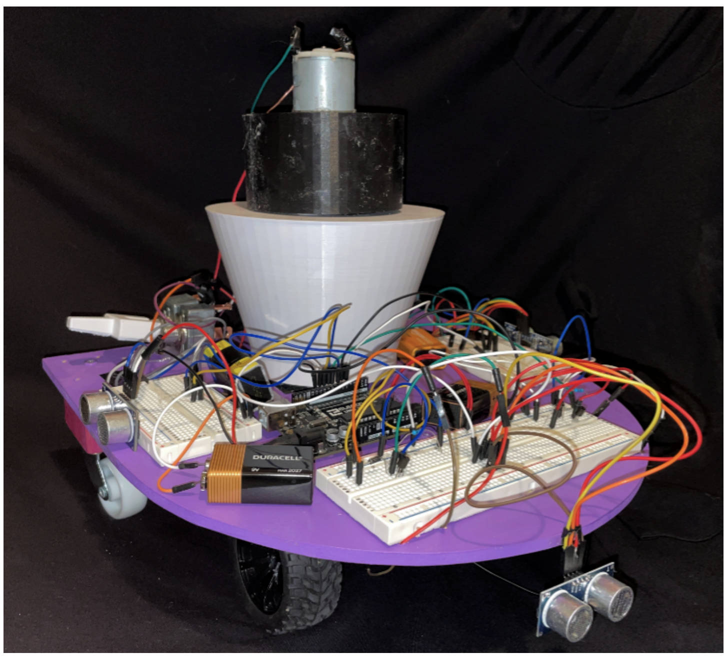
Autonomous Vacuum Cleaner Design Competition Report

MECH 202

Group 9

December 9, 2022



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Colorado State University

Fall 2022 Semester

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Design Problem Statement

For this semester's project, students were tasked with creating an autonomous device that could compete against other devices to vacuum up the most debris. The competition fixture was constructed with wooden boundaries, which resembled a large sandbox, that contained debris such as sand, screws, and marbles. The sides of the arena were around 3.5 inches tall with an internal area of 64 square feet. Each match was 2 minutes long.

Figure 1: Final Model of Competition Fixture

In terms of competition eligibility, students were given a fair amount of creative freedom to design their device in any way they deemed fit as long as it stayed within the requirements outlined below:

- Device must not exceed 12 inches in length and 12 inches in width
- Dimension must not change greater than 1 inch after movement has been initiated
- Must maintain one contact point with the floor at all times
- Must only have one movement prompt for initialization

The device would win the match if:

- Device collects more debris (grams) than the opposing team
- If neither team is able to collect debris, the device that moves the farthest

Specifications Development

Target Customers

The vacuum cleaner has been a staple for household users since its invention over 100 years ago. As of recently, companies have started designing vacuum cleaners that can function all by themselves and the market has drastically changed since. With the increase of consumers desiring autonomous vacuums, this product could potentially have a large customer population.

The intended target customers for this device are people with a need to vacuum with ease. However, it is understood that there are a variety of professional products on competitors shelves, so in reality, this product was mainly designed to compete against all the other groups within the MECH 202 class who had to abide by the same competition requirements. Therefore, the primary intended users of this device are those in MECH 202, Group 9, which also happens to be the developers of the product. The fact that the people who were going to use the device the most were the same people designing and building it made it easier to consult the users to see what the most important factor and specifications for the device functionality were.

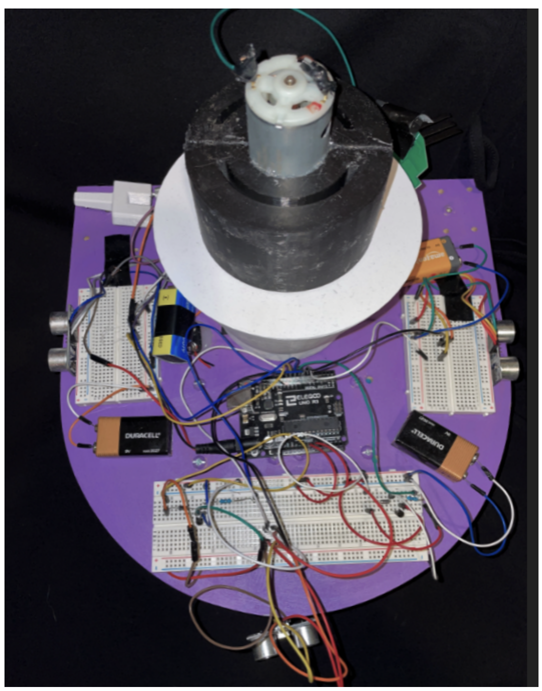


Figure 2: Top View of Device

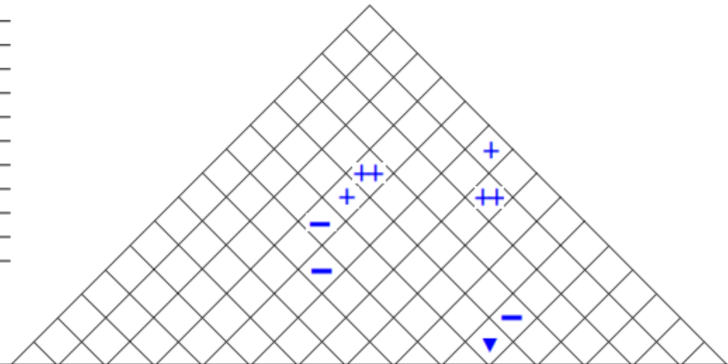
Title: Automated Vaccuum QFD

Author: Group 9 (Daniel Pelphrey, Alaina Bentley, Anna Buckley, Mason Adams)

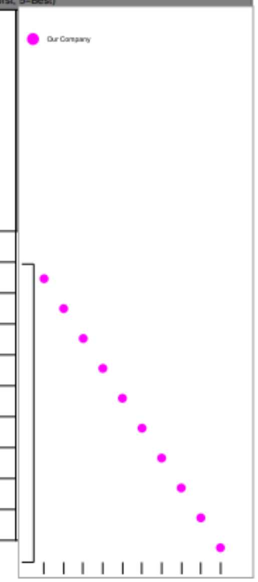
Date: 9/6/2022

Notes: Customers: Instructor/Judges, Household users, Commercial users

Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Length	Width	Manually Start via Switch	Battery	Completely self contained unit	No human input required after start	Programed sensors to detect boundaries and other devices (arduino)	Clearance under wheels	Detachable debris container	Weight	Speed	Battery life	Always have at least one contact point with floor	Must not damage other devices or boundary	Barely adjusts after turned on	Our Company	Roomba	Dyson	Bissell	Shark	Sanitaire
				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Competitive Analysis (0=Worst, 5=Best)					
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	x	x	x	▲	x	x	x	x	x	▼	x	▲	x	x	x						
1	9	0.1	6.6	Vacuum up debris of varying size							O	Θ	O							5	0	3	1	2	5
2	9	0.1	10.0	Autonomous			Θ	▲	Θ	Θ	Θ								O	5	3	2	1	4	0
3	9	0.1	6.7	Sense the debris and room boundaries						Θ			Θ					Θ		5	4	3	2	4	0
4	9	0.1	6.7	Store the debris in replacable compartment					O	Θ	O									5	4	3	2	4	4
5	9	0.0	2.7	Long battery life				Θ							▲	Θ				5	4	3	4	4	0
6	9	0.1	9.3	Run on mutiple surfaces							O	Θ			▲		▲			5	3	2	1	4	0
7	9	0.1	5.7	Reasonable price				Θ			O			▲	O	Θ				5	2	1	2	3	3
8	9	0.0	3.3	Appealing design					Θ		O	▲	O	O			▲			5	5	2	5	4	3
9	9	0.1	10.0	Safe for children										Θ						5	4	4	3	4	3
10	9	0.1	8.3	Manual Start			Θ			O									O	5	2	4	4	3	5
				Target or Limit Value	11.0-12.0 in	11.0-12.0 in	Yes	12.0-15.0 V	Yes	Yes	Yes	1.5-2.0 in	Yes	10.0-12.0 lbs	2.0-5.0 mph	2 min	Yes	Yes	0.0-1.0 in						
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	3	3	0	8	5	5	8	1	2	6	6	1	0	4	3						
				Max Relationship Value in Column			9	9	9	9	9	9	9	9	3	9	1	9	3						
				Weight / Importance			2.3	1.1	2.0	3.2	2.6	2.1	1.2	1.5	0.4	1.0	0.2	0.8	0.8						
				Relative Weight			12.1	5.9	10.1	16.8	13.5	11.0	6.3	7.7	2.1	5.1	1.0	4.2	4.0						



Powered by QFD Online (http://www.QFDOnline.com)

Figure 3: Quality Function Deployment for Device Overview

Customer Requirements

Design Organization: DC Team 9	**Date:** 12/3/2022
Product: Automated Vacuum Cleaner	

Who:

1. **Who are the primary users of the product?**

Household users, commercial users, instructor, judges, and peers.

2. **What skills or education will the primary users have?**

Users may have any background, no advanced education experience is necessary. Skills needed are basic reading skills and common knowledge of working with an electronic device.

3. **Describe any primary user physical conditions that affect the design of the product.**

Product is very user friendly, user only needs to use one switch to turn on, as well as have the ability to un-attach the fan and motor to empty out the debris compartment.

4. **Who will purchase the product?**

Users with a need to clean any sort of surface.

5. **Who else is a stakeholder in the design of the product?**

Our teacher and our judges.

6. **Describe any cultural practices or customs related to the product.**

Customers would need to have the means to have a clean space.

7. **How much is the purchaser willing to pay for the product?**

Product is relatively cheap, users should be expected to pay around $50 for the product.

8. **How much is the user willing to pay to operate the product?**

For operation, only batteries are needed.

9. **How much is the user willing to pay to maintain the product?** User should expect to replace batteries, tires and motors over a longer period of time, all of which can be found at stores. Around ~$20 annually.

How:

1. **For what specific purposes will the product be used?**

Product is used for vacuuming surfaces without having to do the work of moving around.

2. **What is the current process used?**

Only a switch needs to be initiated, and product will work. After use is fulfilled, empty out debris container into trash.

3. **How often will it be used?**

Depending on demand, customer can use product often, but likely once or twice a month will be standard.

4. **How long will it be used each time?**

Product is made to last around 5 minutes before motor will need to cool down.

5. **Describe the quality expected by the user.**

User expects the product to be easy to use and work decently well to have a clean surface.

6. **How far, how often and in what way will product be transported?**

The product does not need to be transported very often, only into and out of storage for use.

Where:

1. **Describe the surroundings for normal use.**

Possibly a messy surface, and lots of obstacles it will have to maneuver around.

2. **Describe the noise, weather, temperature or other environmental factors that may affect the design of the product.**

Product should not be around any sort of water because that will cause it to break and likely short out the circuits.

3. Describe any size or weight limitations. Nothing should be placed on top of the vacuum, could cause the torque to be too much for the motors to power and could stop moving. **4. Describe the aethetics of the use surroundings.** Product can be used in any room in the house, preferably places with hardwood floor or carpet. **5. Describe the energy available when the product is in use.** Energy available is battery power.	
Customer Requirements (include how well the product fulfills each requirement):	
1. Vacuum debris of varying size. Product does this well, depending on the weight of the debris. Can fit up to 0.6 in diameter debris. **2.** Autonomous. Product does this very well. **3.** Sense debris and room boundaries. Product can sense room boundaries well as long as the boundaries are above 3 inches off the ground. Not very good at sensing the actual debris. **4.** Store debris in removable compartment. Compartment is removable and the product stores all debris in it. **5.** Long battery life. Battery life is okay, not great since the motor often overheats. **6.** Run on multiple surfaces. Very good at running on sand from competition fixture and hardwood floor. Product can run on short carpet but not long carpet. **7.** Reasonable price. Product was cheap to manufacture. Sales price should not be too high. **8.** Appealing design. Product is painted purple, and all parts complement the color. **9.** Safe for children. User should not let children play around with the device too much, as there are lots of wires exposed. **10.** Manual Start is easy and only one movement needed to initiate.	
Who Else (List other products that fulfill the requirements):	
1. Roomba 2. Dyson 3. Bissell 4. Shark 5. Sanitaire	
Team member: Alaina Bentley	**Team member:** Ryan Blake
Team member: Anna Buckley	**Prepared by:**
Team member: Daniel Pelphrey	**Checked by:**
Team member: Mason Adams	**Approved by:**
The Mechanical Design Process **Copyright 2018**	**Designed by Professor David G. Ullman** **Form # 16**

When developing the customer requirements, there were a few factors that were taken into consideration. The first of which being personal knowledge. If a vacuum were to be purchased, what would be the main goals for it? It can be said that a customer would want a reliable, safe product that will suction up what they desire. Another factor considered was competing products. When developing a product similar to some already made in industry, those requirements can also be similar. A customer that already has a competing product would ask "Why is this one better than mine and why should I buy it?". This is where the appealing design and reasonable price were decided as a requirement. The requirements listed above are the baseline, while it is acknowledged that there could be many more factors customers consider before purchasing a new device.

Device Competitors

Figure 4: iRobot Image

iRobot (Roomba):

The industry leader for autonomous vacuums is the Roomba produced by iRobot [3]. iRobot gives their own specifications and description of their product. The Roomba is 13.3” wide (would not meet competition regulations) and is powered by a lithium ion battery. It uses a brush system in combination with a vacuum system in order to clean. This was something that could definitely be implemented into the design of the competition robot. The Roomba can avoid obstacles and pet messes, and does not require cleaning up by hand prior to use. A reverse engineering report [4] for an older model roomba was also referenced. This revealed that a bumper sensor system was used to detect obstacles. One drawback of this is that it requires the robot to make contact with objects, rather than avoiding them completely which would be a safer way to operate.

Figure 5: Milwaukee M18 Vacuum Image

Milwaukee M18 FUEL PACKOUT 18-Volt Lithium-Ion Cordless Shop Vacuum:

Another product that was analyzed during the research phase was this battery powered shop vacuum. While it did not meet our requirement of being automated, it is designed for picking up more similar material to the competition (sand, screws, etc.). Milwaukee [4] reports that it measures 17”x10” so it also would be disqualified from the competition. The vacuum runs on an 18V lithium ion battery, and reviews report that it easily suctions up shop debris and matter. This would perfectly need this customer requirement for the competition despite not meeting any of the others. The competition robot likely would require a similar amount of power in order to generate the suction needed to lift the competition debris. The vacuum system developed for the competition will also likely resemble this shop vacuum more than the vacuum system on the roomba, however, it would obviously require the movement system to be added.

Specifications

There are 10 demanded qualities by the targeted customers. They are as follows:

1. Suction debris of varying size
2. Autonomous
3. Sense and avoid room boundaries
4. Store debris
5. Long battery life
6. Traction on multiple surfaces
7. Reasonable manufacturing price
8. Appealing design
9. Safe for children
10. Manual start

Along with these qualities, 15 engineering specifications were developed. These are as follows:

1. Length of device
2. Width of device
3. Manual start via switch
4. Battery
5. Self contained unit
6. No human input after start
7. Programmed sensors
8. Clearance under wheels
9. Detachable Compartment
10. Weight of device
11. Speed of device
12. Battery Life
13. One contact point with ground
14. No damage to competitors or boundaries
15. No adjusting after initiation

Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Length	Width	Manually Start via Switch	Battery	Completely self contained unit	No human input required after start	Programed sensors to detect boundaries and other devices (arduino)	Clearance under wheels	Detachable debris container	Weight	Speed	Battery life	Always have at least one contact point with floor	Must not damage other devices or boundary	Barely adjusts after turned on
Vacuum up debris of varying size							○	⊙	○						
Autonomous			⊙	▲	⊙	⊙	⊙								○
Sense the debris and room boundaries						⊙			⊙					⊙	
Store the debris in replacable compartment					○	⊙	○								
Long battery life				⊙							▲	⊙			
Run on mutiple surfaces							○	⊙			▲		▲		
Reasonable price				⊙			○			▲	○	⊙			
Appealing design					⊙		○	▲	○	○			▲		
Safe for children										⊙					
Manual Start			⊙			○									○

Figure 6: QFD Specifications for Device

Suction Debris of Varying Size

This quality is satisfied by the specifications regarding the size and weight of the device. By quantifying the measurements of the device, it is able to have a certain size of both the vacuum inlet and the debris container. In order to set the diameter of the vacuum inlet, it is necessary to know the maximum size of expected debris, and this was done in the practice arena set up by the professor prior to the competition. Once the maximum size was determined, constraints regarding the size of the inlet and the weight of the device was set.

Another specification that helps satisfy this quality is having clearance under the wheels. After having the size of possible debris, it is important to ensure the device has slightly more height under the wheels, so that it can drive over the debris without high centering itself.

Autonomous and Sensing Room Boundaries

These two qualities are satisfied by three of the specifications. This includes the self contained unit, no human input after start, and programmed sensors. To be a completely autonomous device, there must be a "brain" able to communicate with the rest of the device to prevent damage or unnecessary movements. This “brain” comes from the programmed sensors, which send high frequency waves and wait for them to bounce back. This determines how far an obstacle is away from the sensor. With the use of three sensors, the device is able to adjust its movement, preventing any human input, making it therefore a self contained unit.

Storing Debris

As for storing debris, this quality is satisfied by ensuring there is a detachable compartment. This was a main requirement provided by the professor, so it is a crucial specification. Since the debris compartment is removable, the customer will be able to dispose of the debris in an easy manner. It is also important for the competition so the debris could be emptied and quantified to determine the winner.

Long Battery Life

Satisfying the long battery life quality depends on the battery chosen. To ensure a long battery life, a 6V battery was used for the wheels and 12V batteries were used for the vacuum. The 12V batteries were rechargeable, so they could be used as many times as necessary. This gave the vacuum full power at all times, so the air flow and suction was at its strongest. For the wheels, 6V batteries are very common, and there were multiple batteries purchased so they could be easily replaced if needed.

Traction on Multiple Surfaces

In order to satisfy this quality, the specifications used were the speed of the device and having one contact point with the ground. Having a slow speed is important for traction because the slower the device moves, the less likely it is to slide on the surfaces. However, if the speed is not fast enough, it could also get stuck on certain debris. Finding this balance was a crucial specification to make. Having contact with the ground is also clearly important, because if not, the device would have no traction and would just be flying.

Reasonable Manufacturing Price

To consider the cost of manufacturing, the parts purchased are an important specification. For this project specifically, the battery was the main constraint to make. Batteries can get wildly expensive, so it was crucial to ensure the batteries used would have a long life and be strong enough to power what was necessary. If the battery were to have a short lifespan, then the voltage would significantly decrease and more would have to be purchased to have a useful final product.

Appealing Design

For this device to have the appealing design quality, it had to meet the self contained unit specification, as well as the weight of the device. It could be appealing to a customer to have a unit that is not reliant on their individual input. If a customer is looking for a vacuum, the goal is for this device to be appealing based on its self contained unit. The other specification is the overall weight of the device. Many customers want a lighter product, so if the weight is minimized, it may be more desirable to a customer.

Safety

Every product needs to be safe. There are laws that ensure a product is safe before it can be given to consumers. For this device, it is completely self contained and it is programmed to cause no damage to obstacles or competitors. Both of these specifications provide safety to a consumer and safety to the competitors. As long as the device is not exposed to water or unsafe conditions, it is a safe product.

Manual Start

The manual start quality is satisfied by the self contained unit and the manual switch specifications. Due to the nature of the competition, the device must take only one human input to turn it on and then absolutely no human input until the competition is over. Because of this, it was designed to have one switch to initiate both the wheels and the vacuum motors.

Specifications Tradeoffs

Some of the specifications for the automated vacuum share an inverse relationship. This means that in order to meet some of these standards, other aspects of the device had to be sacrificed to varying degrees. Some example of this are listed below:

Device Power Output vs. Battery Life

The amount of power being generated by the different motors used on the device has an inverse relationship with the battery life. Obviously it was a goal to generate as much suction by running the most powerful motor for our fan, and using the most powerful drive motors to move the vacuum, however these were both limited by the need to have sufficient battery power to run the device for 2 minutes at a time and recharge it back to competition ready levels in 15-20 minutes.

Sensory Ability vs. Price

Another set of specifications that required a tradeoff were the quality of our sensors and the amount of money spent on the project. High quality sensors would have been very useful to make the vacuum as efficient as possible in navigating the arena, however, due to cost limits, donated ultrasonic sensors were used to keep the project within the budget. This in turn led to some issues with the sensors failing and not always reading reliable information. The likelihood for error grew when using these donated sensors.

Device Size vs. Debris Storage

Based upon the rules of the design competition, it was required to keep the device under a maximum size limit. This obviously limited the debris storage volume possible purely due to the limit on the room available on which to mound it. This did not end up much of a challenge in the design process.

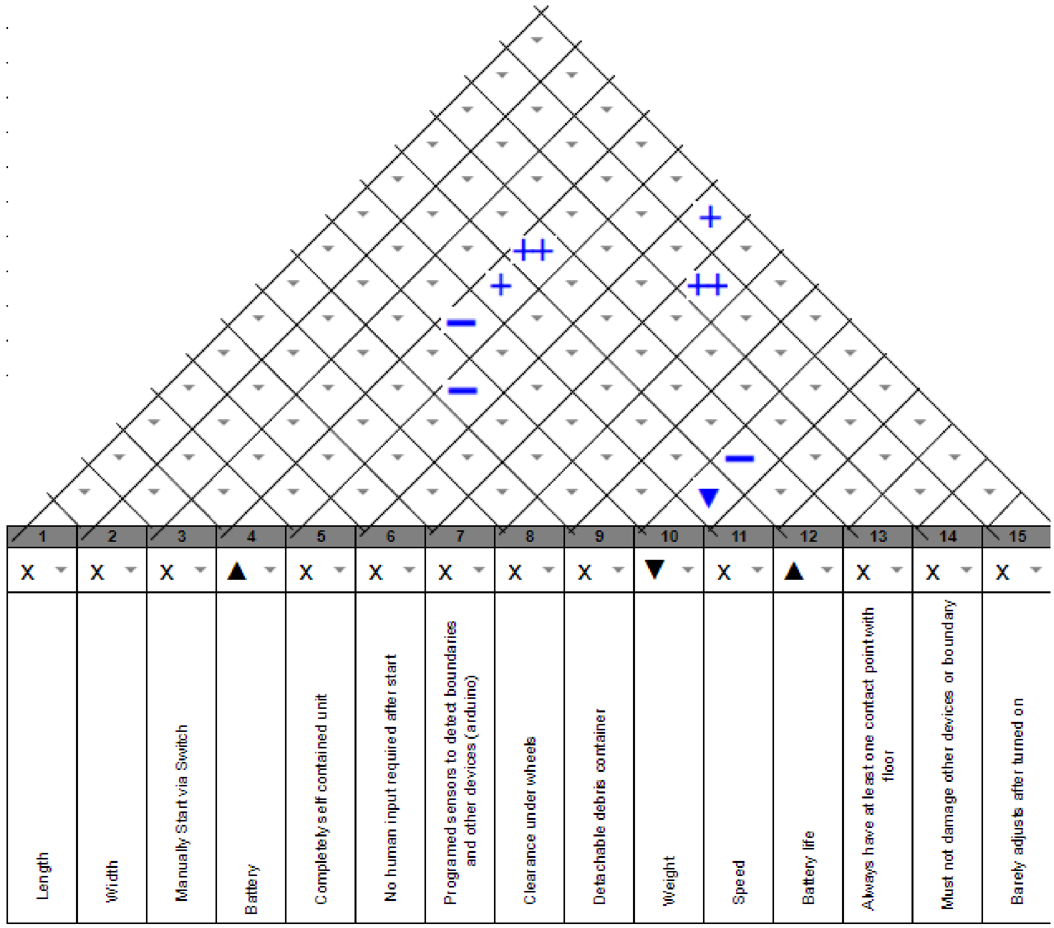


Figure 7: QFD Specifications Tradeoffs

Concept Generation & Selection

In order to start generating concepts for the product, the entire team came together and generated a mind map. This first step was a basic brainstorm involving materials, shapes, and power techniques. The group also discussed how to incorporate competitor designs into the product. After the mind map was complete, each member drew out a concept and explained what was going on and which parts they incorporated from the mind map. After there were four concepts drawn up, further analysis was completed by the entire group. The analysis was completed by going through the customer requirements and deciding which design met the most requirements. The designs that were picked for potential prototyping were the ones that gathered the highest sum of those requirements.

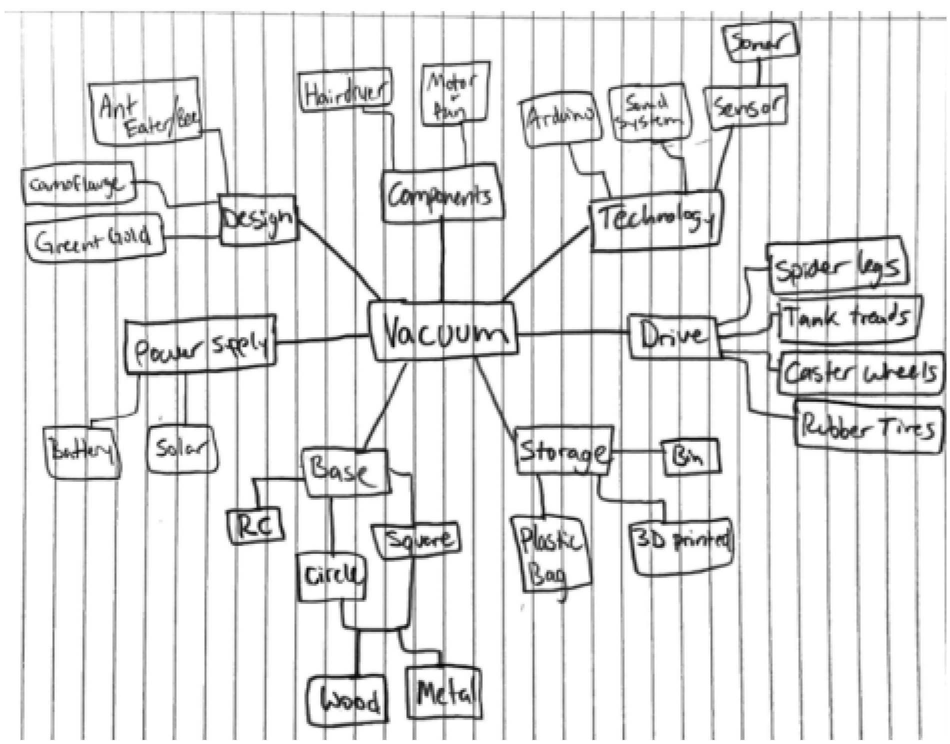
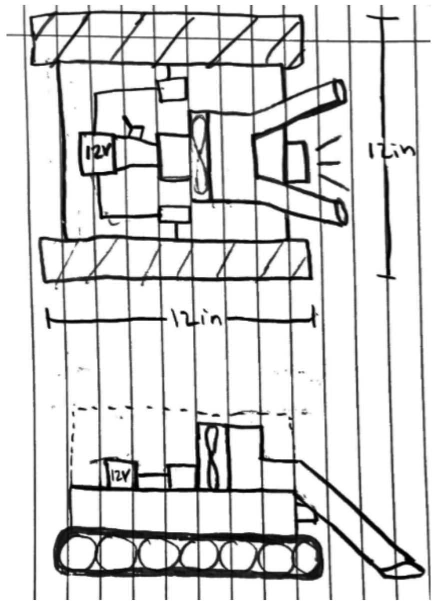
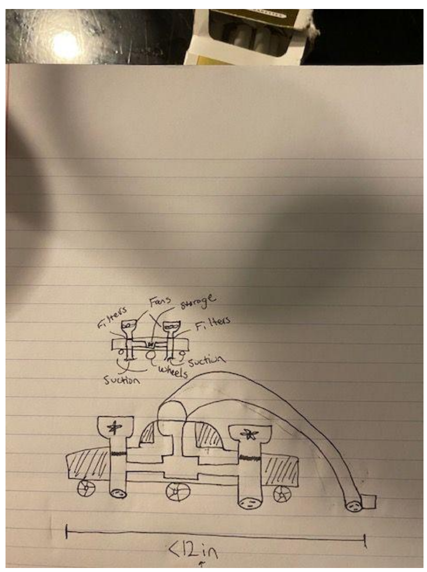


Figure 8: Concept Generation Mind Map

Table 1: Concept Drawings and Descriptions

Concept Number	Drawing	Description
1		- The first concept devised was a square-based vacuum with tank-like tires. The vacuum components of this design consist of a motor and fan, powered by a battery circuit with a switch so users can manually turn it on and off. The fan is then connected to a 3D-printed part that includes a storage bin for debris and a split hose design that protrudes from the front of the vacuum. A sensor is placed between the two hoses in order for it to be able to detect any walls or other devices so it can change its path. The wheels for the base are also powered by batteries and separate motors.
2		- The second concept is also a sort of square-based vacuum but instead of tank-like tires, it had regular large tires as would be on a car. The vacuum components of this design consist of three motors and three fans, powered by high voltage batteries. All of which would be connected to PVC piping and a 3D printed component. There is a storage bin for the debris connected near each motor and fan with a filter and a split section for debris to fall into the bin. There is a sensor on the PVC pipe that is on the front in order to detect any walls or obstacles. Every wheel would be controlled by its own separate motor and batteries in order to maximize the steering range.

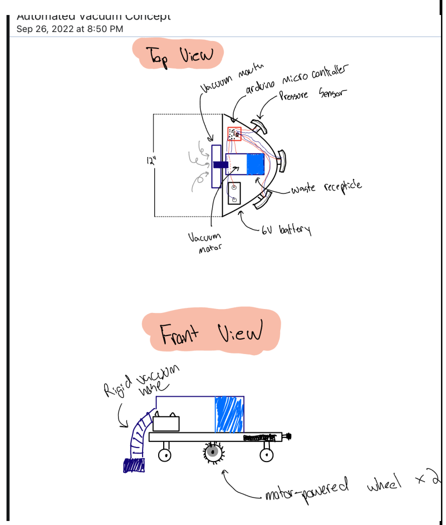
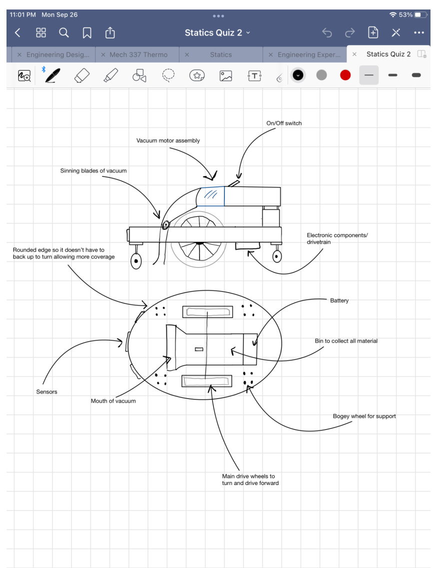
3		This concept operates off of a half-circle base. It would be powered by a 6V battery. An Arduino microcontroller will be used to receive data from three front-mounted pressure sensors, as well as control an electric motor for the drive train. Two centered wheels would receive power so that the vacuum can rotate in place, and 4 more dolly wheels will support the base. A vacuum will be mounted on the top center of the base. The receptacle will be in the front of the machine, and the hose/opening will be in the back.
4		With two main driving wheels, this concept is driven and turns from the force generated through a small motor that is transferred into these main wheels. This concept includes small bogey wheels for added stability. The collection bin sits atop the battery for space conservation. A cut-out in the middle of the base gives the mouth of the vacuum a route to the floor for collection purposes. The main vacuum sits in the middle of the base for stability and to centralize a majority of the weight. The oval shape allows for an easier transition around corners and obstacles.

Table 2: Concept Evaluation against Competitors and Device Specifications

Concept Requirements Analysis (0 = Worst, 5 = Best), (X = target hit, O = target missed)

	Customer Requirements										Technical Requirements																	
Concept Number	Debris of varying sizes	Autonomous	Sense debris and room boundaries	Replacable debris compartment	Long battery life	Run on multiple surfaces	Reasonable price	Appealing design	Safe for children	Manual Start	Length (12 in)	Width (12 in)	Manual start	Battery	Self contained unit	No human input after start	Programmed sensors	Clearance under wheels	Detachable debris container	Weight (10-12 lbs)	Speed (2-5 mph)	Battery life (2 min)	Contact point with floor	Must not damage boundary or other devices	Small or no adjustments after start	**Customer Req Total**	**Total X**	**Total O**
1	4	3	5	2	3	4	2	2	2	5	X	X	X	X	X	X	X	X	O	X	X	X	X	X	X	32	14	1
2	5	4	5	3	5	2	3	3	3	1	X	X	O	X	X	O	X	X	X	X	X	X	X	X	X	34	13	2
3	3	5	5	5	2	3	4	4	3	3	X	X	O	X	X	X	X	X	X	X	X	X	X	X	X	37	14	1
4	3	2	5	4	3	4	3	5	4	5	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	38	15	0
Roomba	0	3	4	4	4	3	2	5	4	2																31		
Dyson	3	2	3	3	3	2	1	2	4	4																27		
Bissell	1	1	2	2	4	1	2	5	3	4																25		
Shark	2	4	4	4	4	4	3	4	4	3																36		
Sanitaire	5	0	0	4	0	0	3	3	3	5																23		

Device Description

Product Decomposition & Reverse Engineering

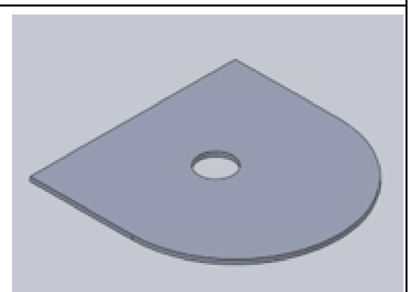
Design Organization: Colorado State University | **Date: 12/09/2022**

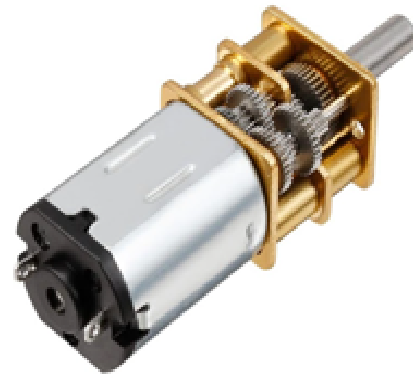
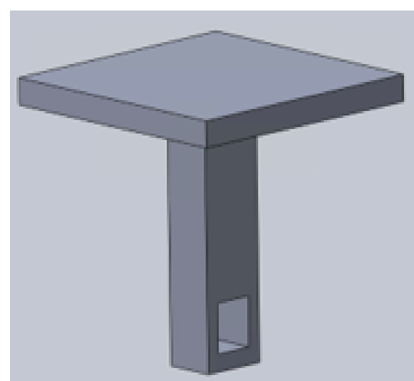
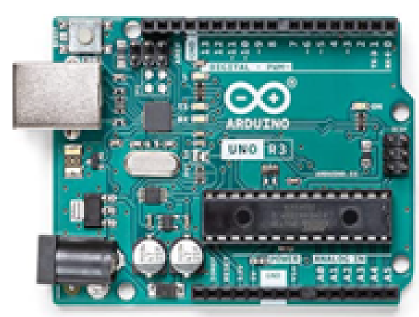
Product Decomposed: Automated Vacuum

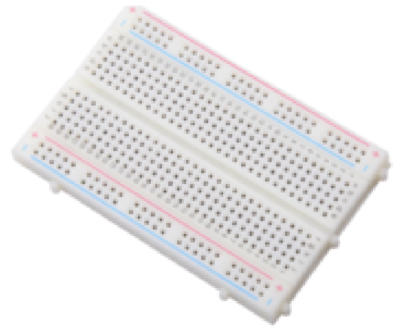
Description: Our device is an autonomous robotic vacuum cleaner which contains a suction system to remove dirt and debris from the floor combined with sensors and a programmed cleaning route.

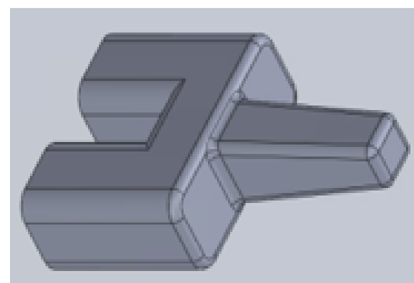
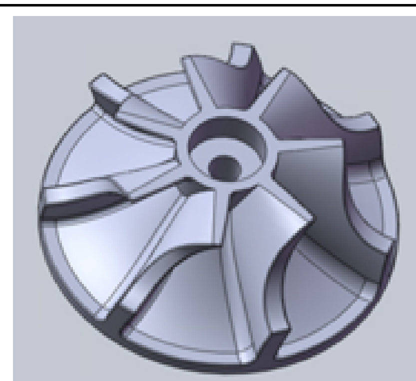
How it Works: This vacuum consists of two main components. The first is the vacuum component which works on account of the suction produced from a fan and motor. The motor is connected to a rechargeable lithium-ion battery which supplies it enough power to rotate at a high RPM. The circuit that connects the battery and motor contains a switch, that opens and closes the path, to allow the user easier access to turning on and off the device. The motor is then connected to a fan which spins in the correct direction to create air flow up through the device generating the desired suction. The fan is attached to a filter, which prevents larger debris from damaging the fan, and a hose/debris container that redirects the suction to the floor. The second component is the base. The base is constructed out of wood so that all the other desired parts can be easily attached. There are four caster wheels which balance and stabilize the base, and two driver wheels. The driver wheels are each connected to a motor, fastened on the bottom of the base, that is wired to a battery. The Arduino at the center of the base is connected to both batteries and three sensors. The sensors are placed at the front of the base and programmed to detect when the device is a certain distance away from a wall. The Arduino is programmed so that when no wall is detected, both batteries are supplied power to make the device go straight. When a wall is detected the Arduino only sends power to the corresponding battery to activate one wheel which allows the device to turn and avoid collision.

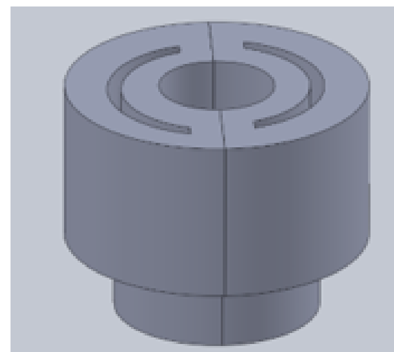
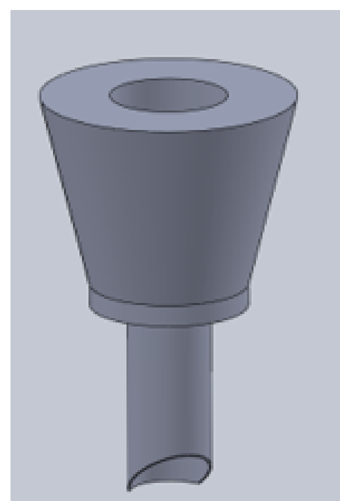
Bill of Materials:

Item #	Mfg. Part #	Part Name	Qty	Material	Mfg. Process	Procurement Source	Image
1	-	Base	1	Wood	Machining	Home Depot	
2	-	Caster Wheels	2	Plastic/Metal	Premade	ACE Hardware	

3	a16010600ux0130	Wheel Motors	2	Metal	Premade	Amazon	
4	B09KDC79D	Wheels	2	Rubber	Injection Molding	Amazon	
5	-	Wheels Support	2	PLA	3D Printing	I2P	
6	A000066	Arduino	1	Metal	Premade	CSU	

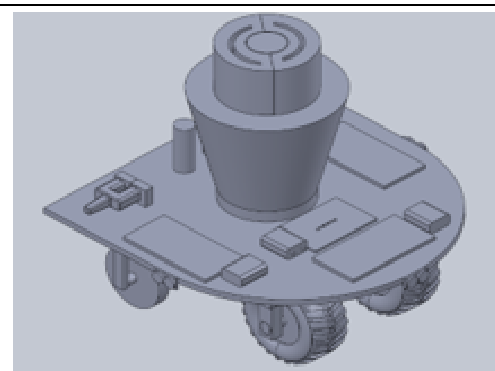
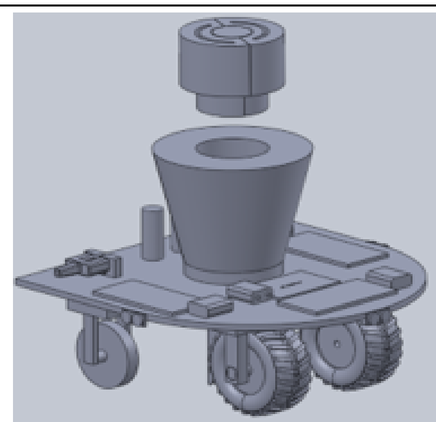
7	2234-HC-SR04-ND	Sensors	3	Metal	Premade	CSU	
8	-	Breadboard	3	Plastic	Premade	CSU	
9	-	9V Batteries	4	Metal	Premade	Walmart	
10	JK908800013117	Fan Batteries	2	Metal	Premade	Walmart	

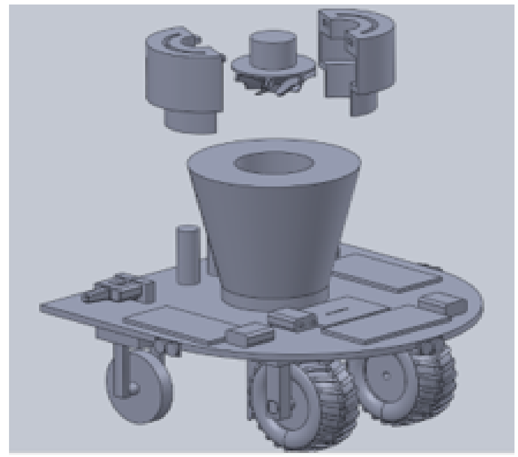
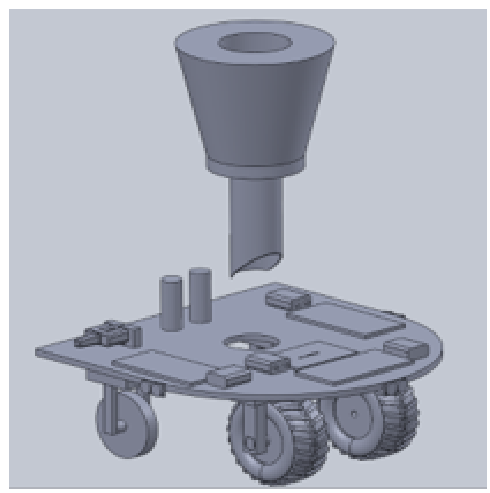
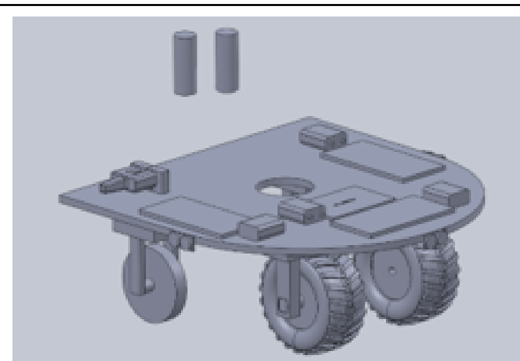
11	-	Circuit Switch	2	Metal	Premade	ACE Hardware	
12	-	Switch Connector	1	PLA	3D Printing	I2P	
13	CHV1410	Vacuum Motor	1	Metal	Premade	Walmart	
14	-	Vacuum Fan	1	PLA	3D Printing	I2P	

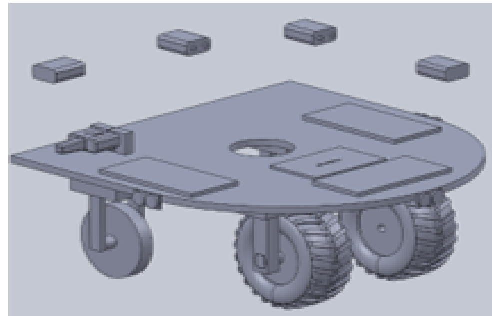
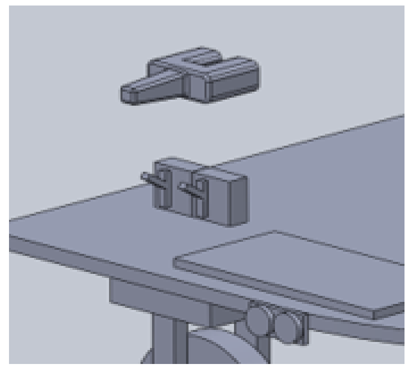
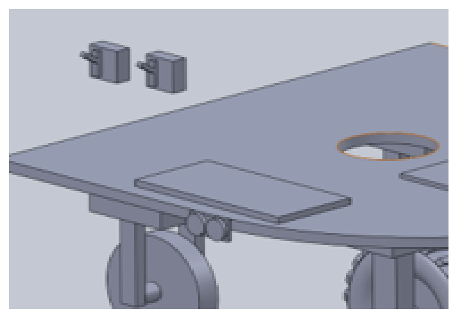
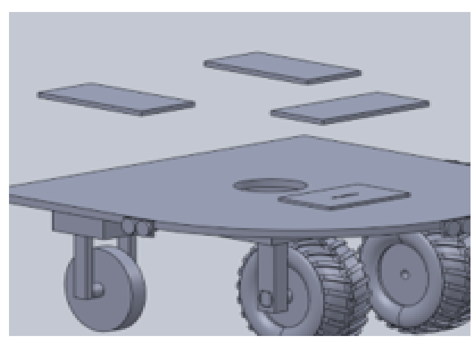
15	-	Fan Filter	1	Cloth	Premade	Walmart	
16	-	Fan/ Motor Holder	1	PLA	3D Printing	I2P	
17	-	Debris Container	1	PLA	3D Printing	I2P	

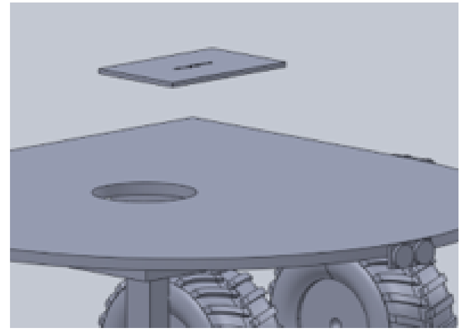
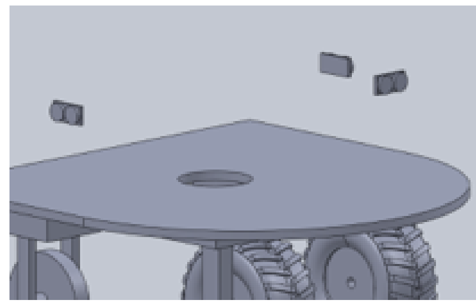
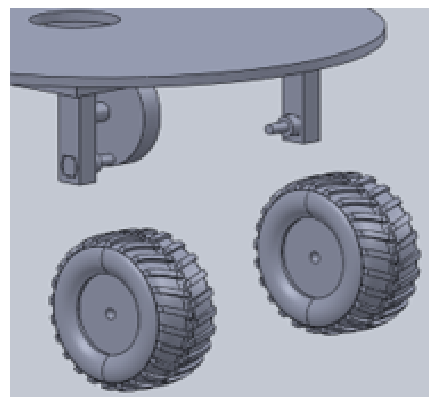
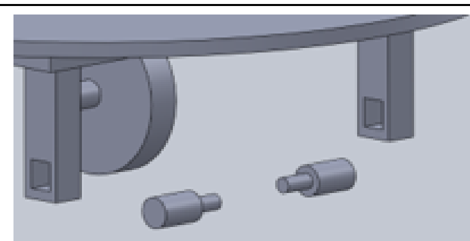
18	-	Wiring	N/A	Wire	Premade	CSU	
19	-	Screws	16	Metal	Premade	ACE Hardware	

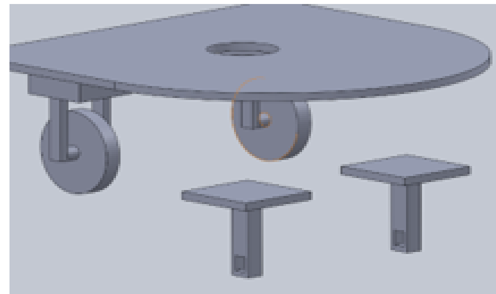
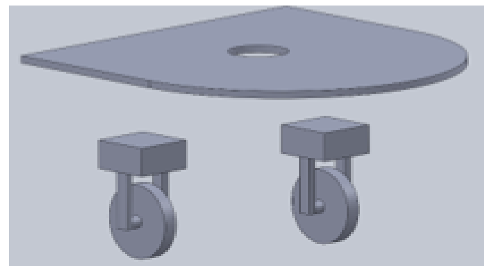
Disassembly:

Step #	Procedure	Item # Removed	Image
1	-Remove all wiring from device	18	
2	-Detach vacuum fan/motor holder from debris container	16	

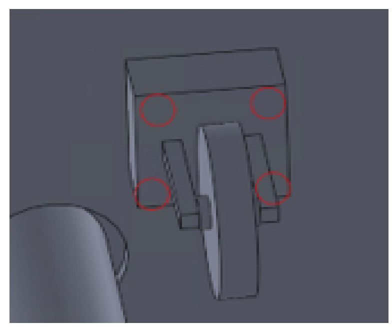
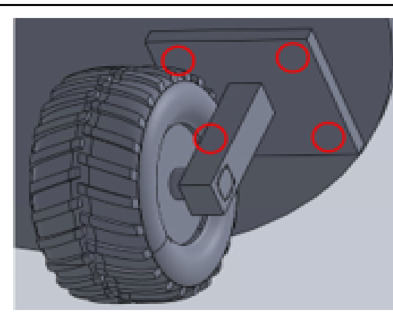
3	-Remove vacuum fan/motor from fan holder	13/14	
4	-Unfasten hose/debris container from base	17	
5	-Separate motor batteries from base	2	

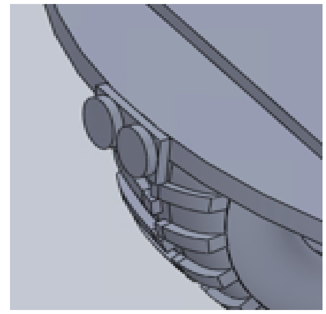
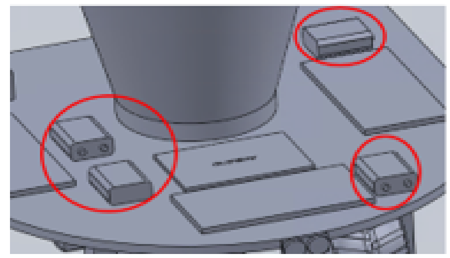
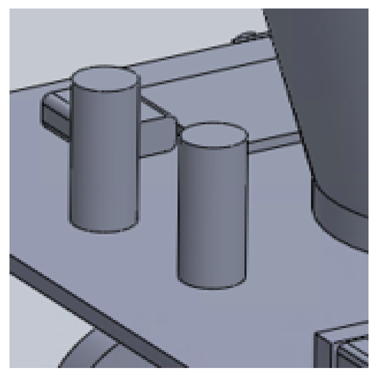
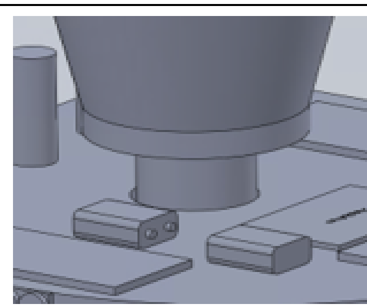
6	-Detach 9V batteries from base	9	
7	-Separate switch connector from switches	12	
8	-Remove switches from base	11	
9	-Pull off breadboards from base	8	

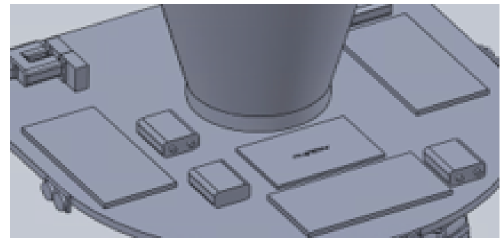
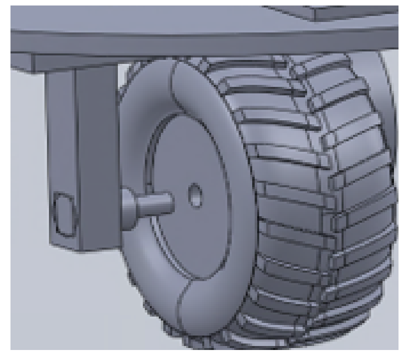
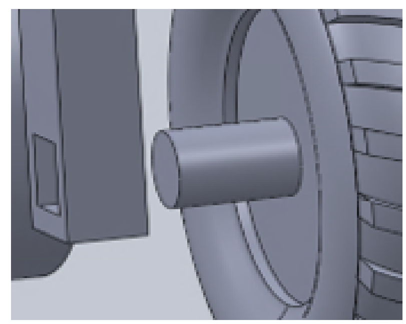
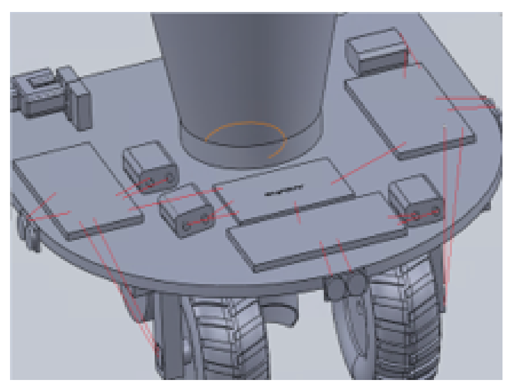
10	-Pull Arduino off of base	6	
11	-Unvelcro sensors from base	7	
12	-Remove wheels from motors	4	
13	-Unfasten motors from wheel supports	3	

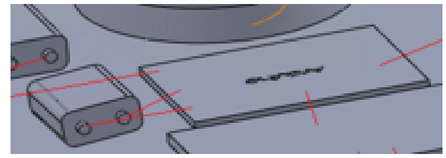
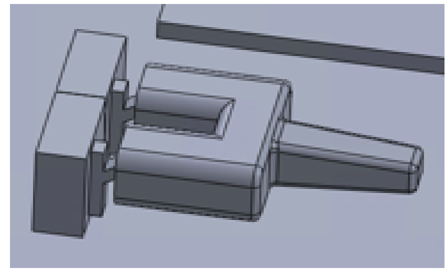
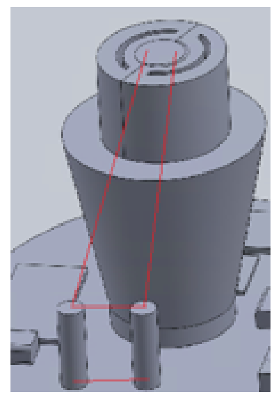
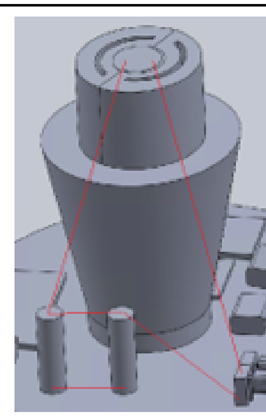
14	-Unscrew wheels supports from base	5	
15	-Unscrew caster wheels from base	2	

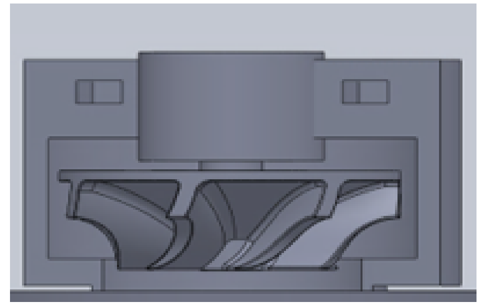
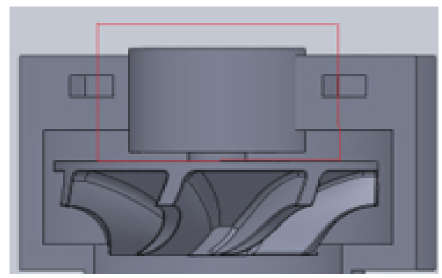
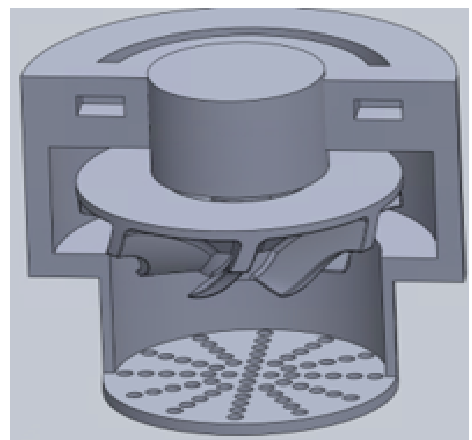
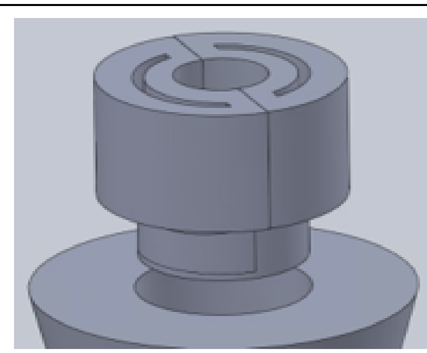
Interfaces with Other Objects (Flows of Energy, Information, and/or Materials):

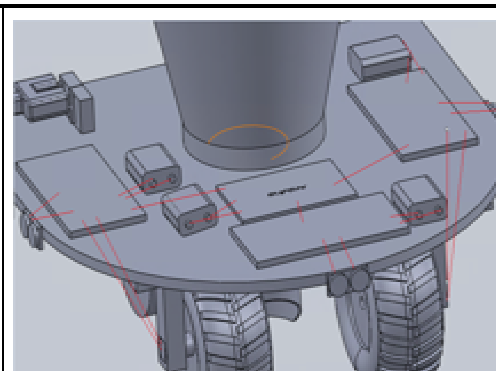
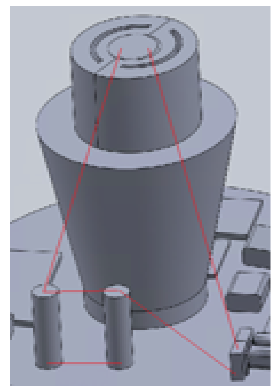
Item #	Interface Item #	Energy Flow	Information Flow	Material Flow	Image
1	2	-	-	-The caster wheels are in direct contact with the base and held in place with screws	
1	5	-	-	-The wheel supports were screwed into the base and held the wheel motors at the correct distance from the ground	

1	7	-	-	-The sensors were secured onto the base with Velcro	
1	9	-	-	-The 9V batteries were just placed directly onto the base	
1	10	-	-	-The fan batteries were taped to the base to ensure that they don't move during operation	
1	17	-	-	-The debris container fit directly into the hole cut in the base	

1	6,8	-	-	-The Arduino and breadboards were all secured onto the base with Velcro	
3	4	-The rotational energy from the axel of the motor was transferred to the wheels which allowed them to rotate	-	-The wheels were super glued to the axes of the motor	
5	3	-	-	-The wheel motors were pressure fitted into the hole in the wheel supports	
6	7,8,3	-	-The sensors would send the information it received from its surroundings to its breadboard which would then send it to the Arduino. The Arduino would then tell the correct breadboard to supply its motor with power	-The Arduino, sensors and breadboards were connected with wires	

6	9	-The Arduino was individually powered with a 9V battery	-	-The 9V and Arduino were connected with wires	
12	11	-As the switch connector was activated, both switches would be able to close their corresponding circuits	-	-The switches and connector were super glued together	
13	10	-The power from the batteries would supply the motor with the correct voltage to allow it the start spinning	-	-The motor and batteries were connected with wires	
13	11	-As the switch was activated, the circuit would close, allowing the power to be supplied to the motor	-	The switch and motor were connected with wires	

13	14	-The rotational energy from the axel of the motor was transferred to the fan, allowing it to spin and create suction		-The fan and motor were secured together with hot glue	
16	13	-	-	-The motor was held in place by being super glued to the fan holder	
16	15	-	-	-The fan filter was taped onto the bottom of the fan holder to stop the bigger debris from damaging the inner components of the vacuum	
16	17	-	-	-The debris container was pressure fitted to the fan holder to allow it to be removed during competition	

18	6,9,8,11,3,7	-The wires connecting all the drive train components allowed power from the batteries to move to and activate all the components	-The wires allowed all the information received from the sensors received to sent back and forth between the Arduino and the motors	-The wires were all secured in place with solder	
18	10,13,11	-The wires connecting all the vacuum components allowed power from the batteries to move to and activate all the components	-	-The wires were all secured in place with solder	

Team member: Anna Buckley	Team member: Alaina Bentely
Team member: Daniel Pelphrey	Prepared by:
Team member: Ryan Blake	Checked by:
Team member: Mason Adams	Approved by:

Annotated Exploded View of Device

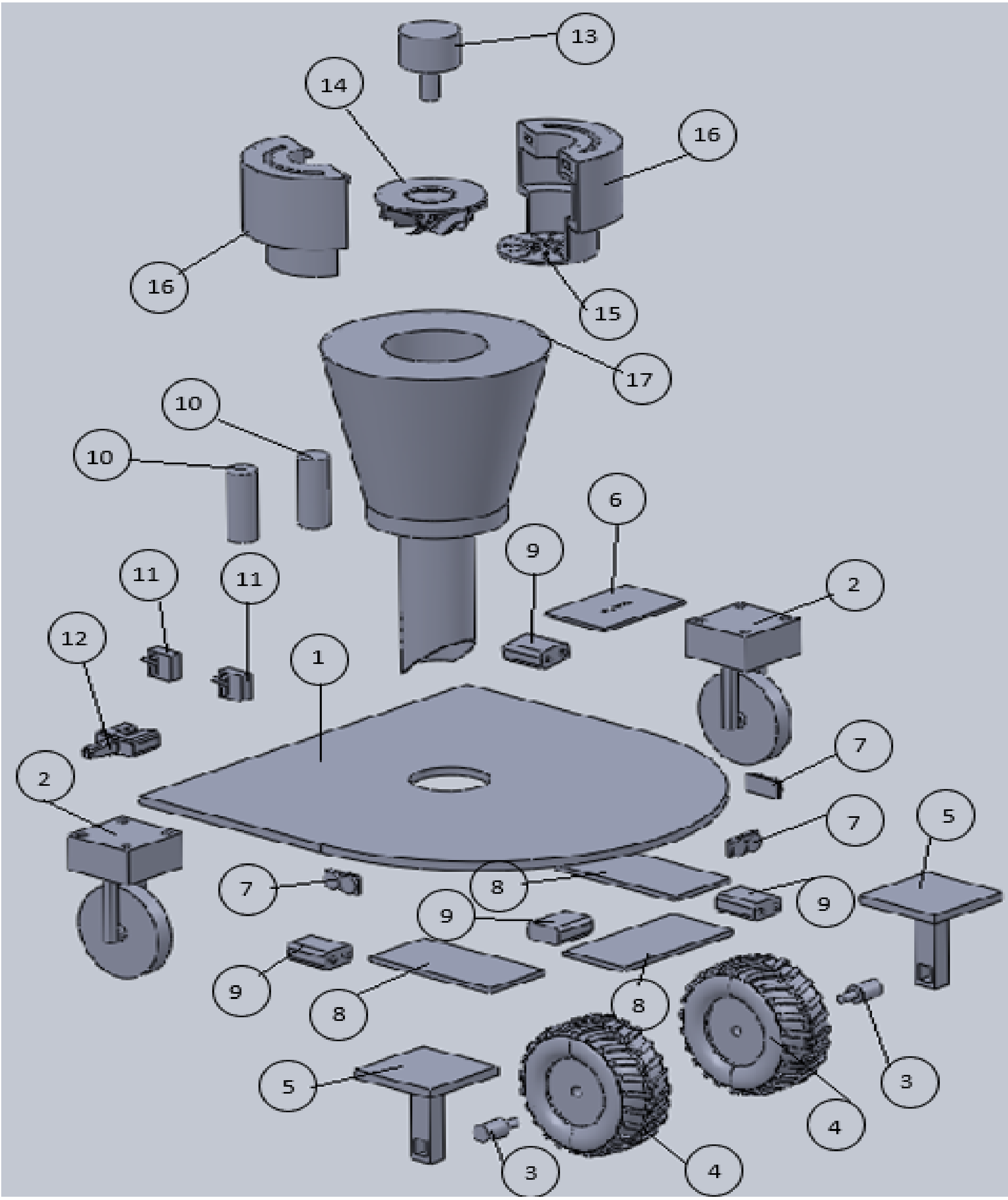


Figure 9: Annotated Exploded View

Design Structure Matrix																	
Tasks	#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Vacuum Up Debris of Varying Size	1	1															
Autonomous	2		2														
Sense the Debris and Room Boundaries	3	X		3													
Store the Debris in Replicable Compartment	4	X		X	4												
Long Battery Life	5				X	5											
Run on Multiple Sources	6		X			X	6										
Reasonable Price	7				X	X		7									
Appealing Design	8								8								
Safe for Children	9		X						X	9							
Manual Start	10		X				X			X	10						
Sense Boundaries and Other Devices	11	X	X									11					
Removable Storage	12				X								12				
Turn in Any Direction	13		X				X	X			X	X		13			
Strong Enough Suction	14	X			X				X						14		
Large Enough Storage Compartment	15	X			X								X			15	
Stay within 12"x12" Size Requirement	16				X		X	X	X							X	16

Figure 10: Design Structure Matrix

Movement

The automated vacuum will be supported by a total of four wheels. There will be two castor wheels that are strictly for support and will be located towards the edges of the vacuum. Along with the castor wheels, will be two power driven wheels near the center of the base that move the device. Both wheels will be fixed in position and face directly towards the arc on the front of the device. They each are powered by a 6V DC motor that will be receiving power from a 6V battery. The motors are designed to be at a slow speed (around 1-2 MPH) depending on the amount of final torque the device generates. An arduino will be installed so that a programing can be uploaded to allow the device to turn when it senses an obstacle, the device will turn by supplying power to only one wheel in order to rotate in place much like a zero-turn lawn mower does.

Navigation

A front mounted ultrasonic sensor will also be wired to the arduino. Code will be written so that when the sensor reads that it is in contact with an obstacle. The device will turn a varying amount of degrees before resuming forward motion. The amount by which the device will rotate will be different each time it reaches an obstacle to prevent the device following the same pattern and not collecting any new debris.

Debris Collection

An electric DC motor powered fan vacuum will be fixed centered on top of the base with the mouth of the intake facing towards the front of the device. Attached to the fan portion will be the debris compartment, which will have the ability to be removed from the fan portion. The vacuum hose will be attached to the debris collector. This hose will then allow the air, as well as the debris to be pulled into the debris compartment and be collected for disposal. There is a filter attached to the fan compartment that will keep the debris out of the fan and push it back into the debris compartment if necessary. It is all powered by one battery attached to the fan motor.

Critical Elements

A wood base/frame will provide the support to which both the vacuum and drive components will be fixed. This should provide adequate strength to survive a low velocity impact with a wall or another robot, as well as allow mechanical components to be securely drilled into and fixed together. A laptop computer will also be necessary to write and upload the code to the arduino for navigation. This will not be actively used during the competition.

Clever Ideas

An idea that was implemented from the very beginning of the design process was designing each component (vacuum/base) separately so every component wouldn't have to be powered and wired to the same power source. Instead each component was created separately with switches that opened and closed their respective electrical circuits individually. Then a component was 3D printed to turn both switches at once so each component was turned on at the same time.

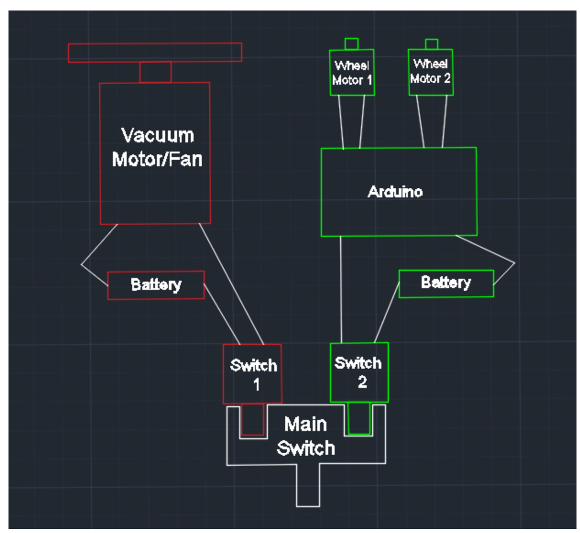


Figure 11: Electrical Circuits for Each Component

Total Device Production Cost

Design Competition Team 9: Total Cost		
Vacuum		
Motor/Batteries	$18.99	
Motor Casing	Free	
Debris Container (Prototypes + Final)	Free	
Switch	$3.99	
Base		
Wood	$27.99	
2X Motor	$11.49	
Wheels	$12.99	
Wheel Supports	Free	
Castor Wheels	$5.59	
Arduino	Free	
3X Breadboards	Free	
Switch	$3.99	
3X Sensors	Free	
4X 9V Batteries	$11.99	
Wiring	Free	
Total Cost	**$97.02**	

Figure 12: Competition Ready Device Total Cost

This cost breakdown includes all the parts used to fabricate the competition ready device, Most of the cost comes from a few key portions. This includes the motor for the vacuum, the wood used for the base, and the myriad of batteries. These were the parts that were impossible to make from scratch without sacrificing the reliability of the device. The parts that were "free" were mostly parts that were 3D modeled in SolidWorks, and then printed in the CSU Idea2Product lab. The other "free" parts were given to groups before the project started, including the wiring and arduino. Because these parts were free to the students, it was favored over purchasing parts that were premade due to the cost restriction.

After compiling the prices for all the products used during the semester, including the parts that were produced and did not make it into the final device, it was determined that the total cost of manufacturing this device was $97.02.

Engineering Analysis

In the process of designing this machine, many engineering concepts and processes have been applied. Technical skills developed in MECH201(Engineering Design 1) allowed for the creation of SolidWorks models for the prototype. Dynamics concepts were used to calculate the gearing for the motors in order to have the device move at the proper velocity and in the right direction.

$$\text{Gear Ratio} = \frac{\omega_1}{\omega_2} = \frac{n_1}{n_2} = \frac{\text{Input gear speed}}{\text{Output gear speed}}$$

Figure 13: Equation for Gearing Down Motors

Statics concepts were applied in order to maintain the structural integrity of the device. The methods practiced in introduction to mechanical engineering were used to design the arduino control system plan to control the machine.

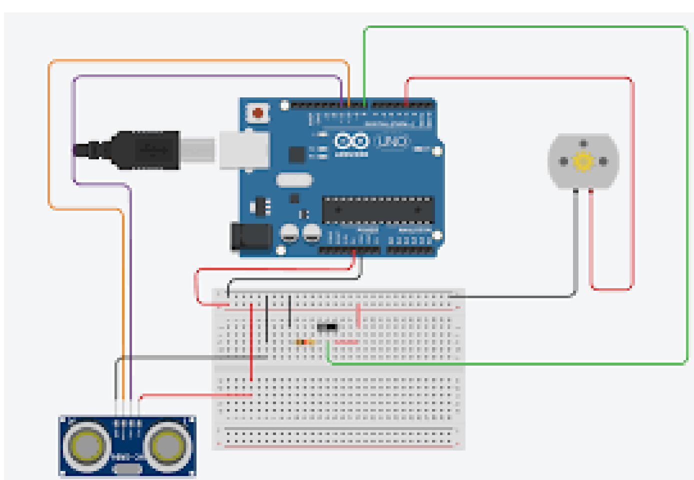


Figure 14: Sample Circuit for Arduino with Sensor and Motor

Several human resources have been utilized to gain insight on some of the best approaches to the design. This class has provided many guidelines and templates for useful design creation tools like the Design Structure Matrix and idea generation strategies. The group reached out to a remote control car shop owner who works with small electric motors professionally.

When coming up with the design for the mouth of the vacuum assembly, the group started out with a rectangle angled at 45° in relation to the ground. When going through initial testing it was found that the geometry of the prototype prevented substantial airflow to create the desired suction to get the sand and other debris to enter into the vacuum assembly. Additionally, it was determined using knowledge of thermodynamics that more effective suction could be achieved by reducing the area of the mouth's opening. The design was later changed to a smaller, circular opening that is positioned perpendicular to the ground. This allowed for the device to have much more effective suction when testing and competing, and resulted in a pair of victories in the tournament.

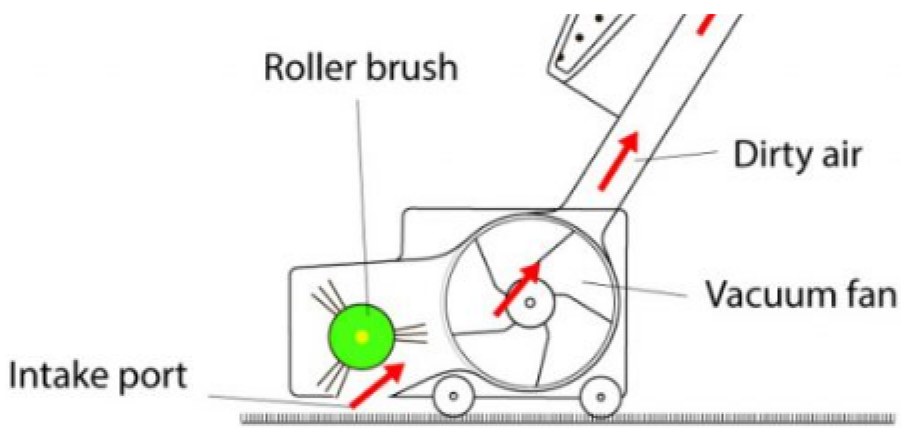


Figure 15: Direction of Airflow to Create Powerful Suction

Test Report

Design Organization: CSU DC Team 9	Date: 10/23/2022

Device or system tested: Automated Vacuum

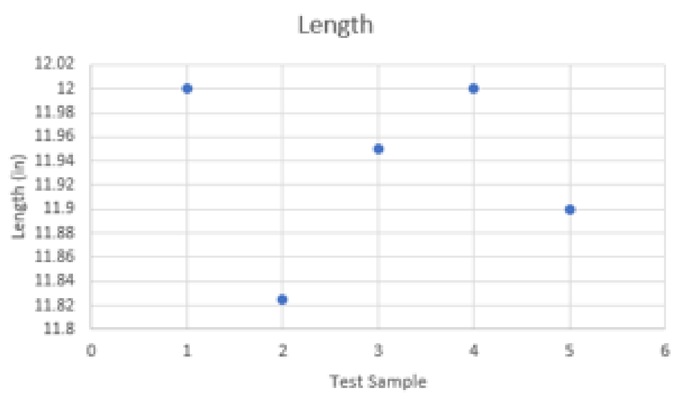
Objective of experiment (Engineering Specifications to be verified):
Length

Methods and Materials (or Equipment): Tape Measure

Experimental Procedure:

1.) Ensure device is stationary
2.) Use tape measure to measure length of device
3.) Record and plot data
4.) Repeat test 5 times

Results:



Discussion: To ensure that our device met the required specification of being under 12" in length, the experimental procedure was developed and performed. We each took turns measuring the length and recorded our findings.

Analysis: Based on the data above, even with the variety of test results, that stemmed from each testers method and reading of the tape measure, it can be ensured that the device is under 12" in length.

Interpretation: By ensuring that our devices length is under 12" we can be certain that it abides by the competition rules.

Test Report

Design Organization: CSU DC Team 9	Date: 10/23/2022

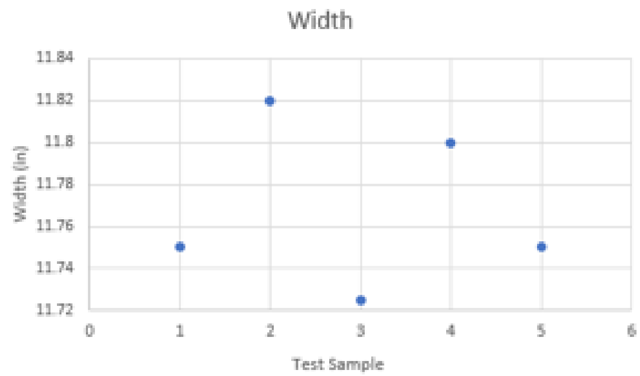
Device or system tested: Automated Vacuum

Objective of experiment (Engineering Specifications to be verified):
Width

Methods and Materials (or Equipment): Tape Measure

Experimental Procedure:
1.) Ensure device is stationary
2.) Use tape measure to measure width of device
3.) Record and plot data
4.) Repeat test 5 times

Results:



Discussion: To ensure that our device met the required specification of being under 12" in width, the experimental procedure was developed and performed. We each took turns measuring the width and recorded our findings.

Analysis: By analyzing the data above, even with the variety of test results, that stemmed from each testers method and reading of the tape measure, it can be ensured that the device is under 12" in width.

Interpretation: By ensuring that our devices length is under 12" we can be certain that it abides by the competition rules.

Test Report

Design Organization: CSU DC Team 9	Date: 10/23/2022

Device or system tested: Automated Vacuum

Objective of experiment (Engineering Specifications to be verified):
Manual Start via Switch

Methods and Materials (or Equipment): N/A

Experimental Procedure:

1.) Activate switches on device to ensure each component receives power
2.) Record and plot data
3.) Repeat test 5 times

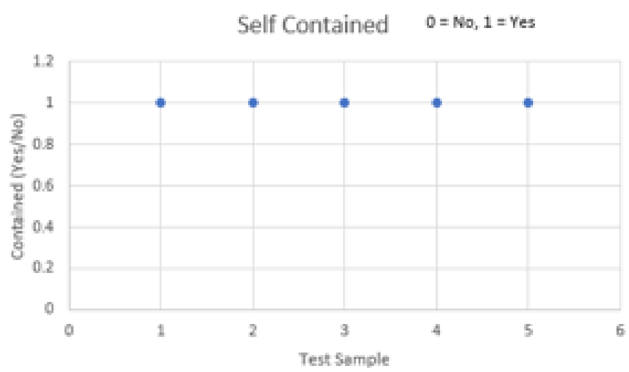
Results:

Discussion: To ensure that the device met the developed specification of having a manual switch to activate, the experimental procedure above was developed and performed. There are two components on our device that each require a switch to be activated. This test was to guarantee that each component has a working switch.

Analysis: Based on the results from the tests, we can be certain that each component has a working switch that can be activated to turn the device on and off.

Interpretation: After further research into the rules of the competition, we now know that all the components of the vacuum need to be turned on with one switch. This can be remedied by created a 3D printed device that goes over both switches to they can both be turned on at the same time.

Test Report

Design Organization: CSU DC Team 9	**Date: 10/23/2022**
Device or system tested: Automated Vacuum	
Objective of experiment (Engineering Specifications to be verified): Completely Self Contained	
Methods and Materials (or Equipment): N/A	
Experimental Procedure: 1.) Observe device to ensure all components are secured together 2.) Record data 3.) Repeat test 5 times	
Results: 	
Discussion: To ensure that our device met the required specification of being a completely self-contained unit, the experimental procedure was developed and performed. We each took turns examining the device and recorded our findings.	
Analysis: Based on the results from the tests, the team concluded that we can be certain that our device remains a completely self-contained unit during the race, meaning no tethers, loss of material, nor physical separation of components during operation.	Interpretation: By ensuring that our device remains a completely self-contained device, we can be certain that we are abiding by the competition rules.

Test Report

Design Organization: CSU DC Team 9	Date: 10/23/2022

Device or system tested: Automated Vacuum

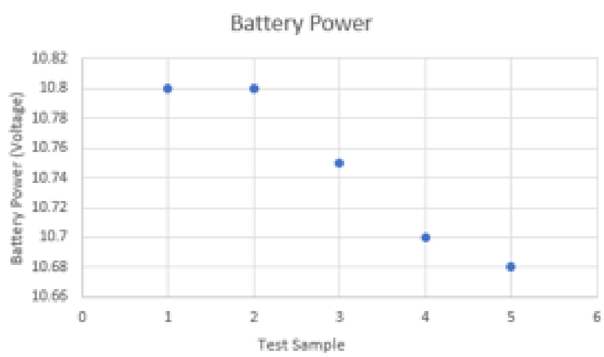
Objective of experiment (Engineering Specifications to be verified):
Battery Power

Methods and Materials (or Equipment): Multimeter

Experimental Procedure:

1.) Separate battery pack from device
2.) Connect corresponding nodes of multimeter to the correct terminals
3.) Record and plot voltage
4.) Repeat test 5 times

Results:



Discussion: To ensure that our device meets the developed technical specification of being operated with a battery that supplies 12-15 volts, the experimental procedure was developed and performed.

Analysis: Based on the findings from the tests, we concluded that the power supplied from the batteries was significantly lower than expected. We also found that as the device was used, the battery power decreased significantly with each usage.

Interpretation: Although the power from the batteries was lower than anticipated, the motor still operates at a high enough RPM to create the desired suction. The team also realized that we needed to develop a way to recharge the batteries, so the suction remains strong enough after each time we run the device.

Test Report

Design Organization: CSU DC Team 9	**Date: 10/23/2022**

Device or system tested: Automated Vacuum

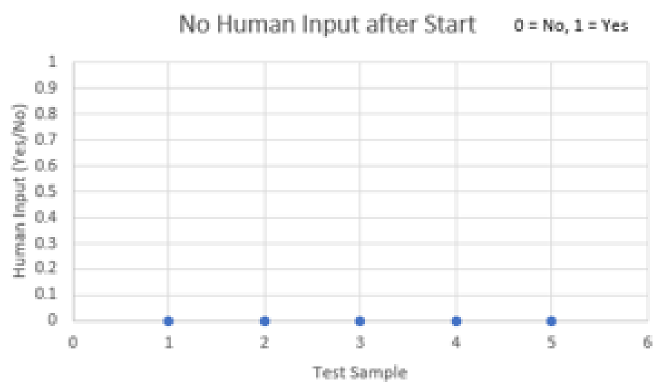
Objective of experiment (Engineering Specifications to be verified):
No human input after start

Methods and Materials (or Equipment):

Experimental Procedure:

1.) Activate device to observe and record if it can operate correctly without human input
2.) Record data
3.) Repeat test 5 times

Results:



Discussion: To ensure that our device maintains the required specification of not needing any human input after starting to operate correctly, the experimental procedure was developed and performed. We each took turns examining the device and recorded our findings.

Analysis: By analyzing the findings from the experiments, the team concluded that the device does not require any human input after start to operate correctly.

Interpretation: With the information we gathered form this experiment we can now be certain that our device abides by the competition rules and does not need any human interaction after starting.

Test Report

Design Organization: CSU DC Team 9	Date: 10/23/2022

Device or system tested: Automated Vacuum

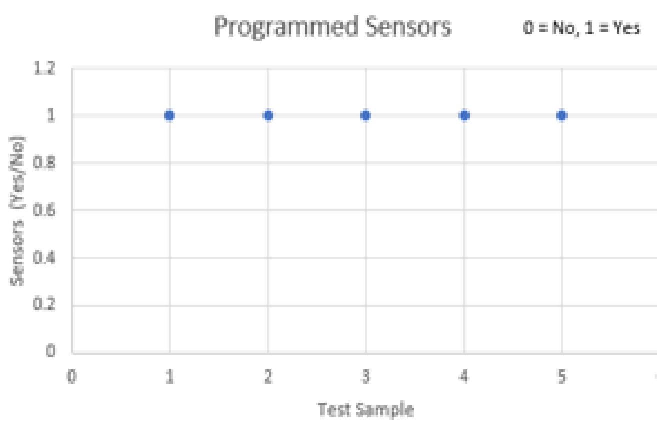
Objective of experiment (Engineering Specifications to be verified):
Programmed Sensors

Methods and Materials (or Equipment): N/A

Experimental Procedure:

1.) Activate device to observe if programmed sensors work as specified
2.) Check if both motors run with no boundary
3.) Check if correct wheel is turned off to allow device to turn in the right direction when presented with an obstacle
4.) Record data
5.) Repeat test 5 times

Results:



Discussion: To ensure that our device meets the developed specification of having programmed sensors at the front of the device to detect any boundaries, the experimental procedure was developed and performed. We presented the sensors with a variety of boundaries in different locations to determine if they could send the right information to the Arduino to activate to correct motor.

Analysis: Based on the results of the experiment, we concluded that the written program and wiring for the sensors ensure that the device will not run into any boundaries and turn in the correct direction when sensed.

Interpretation: With the information gathered during this experiment we can now be certain that our devices sensors operate correctly and will allow the device to run smoothly without running into any boundaries or other devices.

Test Report

Design Organization: CSU DC Team 9	Date: 10/23/2022

Device or system tested: Automated Vacuum

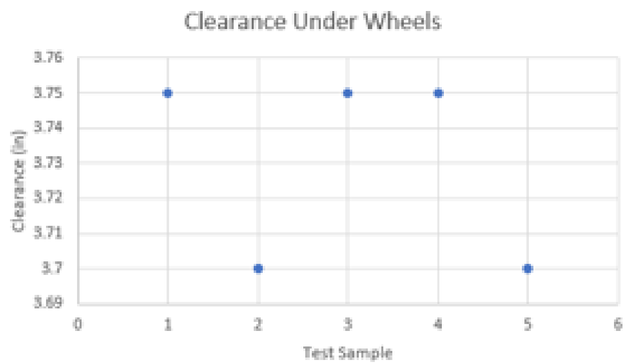
Objective of experiment (Engineering Specifications to be verified):
Clearance under wheels

Methods and Materials (or Equipment): Tape Measure

Experimental Procedure:

1.) Ensure device is stationary
2.) Use tape measure to measure length of space under the base
3.) Record and plot data
4.) Repeat test 5 times

Results:



Discussion: To ensure that our device meets the developed specification of having 1.5-2.0" of clearance under the wheels, the experimental procedure was developed and performed. We each took turns measuring the length and recorded our findings

Analysis: Based on the data we recorded during the experiment, even with the variety of test results, that stemmed from each testers method and reading of the tape measure, we found that the clearance under the wheels was a lot bigger than we had originally planned for.

Interpretation: With this information our team decided to make adjustments to the rest of the components that were supposed to fit under the device accordingly. The vacuum hose length was increased to allow it to reach the floor from this new height.

Test Report

Design Organization: CSU DC Team 9	**Date:10/30/22**

Device or system tested: Automated Vacuum

Objective of experiment (Engineering Specifications to be verified):
Detachable debris container
Determine if the debris container can detach from device while still holding all debris safely and securely.

Methods and Materials (or Equipment): Scale

Experimental Procedure:

1) Ensure device is held stationary
2) Press ON switch and let device suck up some test debris.
3) Turn device OFF and remove debris container.
4) Watch and determine if any debris is lost in the process.
5) If debris is lost, weigh the debris
6) Adjust part if needed
7) Repeat steps 5 times and record data

Results:

#1 Debris lost = 0.23g	#4 No debris lost
#2 Debris lost = 0.10g	#5 No debris lost
#3 Debris lost = 0.11g	

Discussion: Part was modified by using different rubber suction bands in order to secure the container.

Analysis:	Interpretation:
After a few different tests, we decided the best rubber suction pieces were shaped a little larger than the radius. This gave us the ability to have a more secure and enclosed debris container so the debris would not fall out when being transported from points A to B.	We want the rubber suction piece to be as large as possible in order to seal the container and keep the debris inside.

Test Report

Design Organization: CSU DC Team 9	**Date:10/30/22**

Device or system tested: Automated Vacuum

Objective of experiment (Engineering Specifications to be verified):
Weight
Device needs to be within 10-12lbs before and after completed competition

Methods and Materials (or Equipment): Scale

Experimental Procedure:

1) Assemble the completed device with all parts
2) Run the device through a 2 minute test run
3) Weigh the device after the test has been completed
4) Repeat 5 times and record the data

Results:

#1 10.1 lbs
#2 10.27 lbs
#3 10.21 lbs
#4 10.12 lbs
#5 10.3 lbs

Discussion: Only adjustments made during testing was the amount of debris on the ground

Analysis:
After testing, we can acknowledge that the actual weight of the device is around 10 lbs exactly. Our goals are met for this experiment

Interpretation:
The final weight will depend on how much debris it will pick up after the completion of its tests.

Test Report

Design Organization: CSU DC Team 9 | **Date:10/30/22**

Device or system tested: Automated Vacuum

Objective of experiment (Engineering Specifications to be verified):
Speed
Overall speed to be around 2-5 mph

Methods and Materials (or Equipment):
Tape Measure
Stop Watch

Experimental Procedure:

1) Run the completed part along a pre measured distance
2) Use a stop watch to measure the amount of time it takes for the device to complete the distance
3) Repeat the procedure 5 times and record the data, use equations to compute the average velocity.

Results:

Distance(ft)	Total Time(s)	Velocity (ft/s)	Velocity (mph)
30	11	2.727272727	1.859509091
30	14	2.142857143	1.461042857
30	12	2.5	1.70455
30	9	3.333333333	2.272733333
30	8.2	3.658536585	2.494463415
	Average Velocity	**2.872399958**	**1.958459739**

Discussion: All velocities shown are average, and do not account for changes in speed during the test.

Analysis:
As you can see, our overall average velocity is under the minimum 2 mph that we had wanted. This is due to its weight and motor power. If we want the higher mph we would need a stronger motor.

Interpretation:
Since the device is slow, we could get a stronger motor that can handle more torque, or we could reduce the weight of our device.

Test Report

Design Organization: CSU DC Team 9 | **Date:10/30/22**

Device or system tested: Automated Vacuum

Objective of experiment (Engineering Specifications to be verified):
Speed
Overall speed to be around 2-5 mph

Methods and Materials (or Equipment):
Tape Measure
Stop Watch

Experimental Procedure:

1) Run the completed part along a pre measured distance
2) Use a stop watch to measure the amount of time it takes for the device to complete the distance
3) Repeat the procedure 5 times and record the data, use equations to compute the average velocity.

Results:

Distance(ft)	Total Time(s)	Velocity (ft/s)	Velocity (mph)
30	11	2.727272727	1.859509091
30	14	2.142857143	1.461042857
30	12	2.5	1.70455
30	9	3.333333333	2.272733333
30	8.2	3.658536585	2.494463415
	Average Velocity	**2.872399958**	**1.958459739**

Discussion: All velocities shown are average, and do not account for changes in speed during the test.

Analysis:
As you can see, our overall average velocity is under the minimum 2 mph that we had wanted. This is due to its weight and motor power. If we want the higher mph we would need a stronger motor.

Interpretation:
Since the device is slow, we could get a stronger motor that can handle more torque, or we could reduce the weight of our device.

Design Organization: CSU DC Team 9	Date:10/30/22

Device or system tested: Automated Vacuum

Objective of experiment (Engineering Specifications to be verified):
Battery Life
Maintain good speed for 2-4 minutes without recharge

Methods and Materials (or Equipment):
Stop Watch
Tape Measure

Experimental Procedure:
1) Run the completed device for one minute as it drives in a straight line.
2) Record its final distance
3) Repeat 5 times and record its final distance

Results:

Time (s)	Distance Traveled (ft)
60	184
60	165
60	172
60	159
60	142

Discussion: Straight line traveled with no debris. Battery was not charged in between tests.

Analysis:
Every distance is similar in range. The feet traveled in the first test was 184, and the final was 142. There was about a 42 feet difference after the 5 minutes of battery running which is exactly what we wanted.

Interpretation:
Will need to bring extra batteries to competition in order to keep speed up. We could also lower the weight of our device so the motors do not use as much battery power.

Test Report

Design Organization: CSU DC Team 9	Date:10/30/22

Device or system tested: Automated Vacuum

Objective of experiment (Engineering Specifications to be verified):
Always at least one contact point with floor

Methods and Materials (or Equipment): **N/A**

Experimental Procedure:

1) Drive the vehicle in its complete run with code.
2) Observe the device for 2 minutes.
3) Record if the vehicle stays in contact with the floor.
4) Repeat 5 times.

Results:
Each time the device stayed on the floor and did not lose contact.

Discussion: Not designed to leave the ground

Analysis:	Interpretation:
As you can see, the device meet our specifications and stayed in contact with the ground.	No further testing is necessary.

Test Report	
Design Organization: CSU DC Team 9	**Date:10/30/22**
Device or system tested: Automated Vacuum	
Objective of experiment (Engineering Specifications to be verified): Must not damage other devices or boundary	
Methods and Materials (or Equipment): **Obstacles**	
Experimental Procedure: 1) Run the device in a boundary area with random obstacles 2) Examine the obstacles and boundaries after 2 minutes. 3) Record any observations to differences in the obstacles and boundaries 4) Repeat 5 times.	
Results: #1 Small damage to boundary after device ran into and could not move anywhere else #2 No damage #3 No damage #4 No damage #5 No damage	
Discussion: The speed was slowed down after the first test.	
Analysis: After redesign was made, the device did not cause any damage to any of the obstacles or boundaries.	Interpretation: Due to decreased speed and power, the device did not have enough speed or force to damage the boundaries/obstacles.

Test Report

Design Organization: CSU DC Team 9 | **Date:10/30/22**

Device or system tested: Automated Vacuum

Objective of experiment (Engineering Specifications to be verified):
Barely adjusts after turned on

Methods and Materials (or Equipment):
Tape Measure

Experimental Procedure:

1) Measure device in length and width and height while device is powered off.
2) Record all measurements
3) Run the device for 1 minute.
4) Measure device again in all areas while still powered on.
5) Repeat 5 times and record.

Results:

Test	**Before Running**	Length	Width	Height	**After Running**	Length	Width	Height
1	[redacted]	12	12	4	[redacted]	12	12	4
2		12	12	4		12	12	4
3		11.5	12	9		11.5	12	9
4		11.5	12	9		11.5	12	9
5		11.5	12	9		11.5	12	9

Discussion: Redesign completed during testing of this experiment, in between tests 2 and 3.

Analysis:
None of our parts moved during the performance, except for the wheels. It is not designed to change when turned on.

Interpretation:
Our specifications were met.

Test Results

Fifteen total tests were conducted with the mostly complete Vacuum. Every test had different goals in order to ensure desired results were obtained. For each test, five trials were run and all results were recorded either in an Excel graph or spreadsheet. Each test we ran with a "Pass/Fail" result depending on our goal. Here are the 15 test goals summarized:

Table 3: Test Results Summary

Test Number and Title	Test Goal	Test Outcome
#1: Length	Ensure the length is within the 12" specification	Pass
#2: Width	Ensure the width is within the 12" specification	Pass
#3: Manual Start	Ensure the manual switch specification is met and guarantee the switch worked	Pass
#4 Battery Power	Ensure the voltage of the battery was within the 12-15V specification	Fail
#5 Completely Self Contained	Ensure the device performed without physical separation of components or loss of materials	Pass
#6 No Human Input After Start	Ensure the device needs no stimulation from human after initiation	Pass
#7 Programmed Sensors	Ensure the device uses all three sensors properly	Pass
#8 Clearance Under Wheels	Ensure device meets the 1.5-2.0" clearance specification	Pass
#9 Detachable Debris Container	Ensure debris container is able to detach from body without causing damage	Pass
#10 Weight	Ensure device is within 10-12	Pass

	pound specification	
#11 Speed	Ensure device meets the speed specification of being 2-5 mph	Fail
#12 Battery Life	Ensure battery life will last more than 2 minutes for competition	Pass
#13 Always Contact with Floor	Ensure device does not fly or jump around	Pass
#14 No Damage to Boundaries or Competitors	Ensure the device can properly avoid obstacles	Pass
#15 Barely Adjusts After Turned On	Ensure the device meets the <1 in adjustment specification after initiation	Pass

Risk & Reliability Analysis

FMEA

FMEA

Process/Product Name: Vacuum Cleaner Roomba

Organization Name: DC TEAM 9

Team Member Names: Alaina Bentley, Ryan Blake, Anna Buckley, Danny Pelphrey, Mason Adams

Prepared By: Alaina Bentley

Checked By:

Approved By:

FMEA Date (Orig.): (Rev.):

Process Step/Input	Potential Failure Mode	Potential Failure Effects	SEVERITY (1 - 10)	Potential Causes	OCCURRENCE (1 - 10)	Current Controls	DETECTION (1 - 10)	RPN	Action Recommended	Resp.	Actions Taken	SEVERITY (1 - 10)	OCCURRENCE (1 - 10)	DETECTION (1 - 10)	RPN
What is the process step, change or feature under investigation?	In what ways could the step, change or feature go wrong?	What is the impact on the customer if this failure is not prevented or corrected?		What causes the step, change or feature to go wrong? (how could it occur?)		What controls exist that either prevent or detect the failure?			What are the recommended actions for reducing the occurrence of the cause or improving detection?	Who is responsible for making sure the actions are completed?	What actions were completed (and when) with respect to the RPN?				
Vacuum up debris of varying size	Suction not strong enough	Will not pick up debris	8	Air loss in vacuum components	4	Visual Inspection	4	128	Make sure all components are packed as close as possible	Anna and Alaina	Visual Inspection completed regularly	4	6	4	96
Autonomous	Does not move without controls	Will not move and therefore a pointless product for customer	8	Incorrect coding, sensors fail, motors fail	3	Coding is checked and does not need revision	6	144	Product should be stored in safe space	Ryan	Coding is confirmed 11/11	4	2	3	24
Sense the debris and room boundaries	Cannot sense the room boundaries	Runs into walls, causing damage to room and/or device	6	Sensors fail, coding errors	3	Coding is checked and does not need revision	5	90	Product should be stored in safe space	Ryan	Coding is confirmed 11/11	2	2	2	8
Store the debris in a replaceable compartment	Debris does not collect in compartment or cannot be removed	Short-term life or difficult long-term use	6	Air flow does not push debris into storage compartment	2	Strong air flow and little air loss between components	8	96	Make sure all components are packed as close as possible	Anna	Components checked and made as closely packed 11/9	3	4	2	24
Long Battery Life	Battery dies during use	Vacuum job incomplete, messy area	4	Fail to recharge, weak batteries	8	Fully charged battery, easy to charge	5	160	Charge batteries in between uses	Anna	3 sets of batteries, charged often	5	8	3	120
Run on multiple sources	Bottoms out when running or cannot drive completely	Vacuum job incomplete if customer requires multiple surfaces	5	Weak tire tread over time	5	Tires with strong tread and does not rely on air	7	175	Do not run on unnecessary surfaces	Alaina	New tires, all same size and tread purchased 10/15	2	2	1	4
Reasonable Price	Too expensive or too cheap	No purchase, wasteful	3	Too much money spent during manufacturing=high selling price	1	Most parts were 3D printed, keeping manufacturing price low	10	30	Make sure all components are packed as close as possible	DC TEAM 9	Components checked and made as closely packed 11/9	1	1	1	1
Appealing Design	Customer will not buy	No purchase, wasteful	2	Paint wears off, components do not correspond correctly	1	Paint is sealed on, all parts were printed in neutral colors	10	20	Make sure all components are packed as close as possible	Alaina	Paint sealed on 11/8, wires safe checked on 11/11	2	2	2	8
Safe for children	Electronics could shock or vacuum runs into a child	Harm a child	10	Wires become exposed, sensors fail	1	Wires are covered	9	90	Keep away from harmful scenes (water, wind, pets)	DC TEAM 9	Wires covered on 11/12	4	3	3	36
Manual Start	One or both functions will not start when prompted	Product will not function properly	7	One push lever becomes detached over time	3	Lever is strongly glued and not openly exposed for quicker wear	8	168	Do not try to pry apart components	Anna	Lever glued and secured on 11/10	1	2	2	4

Figure 16: Failure Modes and Effects Analysis

Fault Tree Analysis

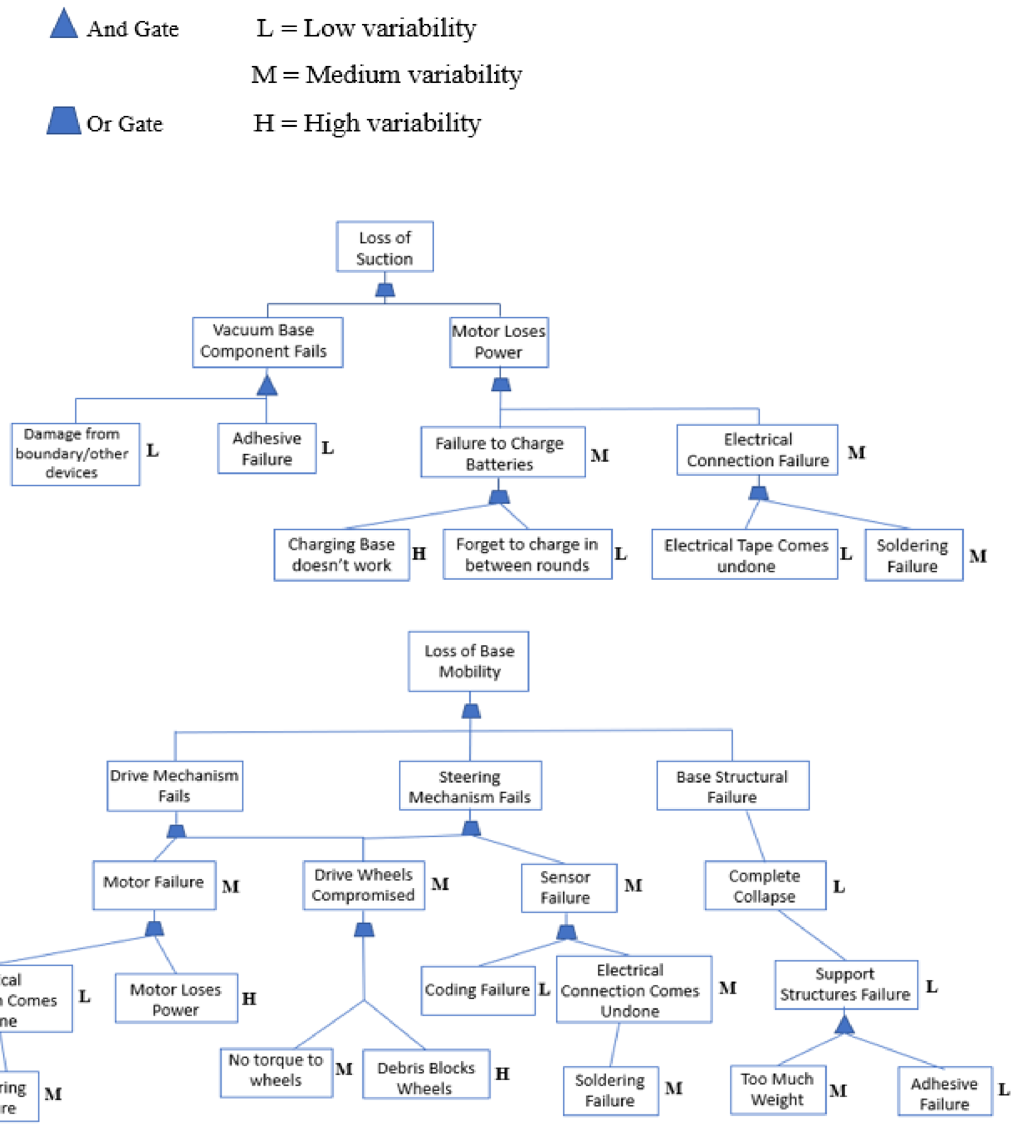


Figure 17: Fault Tree Analysis for Device

Safety

The design of the Autonomous Vacuum Cleaner encountered many different safety concerns throughout the process. The safety analysis is outlined below.

Table 4: Safety Analysis and Evaluation

Safety Analysis

Team 9

Mishap	Damage to	Mishap Probability	Mishap Severity	Hazard-Risk Index	Criterion	Action Taken to Reduct Hazard-Risk	Updated Mishap Probability	Updated Mishap Severity	Updated Hazard-Risk Index	Updated Criterion
Loose Connection	Product	Occasional	Marginal	11	Acceptable with Review	Check Product Before Use	Improbable	Marginal	16	Acceptable with Review
Loose Parts	Product	Occasional	Marginal	11	Acceptable with Review	Check Product Before Use	Improbable	Marginal	14	Acceptable with Review
Dropped Product	Product	Remote	Critical	10	Acceptable with Review	Careful and Training	Remote	Critical	10	Acceptable with Review
Electric Shock	Personel	Improbable	Negligible	20	Acceptable without Review	Careful and Training	Improbable	Negligible	20	Acceptable without Review
Burn	Personel	Improbable	Negligible	20	Acceptable without Review	Careful and Training	Improbable	Negligible	20	Acceptable without Review
Broken Pieces	Product	Occasional	Critical	10	Acceptable with Review	Check Product Before Use	Remote	Marginal	14	Acceptable with Review
Part Failure	Product	Remote	Critical	13	Acceptable with Review	Check Product Before Use	Remote	Marginal	15	Acceptable with Review

Improvements

There was more than one issue that presented itself throughout the testing of the device. One of the biggest problems was the amount of power that was being supplied to the device. There were a myriad of components that needed a power supply. The two wheel motors, the vacuum motor, and the Arduino board. With all those components, one single battery was not going to do the job. After testing, a decision was made to switch from the one power source to four power sources- one for each component. The vacuum motor received a 12V motor, while everything else utilized 6V batteries. With that improvement, it would make it easier to switch out batteries during the competition for maximum power if needed.

Another issue that came up happened to be the actual wood base itself. It was sharp and not sanded so there was a possibility for personnel to receive splinters or cuts if the device was mishandled unknowingly. The wood was sanded down and deburred in order to remove those sharp edges and flaws, and then it was painted and sealed with Mod Podge to ensure the safety of the paint and the wood.

The last main issue that arose was the overall suction of the vacuum. After analysis, it was determined that there was no outlet near the fan blade for air to flow. There were also too many 3D printed components to ensure no airflow was lost. Both factors were significantly decreasing the amount of air flow and subsequently, the suction power of the vacuum also. The vacuum inlet was redesigned two more times to minimize the components as well as the loss of airflow. The fan blade component was also redesigned with slots on the top to produce more air.

Figure 18 : First Vacuum Inlet Prototype

Figure 19: Second Vacuum Inlet Prototype

Service & Support Plan

Table 5: Service and Support Plan

	Drive Train Failure	**Wire Breaking/Circuit**	**Vacuum Failure**	**What if it does not do the necessary tasks?**
Procedure	If any part of the drivetrain should fail except for the motor, we plan to replace it with a new part.	Replace compromised circuit parts and hot glue to keep in place.	Replace compromised parts and reseal vacuum where needed.	Fix and adjust any part on the spot to increase usefulness.
Tools Required	2 Axles 2 Wheels 1 Castor Wheel	Wires Sensors 9V Batteries Solder/ Soldering Iron	Batteries Command Strips Adhesive	Tape Hot glue Superglue
Responsibility	Danny	Ryan	Anna	Alaina, Mason

Project Plan

<table>
<tr><td colspan="2">Project Planning 1</td></tr>
<tr><td colspan="2">Design Organization:DC Team 9   Date: 9/1/2022</td></tr>
<tr><td colspan="2">Product Name: Vacuum Design</td></tr>
<tr><td rowspan="8">Task
1
Snapshots</td><td>Name of Task: Brainstorm</td></tr>
<tr><td>Objective: To work together to try and think of ideas on what we want our design to look like and how we want it to function</td></tr>
<tr><td>Deliverables: None</td></tr>
<tr><td>Decisions/Milestones with Dates:
1. Have a few ideas narrowed down. Started 8/30/2022, completed by 9/2/2022
2. Make a big graph or picture of ideas. Started 8/30/2022, completed by 9/2/2022</td></tr>
<tr><td>Personnel Needed:
Title: All Teammates   Hours: 3   Percent full time:100%</td></tr>
<tr><td>Time: Estimated Total Hours: 3-5   Actual Total Hours:3</td></tr>
<tr><td>Sequence: Predecessors: None   Successors: Narrow to One Idea
Planned Start Date: 8/30/2022   Planned Finish Date: 9/2/2022
Actual Start Date: 8/30/2022   Actual Finish Date: 9/4/2022</td></tr>
<tr><td>Costs: Capital Equipment N/A Disposables: N/A</td></tr>
<tr><td rowspan="5">Task
2
Snapshots</td><td>Name of Task: Narrow to One Design</td></tr>
<tr><td>Objective: To use our brainstorming ideas in order to finalize an initial design</td></tr>
<tr><td>Deliverables: Project Plan</td></tr>
<tr><td>Decisions/Milestones with Dates:
1. Look at brainstorming ideas and each have a favorite design by 9/2/2022.
2. Come together and decide on overall best idea by 9/3/2022</td></tr>
<tr><td>Personnel Needed:
Title: All Teammates   Hours: 2   Percent full time:100%</td></tr>
</table>

	Time: Estimated Total Hours: 2-3 Actual Total Hours: 4
	Sequence: Predecessors: Brainstorm Successors: Drawing Planned Start Date: 9/1/2022 Planned Finish Date: 9/3/2022 Actual Start Date: 9/2/2022 Actual Finish Date: 9/5/2022
	Costs: Capital Equipment **N/A** Disposables: N/A

Project Planning 2

Design Organization:DC Team 9	**Date: 9/1/2022**
Product Name: Vacuum Design Project	

Task 3 Snapshots	**Name of Task:** Drawing
	Objective: Create an initial drawing of what we want our project to look like.
	Deliverables: None
	Decisions/Milestones with Dates: 3. Each create somewhat of a 2D drawing by 9/6/2022. 4. Come together as a team to compare drawings, work together to decide which design looks the best and makes the most logical sense to work on by 9/7/2022.
	Personnel Needed: Title: All teammates Hours: 1-2 Percent full time: 100%
	Time: Estimated Total Hours: 3 Actual Total Hours: 3
	Sequence: Predecessors: Narrow to One Design Successors: 3D Model Planned Start Date: 9/5/2022 Planned Finish Date: 9/7/2022 Actual Start Date: 9/5/2022 Actual Finish Date: 9/9/2022
	Costs: Capital Equipment **N/A** Disposables: N/A
Task 4 Snapshots	**Name of Task:** 3D Model
	Objective: Create a 3D model in Solidworks of our initial design
	Deliverables: None
	Decisions/Milestones with Dates:

	3. Create initial 3D model in Solidworks by 9/10/2022. 4. Come back together as a team and discuss what needs to be modified by 9/10/2022. 5. Have final 3D model in Solidworks by 9/12/2022
	Personnel Needed: Title: Anna Buckley, Ryan Blake Hours: 20 Percent full time: 90%
	Time: Estimated Total Hours: 23 Actual Total Hours: 20
	Sequence: Predecessors: Drawing Successors: Collect Parts Planned Start Date: 9/7/2022 Planned Finish Date: 9/12/2022 Actual Start Date: 9/10/2022 Actual Finish Date: 9/20/2022
	Costs: Capital Equipment **N/A** Disposables: N/A
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Project Planning 3

Design Organization: DC Team 9	**Date: 9/1/2022**
Product Name: Vacuum Design Project	
Task **5** **Snapshots**	**Name of Task:** Collecting the Parts
	Objective: Collect all parts necessary for initial design
	Deliverables: None
	Decisions/Milestones with Dates: 5. Decide and make a list of what all we will need to buy by 9/14/2022. 6. Find costs and split up evenly by 9/15/2022. 7. Order and buy all parts by 9/18/2022.
	Personnel Needed: Title: All Teammates Hours: 3 Percent full time: 100%
	Time: Estimated Total Hours: 5 Actual Total Hours: 10
	Sequence: Predecessors: 3D Model Successors: First Assembly Prototype Planned Start Date: 9/12/2022 Planned Finish Date: 9/18/2022

	Actual Start Date: 9/20/2022 Actual Finish Date: 9/28/2022
	Costs: Capital Equipment: Unknown Disposables: Unknown
Task 6 Snapshots	**Name of Task:** First Assembly Prototype
	Objective: Create a first proof of concept prototype.
	Deliverables: Proof of Concept Prototype Meeting with TA/Professor
	Decisions/Milestones with Dates: 6. All parts received by 9/22/2022. 7. Create out a plan on who is building/designing what by 9/23/2022. 8. Each member individually works on their own tasks, working together when necessary. 9. All initial prototype contributions should be done by 10/6/2022. 10. Come together with completed parts/programs and place pieces together by 10/10/2022. 11. Part should work and be ready to go for the week of 10/10/2022 for meeting.
	Personnel Needed: Title: Alaina Bentley Hours: 30 Percent full time: 20% Title: Anna Buckley Hours: 30 Percent full time: 20% Title: Daniel Pelphrey Hours: 30 Percent full time: 20% Title: Mason Adams Hours: 30 Percent full time: 20% Title: Ryan Blake Hours: 30 Percent full time: 20%
	Time: Estimated Total Hours: 150 Actual Total Hours: 100
	Sequence: Predecessors: Collecting the Parts Successors: Testing Planned Start Date: 9/18/2022 Planned Finish Date: 10/11/2022 Actual Start Date: 9/20/2022 Actual Finish Date: 10/20/2022
	Costs: Capital Equipment **Unknown** Disposables: Unknown
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Project Planning 4

Design Organization: DC Team 9		Date: 9/1/2022
Product Name: Vacuum Design Project		
Task 7 Snapshots	**Name of Task:** Testing	
	Objective: Analyze the functionality of the first prototype and write everything.	
	Deliverables: Unknown	
	Decisions/Milestones with Dates: 8. Work together after meeting to see how the part functions by 10/15/2022. 9. Decide what needs to be fixed and write up report on that by 10/17/2022.	
	Personnel Needed: Title: All Teammates Hours: 6 Percent full time: 100%	
	Time: Estimated Total Hours: 8-10 Actual Total Hours: 5	
	Sequence: Predecessors: First Assembly Prototype Successors: Redesigns Planned Start Date: 10/12/2022 Planned Finish Date: 10/17/2022 Actual Start Date: 10/22/2022 Actual Finish Date: 11/3/2022	
	Costs: Capital Equipment **Unknown** Disposables: Unknown	
Task 8 Snapshots	**Name of Task:** Redesigns	
	Objective: Redesign the project to meet goals and needs.	
	Deliverables: Unknown	
	Decisions/Milestones with Dates: 12. Decide as a team what needs to be fixed and split up goals by 10/19/2022. 13. Each work individually on everything outlined together by 10/26/2022. 14. Come back together and re-test the project by 10/28/2022. 15. Repeat if needed.	
	Personnel Needed: Title: All Teammates Hours: 8 each Percent full time: 100%	
	Time: Estimated Total Hours: 40 Actual Total Hours: 20	
	Sequence: Predecessors: Testing Successors: Analysis Planned Start Date: 10/17/2022 Planned Finish Date: 10/30/2022	

	Actual Start Date: 10/21/2022 Actual Finish Date: 11/8/2022
	Costs: Capital Equipment **Unknown** Disposables: Unknown
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Project Planning 5

Design Organization: DC Team 9	**Date: 9/1/2022**

Product Name: Vacuum Design Project

Task 9 Snapshots	**Name of Task:** Analysis
	Objective: Analyze final parts and meet necessary requirements.
	Deliverables: Unknown
	Decisions/Milestones with Dates: 10. Write up everything the whole process 11. All deliverables will be in Canvas so work together as a team to meet every goal.
	Personnel Needed: Title: All Teammates Hours: 10 Percent full time: 100%
	Time: Estimated Total Hours: 10 Actual Total Hours: 5
	Sequence: Predecessors: Redesigns Successors: Final Part Test and Meeting with TA/Professor Planned Start Date: 10/30/2022 Planned Finish Date: 11/1/2022 Actual Start Date: 11/8/2022 Actual Finish Date: 11/10/2022
	Costs: Capital Equipment: **Unknown** Disposables: Unknown
Task 10 Snapshots	**Name of Task:** Final Part Test and Meeting with TA/Professor
	Objective: Test the final project and have meeting with our TA
	Deliverables: "Final" Project
	Decisions/Milestones with Dates: 16. Have Meeting with our Professor and write down notes and observations by 11/3/2022

	17. Analyze Notes by 11/4/2022
	Personnel Needed: Title: All Teammates Hours: 5 Percent full time: 100%
	Time: Estimated Total Hours: 5-10 Actual Total Hours: 8
	Sequence: Predecessors: Analysis Successors: Final Redesigns for Competition Planned Start Date: 11/1/2022 Planned Finish Date: 11/4/2022 Actual Start Date: 11/8/2022 Actual Finish Date: 11/11/2022
	Costs: Capital Equipment: **Unknown** Disposables: Unknown

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 Form # 10

Project Planning 6

Design Organization: DC Team 9	**Date: 9/1/2022**
Product Name: Vacuum Design Project	

Task **11** **Snapshots**	**Name of Task:** Final Redesigns for Competition
	Objective: Analyze notes from meeting with TA and redesign to finalize the project and be ready for competition
	Deliverables: Unknown
	Decisions/Milestones with Dates: 12. Go over notes and decide what needs to be fixed by 11/5/2022 13. Work together as a team and finalize the product by 11/11/2022
	Personnel Needed: Title: All Teammates Hours: 10 Percent full time: 100%
	Time: Estimated Total Hours: 10-12 Actual Total Hours: 3
	Sequence: Predecessors: Final Part Test and Meeting Successors: COMPETITION Planned Start Date: 11/4/2022 Planned Finish Date: 11/11/2022 Actual Start Date: 11/10/2022 Actual Finish Date: 11/13/2022
	Costs: Capital Equipment **Unknown** Disposables: Unknown

<table>
<tr><td rowspan="8">Task

12

Snapshot
s</td><td>Name of Task: COMPETITION!!!!</td></tr>
<tr><td>Objective: Compete in the design competition</td></tr>
<tr><td>Deliverables: Final Product</td></tr>
<tr><td>Decisions/Milestones with Dates:

18. Have part completed by 11/11/2022.
19. Show up to the competition on 11/12/2022</td></tr>
<tr><td>Personnel Needed:

Title: All Teammates Hours: 3 Percent full time: 100%</td></tr>
<tr><td>Time: Estimated Total Hours: 3 Actual Total Hours: 3</td></tr>
<tr><td>Sequence: Predecessors: Final Redesigns for Competition Successors: None

Planned Start Date: 11/11/2022 Planned Finish Date: 11/12/2022

Actual Start Date: 11/12/2022 Actual Finish Date: 11/13/2022</td></tr>
<tr><td>Costs: Capital Equipment Disposables:</td></tr>
<tr><td colspan="2">The Mechanical Design Process Designed by Professor David G. Ullman

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</table>

Gantt Chart

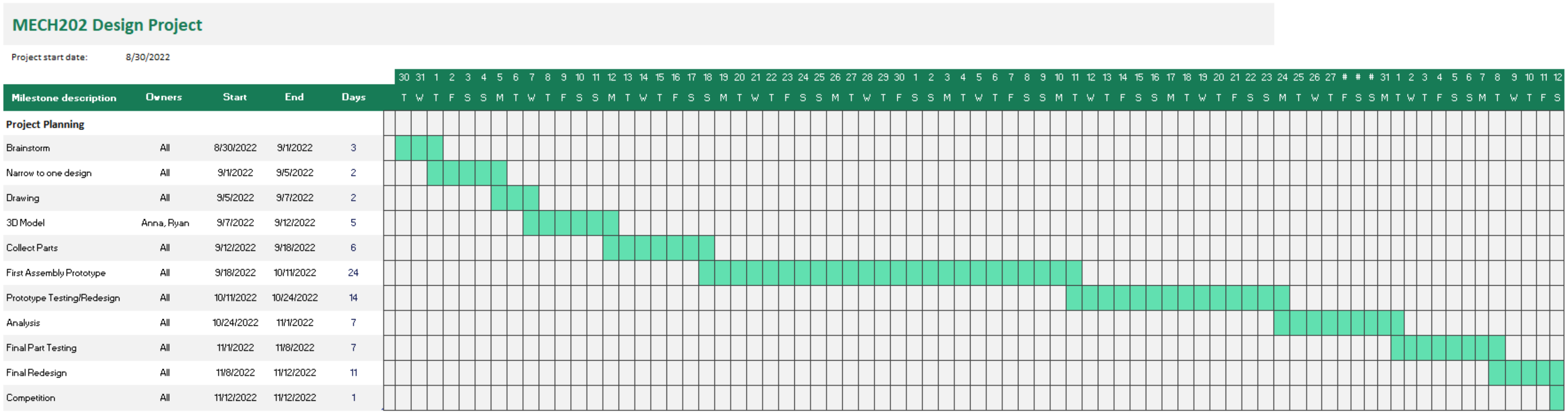

Figure 20: Initial Gantt Chart

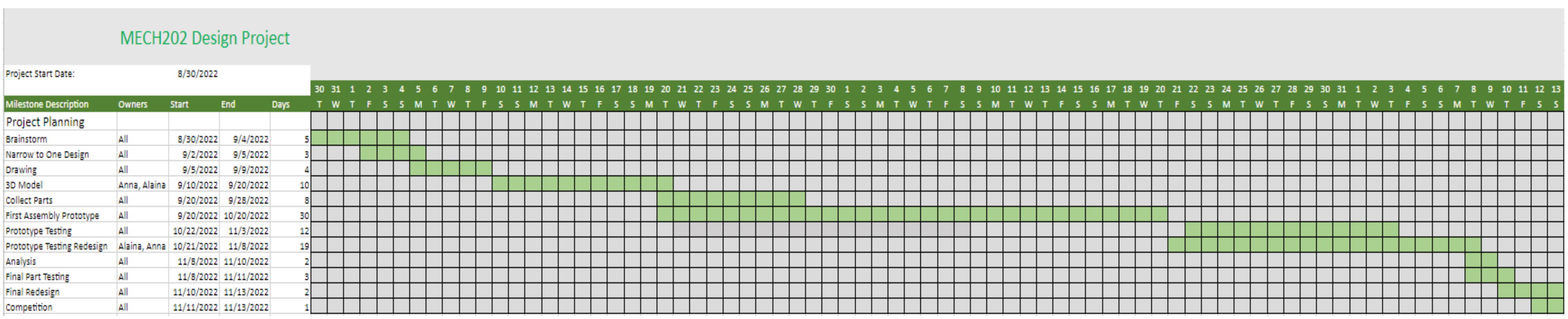

Figure 21: Final Gantt Chart

Above are two Gantt charts that were used during the process of the design project. The first chart explains the initial goal of the team members with the expected dates of working on the project. The second Gantt chart however explains the final and actual dates of the milestones the group met. It is slightly adjusted, as the milestones did not always get completed on time or took different amounts of time than originally predicted.

Team Assessment

The team worked together to complete the project by maintaining constant communication, collaborating on some tasks, and dividing up other tasks based upon individual skill sets and availability. A team contract (below) was drawn up at the beginning of the semester outlining goals as well as strategies for conflict resolution. All team members made sure to attend every class period they were able to so that they were meeting at minimum twice per week face to face. The team also often met outside of class in order to work together and help each other should that be necessary. The team used a group message to maintain constant contact with each other and to alert the group of any issues or important news at a moment's notice. For the majority of the graded assignments, the work would be shared by the team and divided up if there were multiple parts in a way that lent itself such. For the actual design and assembly processes, each team member had an area of the machine that they were focusing on completing. One member was developing the vacuum assembly, one the base, one the drivetrain, one the arduino/sensor assembly, and one storing, the device, solid modeling, and assembling the collective parts.

Team Contract

Design Organization: Team 9		**Date:** 8/25
Team Member	**Roles**	**Signature**
Daniel Pelphrey	design/manufacturing	
Mason Adams	team engineer	Mason Adams
Ryan Blake	Analysis	[illegible]
Anna Buckley	Schedule	[illegible]
Alaina Bentley	Coding / Mediator	[illegible]

Team Goals	Responsible Member
1. Grade check points / deadlines	Team
2. Presence	"
3. Creating something to be proud of	"
4. Efficiency	"
5.	
6.	
7.	
8.	
9.	
10.	

Team Performance Expectations	Initial				
Strive to complete all assigned tasks before or by deadlines	AB	MA	ALB	RB	DP
Complete all tasks to the best of ability	AB	MA	ALB	RB	DP
Listen carefully and attentively to all comments at meetings	AB	MA	ALB	RB	DP
Accept and give criticism in a professional manner	AB	MA	ALB	RB	DP
Focus on results before the fact, rather than excuses after	AB	MA	ALB	RB	DP
Provide as much notice as possible of commitment problems	AB	MA	ALB	RB	DP
Attend and participate in all scheduled group meetings	AB	MA	ALB	RB	DP

Strategies for Conflict Resolution:

- Voting for design issues
- Open to compromise
-
-

Team Members/Team Role Test Results

Anna Buckley

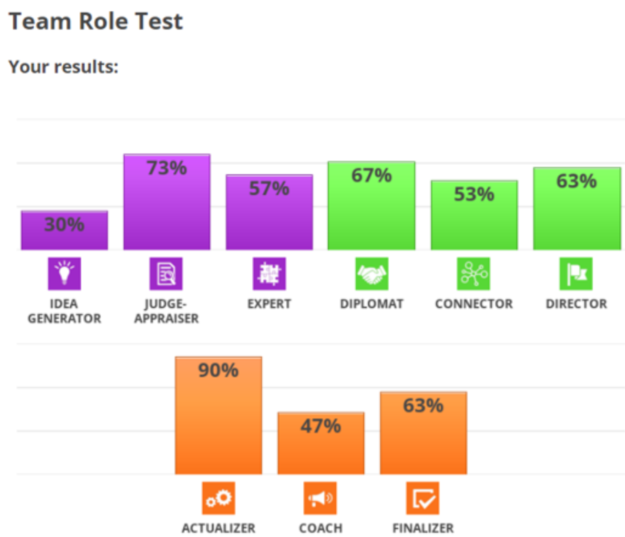

Figure 22: Team Role Test Results for Anna Buckley

Actualizer

Actualizers are team-oriented and listen to all the ideas and suggestions before taking action. They are reliable and efficient and can be counted on to meet deadlines. They like sticking to a plan and don't like deviating from the schedule.

Judge-Appraiser

Judge-Appraisers are great observers and like to evaluate the inner workings of the team to ensure there are no major issues. They are very analytical and need logical justification for all their decisions.

Diplomat

Diplomats are empaths who are excellent at mediating issues between team members without becoming confrontational. Their contributions usually go unnoticed since they keep a lower profile but excel when it comes to helping opposing parties understand one another.

Daniel Pelphrey

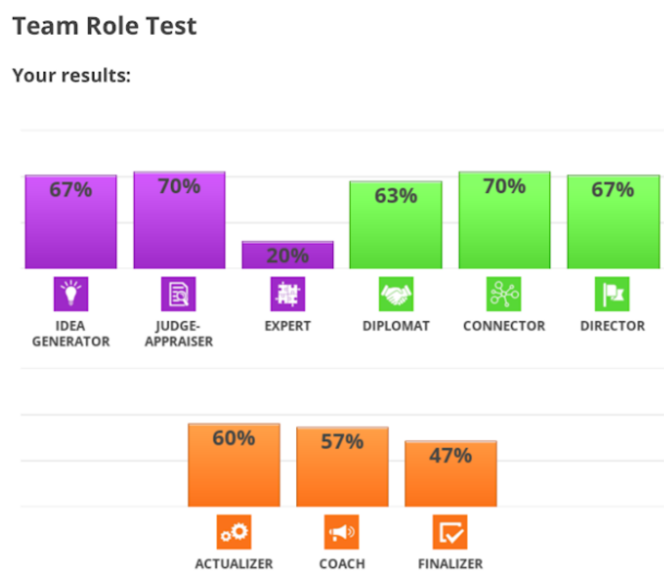

Figure 23: Team Role Test Results for Daniel Pelphrey

Judge-Appraiser

Unbiased problem solvers, who can usually focus on the most logical solution to a problem. They may sometimes lack some of the enthusiasm and passion of other team members.

Connector

Connectors bring energy and enthusiasm to kick off a project. Maintains perspective and awareness of the environment throughout the project. May lose energy towards the end when “grind” type work begins.

Idea Generator

Creatives who can come up with novel and unorthodox ideas. Often imaginative and bright they think in a general manner. May sometimes overlook small details. Will not feel the need to stick to a plan and may look to improvise and adapt as the situation evolves.

Alaina Bentley

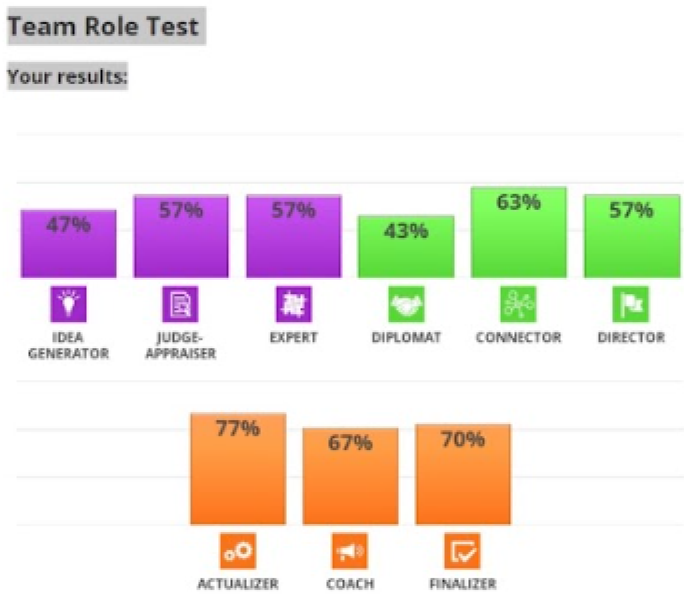

Figure 24: Team Role Test Results for Alaina Bentley

Actualizer

The actualizer is a team member who can take ideas from their team and turn them into a reality. Usually, these are people who can be efficient and are often very set in their ways.

Finalizer

The finalizer is the person who will finish the project and make sure it is perfect. Finalizers need to be accurate and reliable.

Coach

The coach is the team member who wants to win and has to bring energy to the team. They are good at keeping people working and on track. However, sometimes the coach can be aggressive and pushy.

Ryan Blake

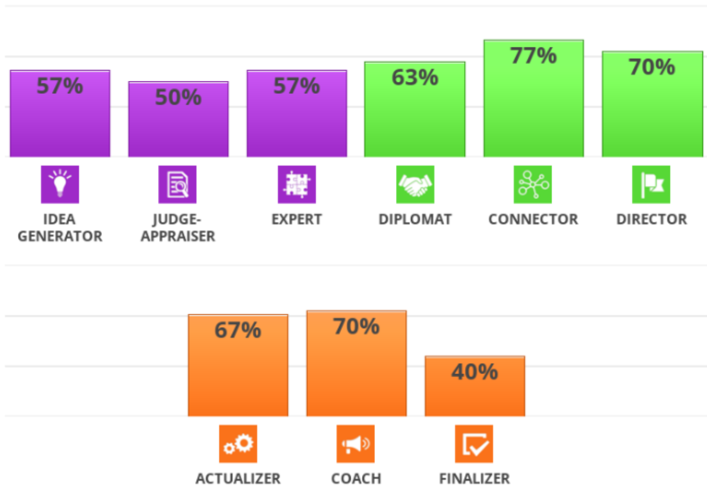

Figure 25: Team Role Test Results for Ryan Blake

Connector

A connector is someone that is constantly seeking new ideas from outside sources. Whether it be from the industry or from other people, a connector is always seeking inspiration from outside of their circle. In addition to this connectors are also great at networking and finding sources of help towards a project

Director

A director is someone that is able to take a leadership role within a team and is able to take a broader look at a project. Directors are able to realize the skills of people that they are working with and are able to delegate tasks that fall in line with an individual's skills. In addition, directors can also play a large role in keeping the group moving in the right direction as well as helping finalize decisions.

Coach

Coaches are driven by the desire to achieve and succeed. While they can be perceived as overbearing and controlling at times, coaches can help provide a spark that motivates a group to push forward.

Mason Adams

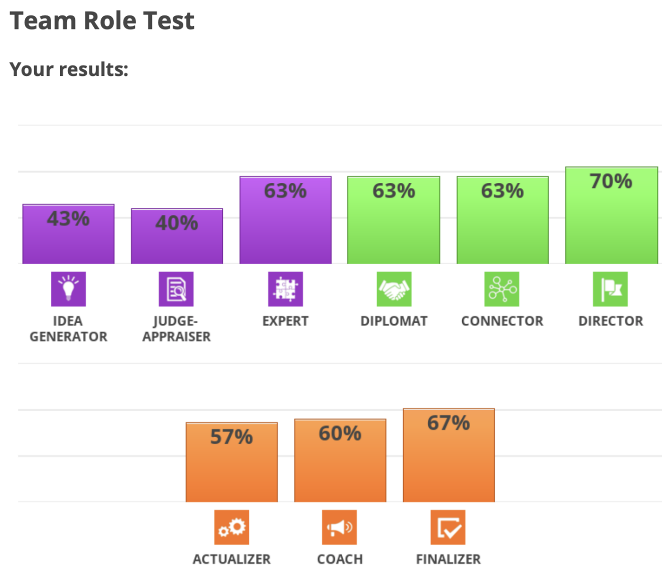

Figure 26: Team Role Test Results for Mason Adams

Director

Confident, stable, and mature all describe a director. Keeping the end goal in mind, a director helps navigate any stress the team may run into.

Finalizer

Give the extra effort to help the team go a step further. Make sure the work provided is adequate and current to the fullest extent. Also calls for a strong aspect of reliability.

Connector

Leading with a rush of enthusiasm to generate outside-of-the-team connections that may be beneficial in the long run. A lot of focus is placed on networking.

Team Health Assessments

Team Health Assessment

Team Assessed: DC Team 9 | **Date: 10/08/2022**

SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree, NA = Not Applicable

	Measure	SA	A	N	D	SD	NA
1	Team mission and purpose are clear, consistent and attainable.	X					
2	I feel that I am part of a team.	X					
3	I feel good about the team's progress		X				
4	Respect has been built within the team for diverse points of view.			X			
5	Team environment is characterized by honesty, trust, mutual respect, and team work				X		
6	The roles and work assignments are clear	X					
7	Team treats every member's ideas as having potential value		X				
8	Team encourages individual differences.		X				
9	Conflicts within the team are aired and worked to resolution.				X		
10	Team takes time to develop consensus by discussing the concerns of all members to arrive at an acceptable solution		X				
11	Decisions are made with input from all in a collaborative environment.		X				
12	The environment encourages communication and does not "kill the messenger" when the news is bad.	X					
13	When one team member has a problem others jump in to help	X					
14	Dysfunctional behavior is dealt with in an appropriate manner			X			
15	When someone on the team says they are going to do something, the team can count on it being done.		X				
16	There is no "them and us" on the team					X	
17	Our team cultivates a "what we can learn" attitude when things do not go as expected.		X				
18							
19							
20							

Remedies for improving the Neutral (N), Disagree (D) and Strongly Disagree(SD) responses:
Talks with the team in order to try and resolve issues.

Assessor: Alaina Bentley

The Mechanical Design Process

Team Health Assessment

Team Assessed: DC Team 9 | **Date: 11/11/2022**

SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree, NA = Not Applicable

	Measure	SA	A	N	D	SD	NA
1	Team mission and purpose are clear, consistent and attainable.	X					
2	I feel that I am part of a team.				X		
3	I feel good about the team's progress				X		
4	Respect has been built within the team for diverse points of view.				X		
5	Team environment is characterized by honesty, trust, mutual respect, and team work		X				
6	The roles and work assignments are clear	X					
7	Team treats every member's ideas as having potential value		X				
8	Team encourages individual differences.		X				
9	Conflicts within the team are aired and worked to resolution.					X	
10	Team takes time to develop consensus by discussing the concerns of all members to arrive at an acceptable solution			X			
11	Decisions are made with input from all in a collaborative environment.		X				
12	The environment encourages communication and does not "kill the messenger" when the news is bad.	X					
13	When one team member has a problem others jump in to help		X				
14	Dysfunctional behavior is dealt with in an appropriate manner			X			
15	When someone on the team says they are going to do something, the team can count on it being done.					X	
16	There is no "them and us" on the team					X	
17	Our team cultivates a "what we can learn" attitude when things do not go as expected.		X				
18							
19							
20							

Remedies for improving the Neutral (N), Disagree (D) and Strongly Disagree(SD) responses:
Unknown. Efforts have not been useful as of now.

Assessor: Alaina Bentley

The Mechanical Design Process

Team Health Assessment

Team Assessed: DC Team 9	**Date: 12/8/2022**

SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree, NA = Not Applicable

	Measure	SA	A	N	D	SD	NA
1	Team mission and purpose are clear, consistent and attainable.	X					
2	I feel that I am part of a team.					X	
3	I feel good about the team's progress		X				
4	Respect has been built within the team for diverse points of view.		X				
5	Team environment is characterized by honesty, trust, mutual respect, and team work				X		
6	The roles and work assignments are clear	X					
7	Team treats every member's ideas as having potential value		X				
8	Team encourages individual differences.		X				
9	Conflicts within the team are aired and worked to resolution.					X	
10	Team takes time to develop consensus by discussing the concerns of all members to arrive at an acceptable solution			X			
11	Decisions are made with input from all in a collaborative environment.		X				
12	The environment encourages communication and does not "kill the messenger" when the news is bad.	X					
13	When one team member has a problem others jump in to help	X					
14	Dysfunctional behavior is dealt with in an appropriate manner						X
15	When someone on the team says they are going to do something, the team can count on it being done.		X				
16	There is no "them and us" on the team					X	
17	Our team cultivates a "what we can learn" attitude when things do not go as expected.		X				
18							
19							
20							

Remedies for improving the Neutral (N), Disagree (D) and Strongly Disagree(SD) responses:
Efforts never ended up working. Team work is low and it is a 2.5/5 person team.

Assessor: Alaina Bentley

The Mechanical Design Process

Failure Analysis

The team finished the competition day with 2 wins and 2 losses. This was not enough to place in the top three of the competition. The device fell short largely due to low performance and quality of its parts and materials. Not enough time and money was budgeted to develop all of the parts to their full potential.

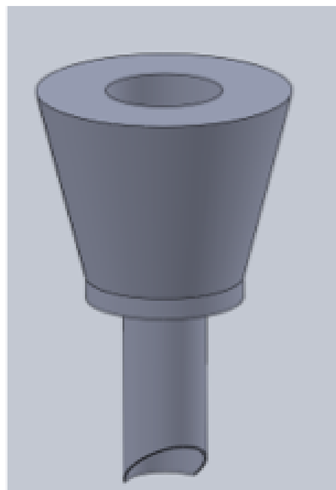

Figure 27: Final Vacuum Assembly

Vacuum Assembly

While the vacuum we developed was able to suck up some matter, it was not as effective as a lot of the competition. This was in large part due to issues developing the housing in a way that significant suction was generated. The team struggled with keeping the housing sealed everywhere while still having a solid exhaust for the air to leave. A proper exhaust was not actually developed until days before the competition and the first iteration of the design had to be used on competition day. For budgeting reasons, the robot was limited to the small motor and 12V battery that also limited the power, affecting the performance of the vacuum.

The design could have been improved in several ways. First, more suction could have been generated simply by using a bigger and more powerful motor to spin our fan. The waste container could also have been designed in a more favorable shape to help overall performance and the removal of collected debris on competition day. The shape used was a hollow cylinder, which allowed air to stagnate from the sharp corners in the design. If it had been rounded inside to create a vortex, it could have more efficiently generated suction from the fan and motor used. The exhaust could have been redesigned as well so that all of the air was leaving the housing on the backside without escaping elsewhere.

Drive Train

The weak point of the drivetrain was the support (dolly) wheels that were essentially just dragging along the ground. While the device was able to move around the arena. It moved at a slower rate than anticipated and would become stopped for short periods of time.

This could have been improved upon in several ways. The wheels could have been replaced with some that spun more smoothly and had better traction on sand in order to help them rotate. Some wheels like this were designed, but not enough time was left to implement them onto the robot. Two more driven wheels could also have been used, allowing all supports to be powered and eliminating drag. This would have been difficult to accomplish without going over budget.

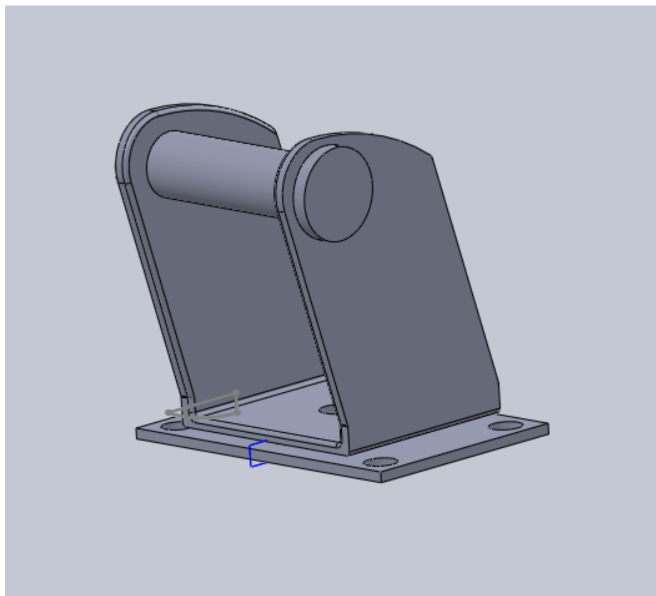

Figure 28: SolidWorks Model of Castor Wheel Hinge

Circuitry

As designed, the circuitry was adequate to be competitive in the competition, the main drawback was durability. One of the sensors stopped working on competition day due to a poor connection. The height of the sensors also needed some competition day adjustment after we found they were too high to get an accurate reading with the height of the 2x4s used to enclose the competition area. After these adjustments, the sensors worked slightly better resulting in more accurate readings and better competition runs.

The design could have been improved by using newer bread boards that would hold better connections and by hot gluing the connections once they were all set properly.

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