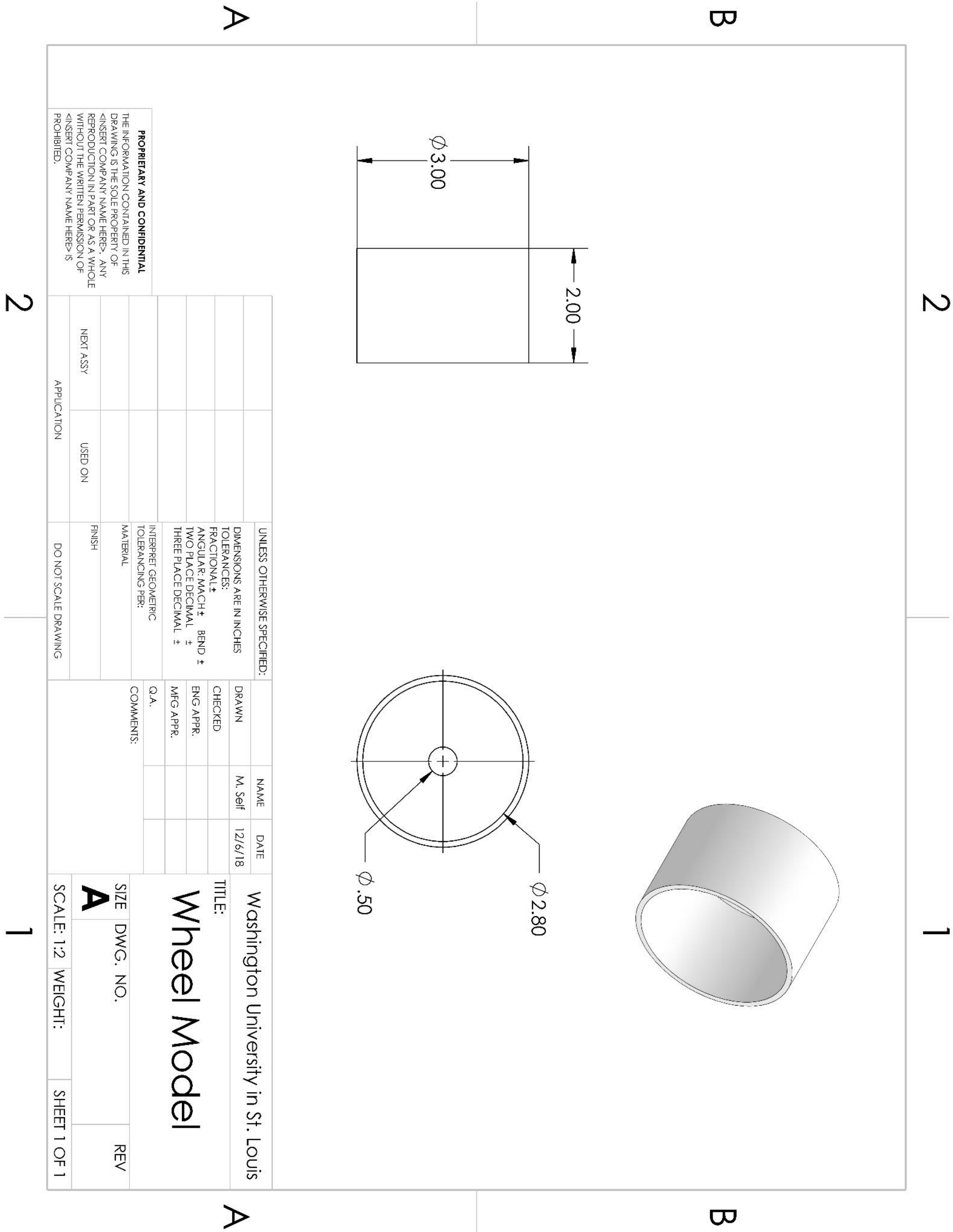


Figure 0-4 Dimensioned drawing for wheel

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