Design for Manufacturing, Reliability, and Economics report

Team 11
Weeding Robot

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Acknowledgments

Thank you to the FAMU-FSU College of Engineering and Mechanical Engineering Department for helping to conceive this project. Thank you also to the machine shop, who has helped us fabricate the parts we needed. We should also thank Yoel Bugin for his help with water jetting many of our parts.

Finally, thanks to Dr. Clark, our advisor, and Mr. Jeff Phipps, our sponsor, because this project would not have been possible without them.

1. Introduction

The idea for this Senior Design project is to design and build a method for getting rid of weeds between the rows of crops on organic farms. Research tells us the idea of integrating robotic systems onto farms to reduce the labor and human dependency is not a new one. A lot of the existing technology will help guide us in the right directions for the purpose of our design.

Organic farms do not use traditional farming techniques such as herbicides and pesticides, so this robot will eliminate the need for a human to pull weeds from the farm plots. The robot will have to navigate between the rows of crops, remove weeds, keep itself charged and running 24/7, as well as follow other design constraints as outlined in this paper. Some of the challenges associated with these desired operations is the method of which the robot will be programmed to navigate through the plot. The team is composed of four mechanical engineers and two electrical engineers, and is sponsored by the mechanical engineering department. The project is sponsored by Jeff Phipps, of the Orchard Pond Organics farm, and is advised by Dr. Clark and Dr. Li.

2. Design for Manufacturing

2.1 Complete Mechanical Project Assembly

2.1.1 Tools needed

- Hex Key
- Phillips head screw driver
- Bearing press
- Wrench
- Welding tools

2.1.2 Assembling the frame

The Dagu Wild Thumper robot frame is the first aspect of the weeding robot that must be assembled. The frame of the robot is mostly assembled out of the box, and all that needs to be assembled is coupling the wheels to the motor. This step only requires the hex key.

Next, the aluminum plates need to be attached to the top of the robot. These will support the weeding mechanism and the motor. Since the top plate comes attached to the robot, it will need to be removed. From the bottom of this plate, align the two aluminum plates with the appropriate holes on the top plate. Insert 2 Phillips head screws into the appropriate holes on one aluminum plate, and then on the other. This top plate can be reattached to the robot.

Using a bearing press, the bearings need to be placed in the appropriate holes. There are two bearings necessary, one on each aluminum plate.

2.1.3 Inserting electronics/Hooking up motors

The motor that will power the basket goes through the larger of the holes on the aluminum plates. An additional circular plate is used. Using Phillips head screws, fix the circular plate to the face of the motor. Following this, again using Phillips head screws, attach the circular plate to the aluminum plate. The fitting for the motor shaft (which includes the sprocket) can be slipped over the shaft. This can be fixed at the end of the motor shaft by placing a washer at the end and fixing it with a screw into the motor shaft.

2.1.4 Assembling the basket

To assemble the basket part of the weeding mechanism, the metal hubs, metal spokes and carriage bolts are needed. Align the square holes on the spoke with the square holes in the hub and couple with the carriage bolt/nut. Tighten with a wrench. Do the same with the other hub.

Using welding tools, the basket should be coupled onto the end of the shaft. The shaft should then be press fit into the bearings. Following this, the sprocket should be welded (?) inches from the opposite end of the shaft. The chain can now be fit over the two sprockets, and the motor should now be able to spin the basket.

2.1.5 Prototypes/Components

The weeding robot team assembled two prototypes before creating the final product. The first prototype was rough and made from wood. This took longer than expected, because it was not machined precisely and some of the dimensions did not match up. The second prototype also took longer than expected. Again, this was because some of the tolerances did not allow certain parts to fit and adjustments had to be made. This was also because the team had to cut the materials, rather than the machine shop.

Number of Components

- 10 x Spokes
- 20 x Carriage Bolts
- 20 x Nuts
- 1 x Shaft
- 1 x Small Sprocket
- 1 x Sprocket Motor Fitting
- 1 x Chain
- 1 x Large Motor
- 1 x Motor Plate (Coupling)
- 4 x Small Motor
- 4 x Wheels
- 12 x Phillips Head Screws
- (Electrical Components)
- 2 x Aluminum Plates
- 2 x Bearings

The design has around 80 components. About half of the components come from the carriage bolts and nuts. Ten bolts/nuts are needed for each side of the basket. It is possible that all of the nuts/bolts could have been done away with by welding the spokes straight on to the hub. However, this is undesirable because the spokes are removable with the current design. If a spoke breaks in some fashion, it is easily replaceable. If the spokes were welded, they would be much less easy to replace.

The exploded views of the robot can be seen in Appendix A. Fig. 1 is an exploded view of the basket showing how the assembly goes together. Fig. 2 shows how the ultrasonic sensor will be connected. Fig. 3 shows how the robot appears from a top down perspective. Fig. 4 shows how the motor should be assembled. Fig. 5 shows how the entire top of the robot is assembled.

2.2 Complete Electrical Project Assembly

1. Purchased all needed components
    a. BeagleBone Black
    b. Logitech C310 USB 2.0 HD Webcam
    c. Dual Motor Controller Cape Mk.6
    d. PICAXE-08M2 Microcontroller
    e. SainSmart HC Range Detector
    f. Converter Adapter
    g. HDMI to Micro HDMI cord
    h. Samsung Class 6 SDHC
    i. USB Hub
    j. Polycarbonate Waterproof Case
    k. Ultrasonic Module Distance Sensor
    l. 4A Motor Shield for Arduino
    m. 5000 mAH LiPo Battery Pack
    n. LiPo Balance Charger with AC Adapter
    o. Marker Supplies
2. Attach Beaglebone Black to the two Motor Control Capes
    a. Upload all updates needed for Debian operating system
3. Connect 7.4 V regulated High output battery to BeagleBone Black 5 volt input.

4. Connect the unregulated 7.4 Volt battery to the BeagleBone Motor Control Capes.
5. Next connect the four motor control wires to the motor control capes.
6. Connect the Webcam to the BeagleBone Black via USB
7. See wiring diagram attached for connection of Ultrasonic Ranging Module to the Beaglebone Black.
8. The Arduino will run off the same regulated high output battery that the Beaglebone Black runs off. Connect this into the 5 volt input on the Arduino Uno
9. Wire the Arduino and BeagleBone Black to the same common ground, and connect pin 4 to pin 8 on the Beaglebone black.
10. Begin coding BeagleBone Black and Arduino; See Appendix A for code

This design did not take long to assemble, due to the fact that it is an electronic system. The most time consuming aspect of this design is the programming of the navigation system. The navigation system consists of the vison system which works in unison with the ultrasonic ranging module to accurately weed the field.

This design could have been simplified by utilizing the system on a chip to handle all the motors on the platform instead of using a separate Arduino UNO. The reason for this complication is the limited time till completion of the project. The motor for the weeding mechanism was added near the end when the main code had already been developed.

1. 5 Volt supply from the main rail to the BeagleBone Black. This provides power to system on a chip and all peripherals attached (Camera, Ultrasonic Ranging Module)
2. Unregulated power to the two BeagleBone Black Motor control capes.
3. Connection of the Ultrasonic ranging module to the BeagleBone Black, See Fig. 7 for detail connections.
4. Connection of Webcam to BeagleBone Black via USB
5. 5 Volt Regulator to reduce the voltage of the 7.4 volt batteries for use with the Arduino UNO and BeagleBone Black
6. Motor control connections for the four motors on the robot chassis
7. Control connections to the motor driving the weeding mechanism from the Arduino motor control shield.
8. Connection for communication between the BeagleBone Black and the Arduino Uno
9. Unregulated power to the two BeagleBone Black Motor control capes.
10. 5 Volt supply from the main rail to the Arduino UNO used to power the Arduino UNO and all GPIO pins.

See Fig. 6 for a pictured summary of this.

3. Design for Reliability

3.1 Mechanical Design for Reliability

When used once, the weeding robot performs as expected, with only minor deviations from expected operations. In terms of durability of the parts, after one use, there are no loose parts and there is no visible wear on the robot. When used 100 times, it is possible that some of the spokes could bend or even break, and that some of the bolts/nuts could have come loose. After this many uses, it is still unlikely that the shaft would bend or the welds would come undone. When used 1000 times, is it possible that some dirt could have gotten into the motors or bearings, and it may affect the performance of the product. After this time, it is still unlikely that the shaft would bend. After 10,000 uses, the motors could likely fail after so many repeated uses and the shaft might possibly be bent. However, with regular maintenance and careful observation of the robot, it is likely that the robot could last for 10,000 uses. The reasoning for this evaluation is the quality of the components used. The shaft is quite heavy and would require much force to bend. The spokes on the basket are thinner sheet metal and are more prone to bending. The motors are high quality and shouldn't be receptive to letting dirt into the motor. The bearings are double sealed and should also prevent dirt from entering.

The main reliability concerns for the weeding robot are the spokes on the basket. These are made of the thinnest material. It is important that these spokes are made with a light and thin material so they are more easily able to cut into the dirt of the plant bed. One answer to these concerns would be to make the parts out of a stronger material that still maintains the desired thickness. However, the method of currently addressing these concerns is to make them easily replaceable, simply by removing the bolt/nut and putting a new spoke on the basket.

Another reliability concern comes from the environment in which the robot will operate. Since there are many metal parts used in this robot (chain, sprocket, frame, basket mechanism), there is some concern that the parts could rust. The team has attempted to address this concern by choosing materials that are much less prone to rust, namely weather/corrosion resistant aluminum. Further, the group could clear coat some of the parts to prevent water from getting to them.

3.2 FMEA (failure modes and effects analysis)

The FMEA analysis is seen in Appendix B Table 1. From the FMEA analysis, the most glaring issue that may arise would be debris getting caught in the chain/basket. This could lead to issues such as inoperability of main components. The least prevalent issue would be dirt covering the camera lens. If this occurs, then the robot will stop, and won’t cause damage to the plant beds.

3.3 ECE Design for Reliability

The navigation system of the weeding robot is the major part of the electrical reliability for the robot. The navigation system has two main parts, vision and ultrasonic system and then the motor control for driving the robot. The main reliability concern for this project is how well the robot is able to identify its position in the row in order to drive down the furrow successfully.

The vision and ultrasonic sensors are made to work in unison in order to improve the reliability of robot navigation. The vision system on its own did not provide accurate enough data to safely drive the robot down the row. This data can be used to position the robot and identify that the robot is still driving down the row, but identifying the center of the markers was not accurate enough to drive off of individually. The visions system alone had approximately a 47% rate of success in driving the robot down the row. In order to improve the reliability of this system, an ultrasonic sensor was added to the front of the robot in order to determine its position from the side of the bed. By itself this system was able to drive the robot down the row about 73% of the time. When these two systems are combined the robot is able to drive down the row successfully at least 90% of the time. With the updated controller the robot is able to drive itself down the row over 90% of the time which is accurate enough to navigate the field. If the robot loses the balls in the row to make sure it doesn’t hit the plants it simple stops the robot. This data was gathered from a set number or trials as shown in the Table 2.

The next reliability concern is the motor control system, which is all run through the Beaglebone black. The actual control of the motor power and speed is run through a software controller, so this is not a reliability concern as long as the data it receives from the sensors is accurate. However, the scope of the project requires an operability time of the robot which exceeds a certain number of hours per day so it is able to affect as much of the plot as possible. The concern affiliated with this and the battery would supply enough power to run the robot all day. Some tests were run and it was insured that this was not a reliability concern. This can be seen in Table 3.

4. Design for Economics

The entire product as is it currently developed costs a total of $2,005.00. The electrical components cost a total of $636.00 while the mechanical components cost a total of $1,346.00. Overall, there is 33% of the budget remaining. It is our hope that in the future, additional components will be designed to add onto the robot to complete additional tasks on the farm. It is likely with all of the added features we would have liked to incorporate into the design, our finished product might cost anywhere from $4,000 - $6,000. The complete bill of materials is found in Table 4.

The charts in Figure 8 show the overall budget allocation for each discipline of the project as well as allocations for certain subcategories of materials.

4.1 Competition and Marketability

There are many similar commercial style “farm robots” similar to our autonomous weeding robot already out on the market. One such robot was developed by inventor Christophe Millot and is capable of pruning and de-suckering grapes in vineyards while also removing unproductive young shoots and collecting data on the heath of the soil and vine stocks. The robot is called Wall-Ye and ‘draws on tracking technology, artificial intelligence and mapping to move from vine to vine, recognize plant features, capture and record data, memorize each vine, synchronize six cameras and guide its arms to wield tools[1]. The similarities between this vineyard robot and our weeding robot is that they both use a vision system for navigation. However, the vineyard robot uses a more advanced collaboration with a GPS to navigate through the vineyard. Also, both robots use a mechanical mechanism to remove an element from a plot of land. Again, the vineyard robot is more advanced in its determination of removal as it uses artificial intelligence to assess the plants of which it interacts with. The estimated cost of Wall-Ye will be about $32,000.

There is also a robot called the Lettuce Bot, a semi-autonomous weeding robot designed by Blue River Technology that is capable of ‘using one set of algorithms to determine whether or not it is seeing a plant, another set of algorithms to determine if the plant is a weed or not (to about 98 or 99 percent accuracy) and a third set of algorithms to determine when the correct moment is to inject the deadly dose of fertilizer on the weed[2]. The difference with this robot is that it is not designed for organic farms where there is no use of chemicals and it requires the help of a farmer to control part of the navigation throughout the farm. The cost of Lettuce Bot has not yet been revealed, however it is likely it will be competitive with the cost of manual labor. On a 7-acre farm like Orchard Pond Organics, assuming a wage of $15.00/hour, the price of Lettuce Bot could be anywhere between $25,000 - $28,000 assuming there is work to be done on the farm 5 days out of the week.

Figure 9 below shows graphical comparison of the price of each of the competition as well as the price for our design. It is evident that if there were more time to complete the product to our desired specifications, the weeding robot would prove to be very marketable and would allow a larger population of farmers to reduce the amount of weeds on their farm and increase productivity overall.

5. Conclusion

Ultimately, for this senior design project the goal of the weeding robot team was to create an autonomous robot that could effectively remove weeds from a plot. The method chosen to remove weeds from the plot was the basket weeding method. The basket weeding method uses spokes that dig into the ground and sweep the weeds out from their root system. This basket is driven by a motor that is powerful enough to overcome the torque needed to drive the mechanism into the dirt. A Beaglebone Black is used to control the robot as well as the motor driving the weeding mechanism. The robot navigates through the plot by using a vision system in parallel with an ultrasonic sensor. The vision system uses a webcam to identify markers on the sides of the row, and then compares it with the data from the ultrasonic sensor in order to autonomously drive the robot straight through the furrow. By using these two systems together they are able to correct any errors or bad data from one of the sensors alone. The mechanical and electrical designs work together to affect 100% of the weeds that the robot encounters.

References

[1] MailOnline, Eddie Wrenn for. "Meet Wall-Ye: The French Grape-picking Robot." Mail Online. Associated Newspapers, 28 Sept. 2012. Web. 31 Mar. 2015.

[2] Pena, Devon G. "Environmental and Food Justice: Precision Farming | Remember Hard Tomatoes? Well, Get Ready for Bland Lettuce." Environmental and Food Justice: Precision Farming | Remember Hard Tomatoes? Well, Get Ready for Bland Lettuce. Environmental and Food Justice, 22 Jan. 2014. Web. 31 Mar. 2015.

Appendix A

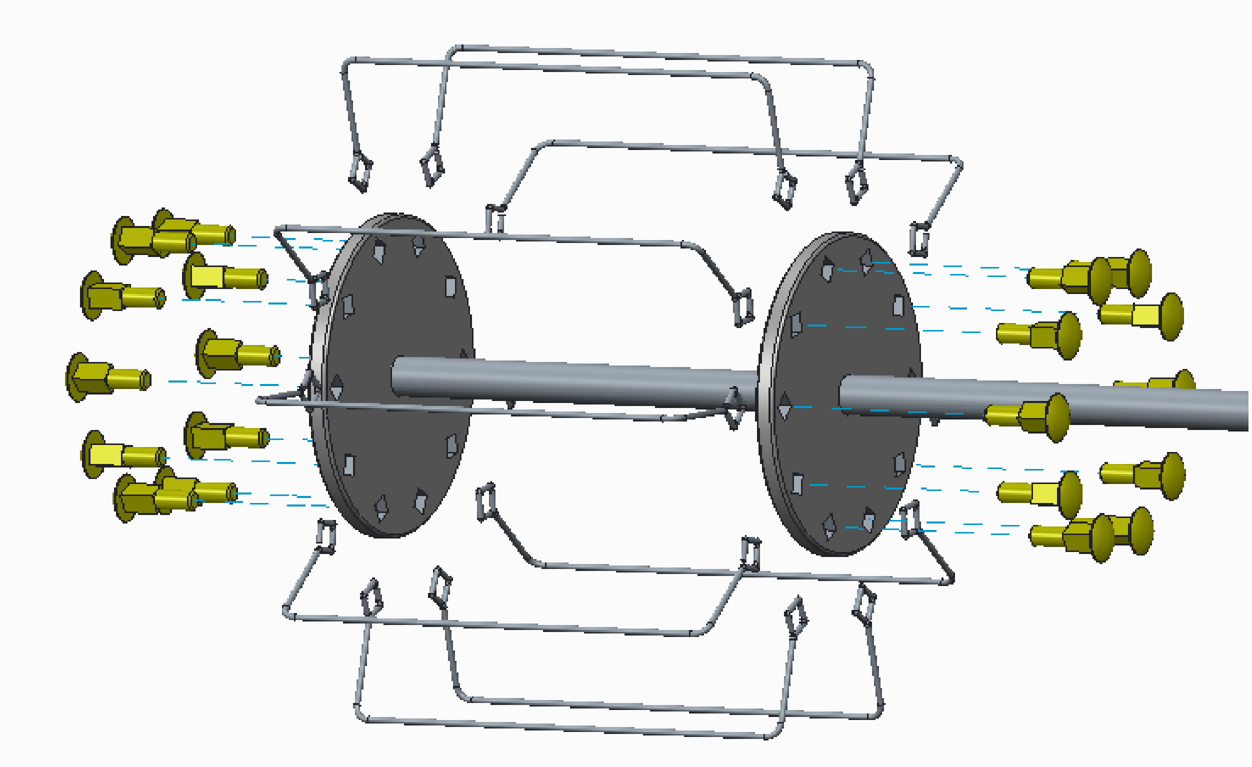

Figure 1 Exploded view of basket

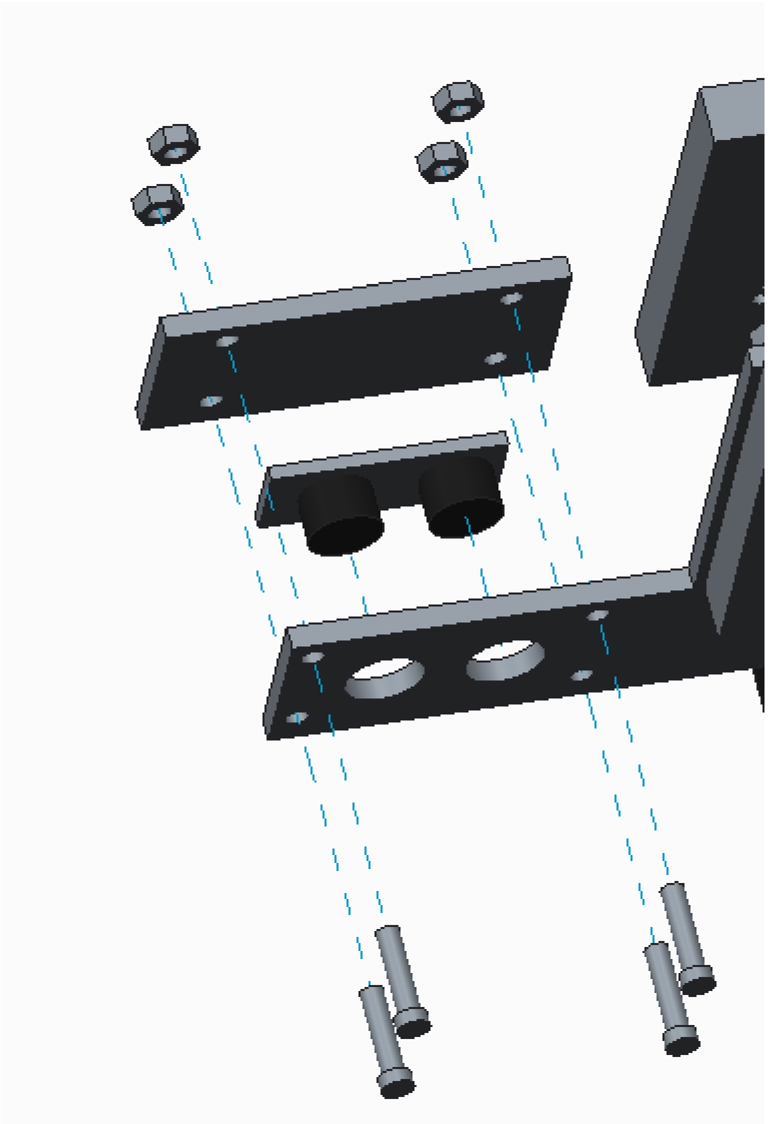

Figure 2 Exploded view of ultrasonic sensor fixture

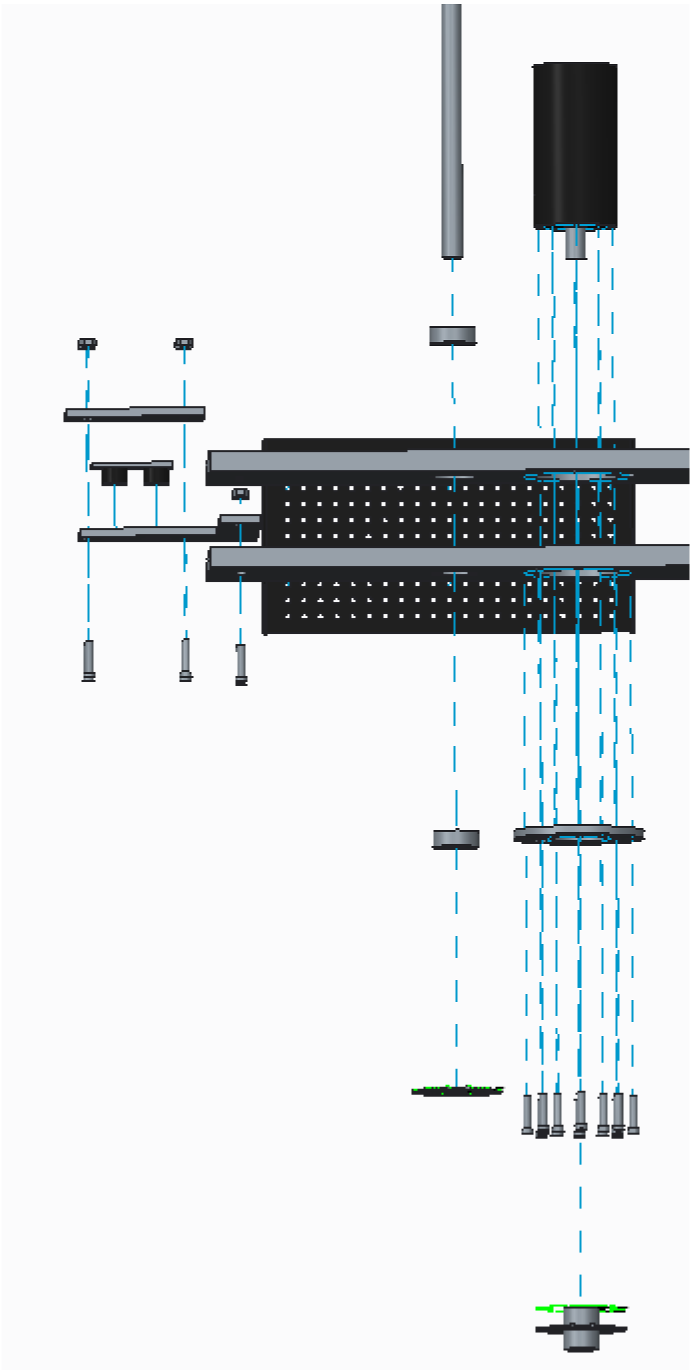

Figure 3 Exploded view from top

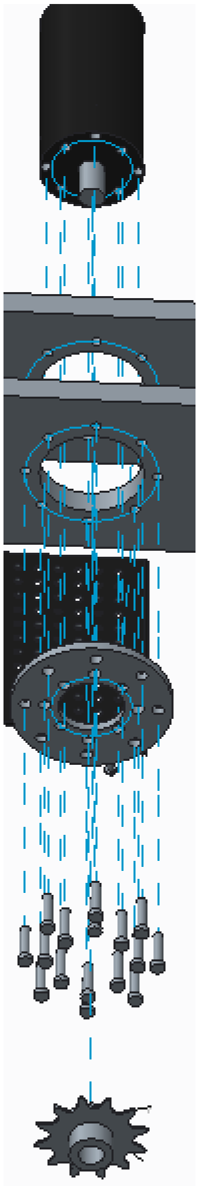

Figure 4 Exploded view of motor

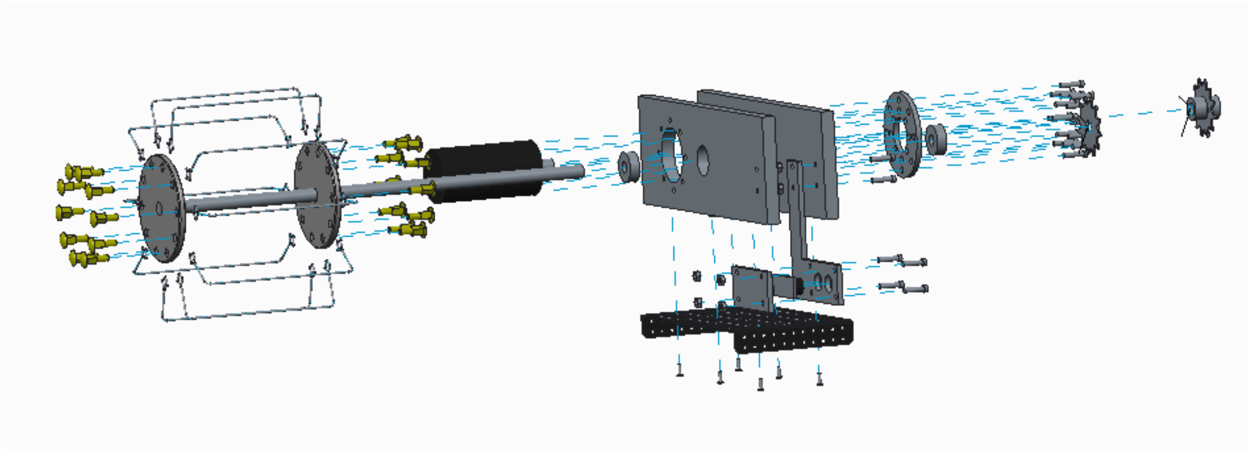

Figure 5 Overall exploded view

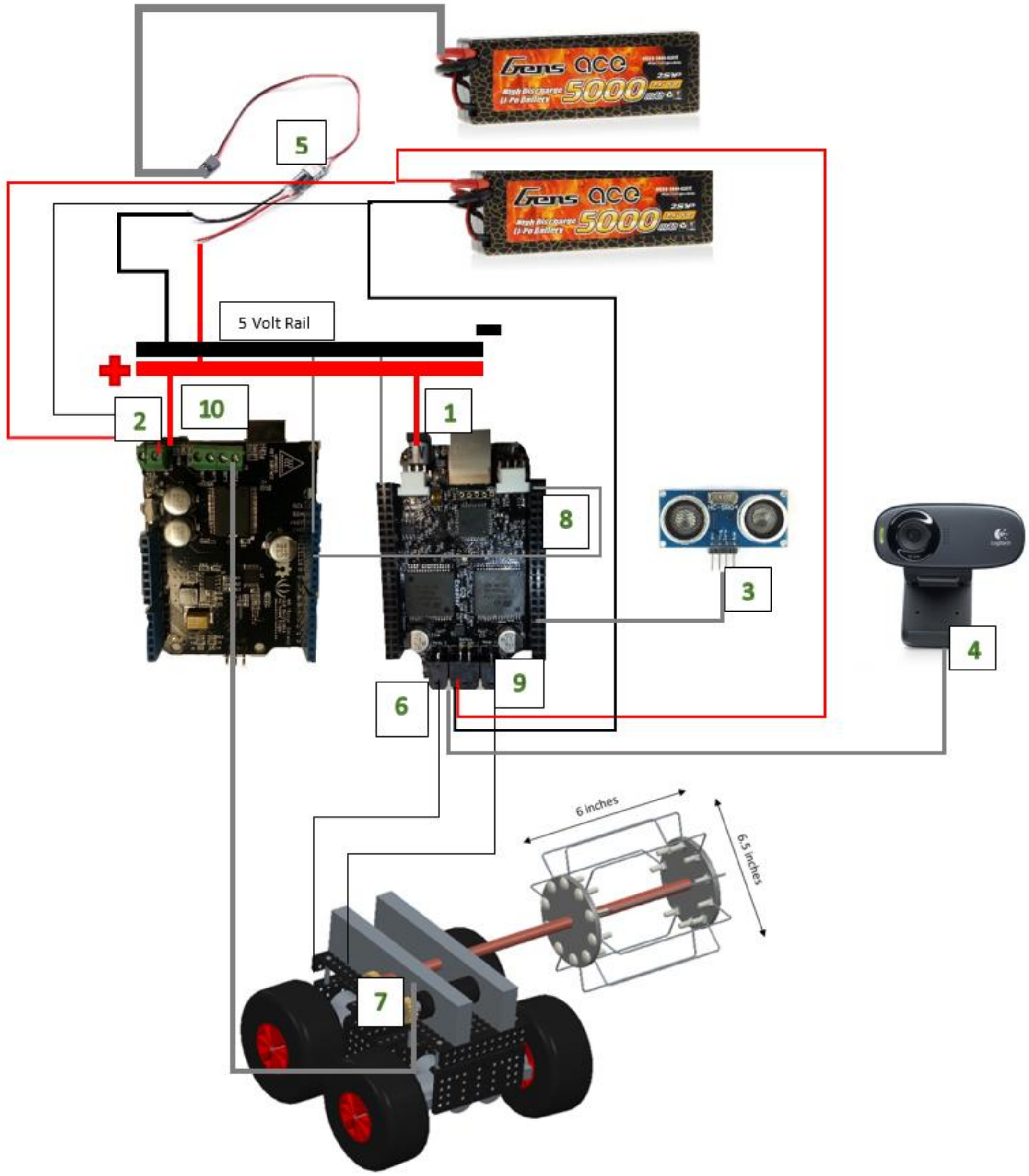

Figure 6 Electronic System Wiring Diagram

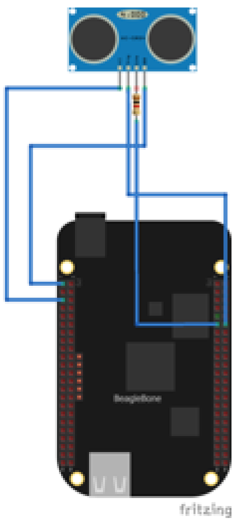

Figure 7 Detailed Ultrasonic Ranging Module Pin layout

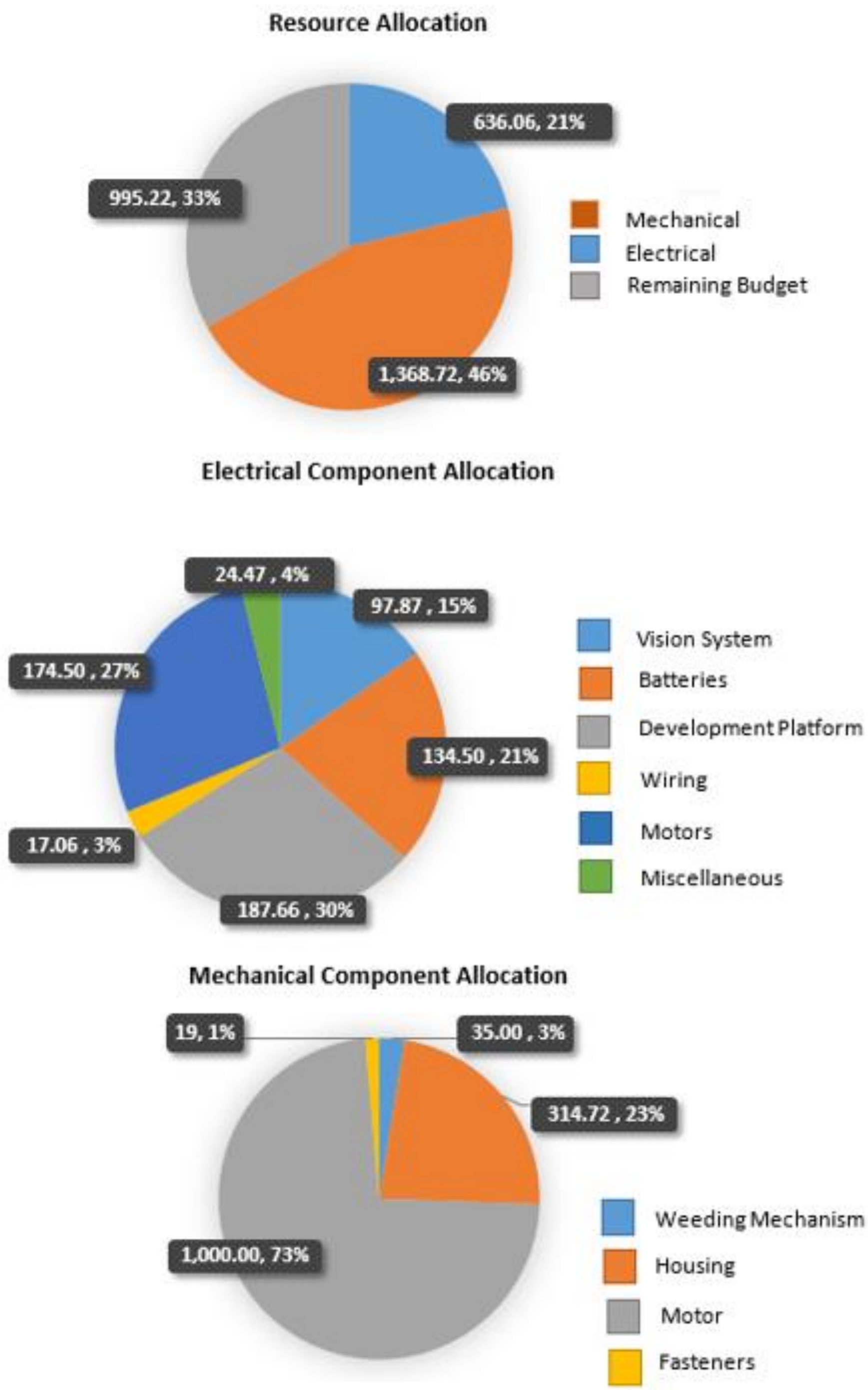

Figure 8 Budget Allocation

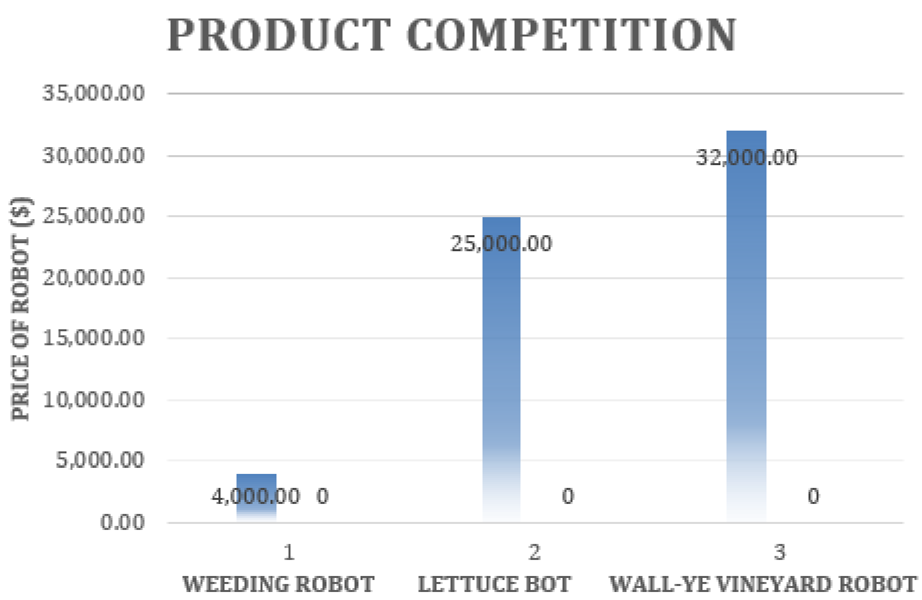

Figure 9 The competitiveness of our product in regards to other similar products

Appendix B

Table 1 Performance Data

Failure Modes Effects Analysis

Team #:	11
Project Title	Weeding Robot

Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.
What is the Process Step or Input?	In what ways can the Process Step or Input fail?	What is the impact on the Key Output Variables once it fails (customer or internal requirements)?	How **Severe** is the effect to the customer?	What causes the Key Input to go wrong?	How **often** does cause or FM **occur**?	What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode?	How well can you **detect** the Cause or the Failure Mode?		What are the actions for reducing the occurrence of the cause, or improving detection?	Who is Responsible for the recommended action?
Rotating basket	Basket gets stopped by large object	Spokes on the basket break	5	Field is filled with rocks or very large roots	3	The rotation of the basket will free itself from objects	3	45	Remove large objects from the plot before using the robot	The farmer or users of the robot
Rotating basket	Basket gets stopped by large object	Motor burns out	8	Field is filled with rocks or very large roots	3	The rotation of the basket will free itself from objects	3	72	Remove large objects from the plot before using the robot	The farmer or users of the robot
Rotating basket	Basket fills with debris	The basket no longer removes weeds	4	If robot is operating in a wet or overdamp enviornment	5	Spaces inbetween basket spokes allow debree to fall through	5	100	Remove large amounts of debree form the field before use	The farmer or users of the robot
Spinning chain	Chain slips off of the gears	The basket no longer rotates	3	Misalignment occurs	3	Gear alignment and tension cause the chain to stay on the gear	4	36	Check alignment of the gears before operating the robot	The farmer or users of the robot
Spinning chain	Chain slips off of the gears	Chain starts hitting other parts of the robot	6	Misalignment occurs	3	Gear alignment and tension cause the chain to stay on the gear	4	72	Check alignment of the gears before operating the robot	The farmer or users of the robot
Spinning chain	Debris gets caught in chain	The chain slips off the gears	4	If robot is operating in a wet or overdamp enviornment	5	The spinning of the chain allows for debris to remove itself form the chain	6	120	Remove large amoutns of debris form the field before use	The farmer or users of the robot
Spinning chain	Debris gets caught in chain	The chain breaks	5	If robot is operating in a wet or overdamp enviornment	5	The spinning of the chain allows for debris to remove itself form the chain	6	150	Remove large amoutns of debris form the field before use	The farmer or users of the robot
Driving down the row	Camera gets dirty	The robot stops	2	Dirt is thrown onto the camera lense	2	The robot stops	3	12	Clean camera before use	The farmer or users of the robot
Driving down the row	The ultrasonic sensors get obstructed	The robot drives with less accuracy	5	Too much debris in the field	5	Use the camera system	5	125	Clean ulrasonic sensors before use	The farmer or users of the robot

Table 2 Performance Data

System Type	*Loading Conditions*	*Success*	*Failure*	*Total Attempts*	*Success Rate*
Vision only	Midpoint calculation	10	5	15	0.67
	Successful Navigation	7	9	15	**0.47**
Ultrasonic only	Distance from Bed	12	3	15	0.80
	Successful Navigation	11	4	15	**0.73**
Vision and Ultrasonic	Successful Navigation	13	2	15	**0.87**

Table 3 Motor Power Analysis

Speed	*Loading Conditions*	*Current Draw (A)*	*Max Battery Life (Hours)*
30%	No Load	0.091	54.95
	Load: Robot only	0.102	49.02
	Load: Robot + Weeding Mech	0.127	39.37
60%	No Load	0.162	30.86
	Load	0.193	25.91
	Load: Robot + Weeding Mech	0.199	25.13
90%	No Load	0.156	32.05
	Load	0.21	23.81
	Load: Robot + Weeding Mech	0.219	22.38

Table 4 Complete Bill of Materials

Component	Item	Unit Cost	Quantity	Total Cost	Supplier
Electrical	BeagleBone Black	55.00	3	165.00	Adafruit
	Logitech C310 USB 2.0 HD Webcam	40.46	1	40.46	Amazon
	Dual Motor Controller Cape Mk.6	68.00	2	136.00	Exadlers Technologies
	PICAXE-08M2 Microcontroller	15.67	1	15.67	PICAXE
	SainSmart HC Range Detector	8.42	1	8.42	Amazon
	Converter Adapter	6.08	1	6.08	Amazon
	HDMI to Micro HDMI cord	3.99	1	3.99	Amazon
	Samsung Class 6 SDHC	6.99	1	6.99	Amazon
	USB Hub	6.99	1	6.99	Amazon
	Polycarbonate Waterproof Case	24.47	1	24.47	Plano Storage Solutions
	Ultrasonic Module Distance Sensor	8.99	1	8.99	Amazon
	4A Motor Shield for Arduino	38.50	1	38.50	NKC Electronics
	5000 mAH LiPo Battery Pack	43.00	2	86.00	Hobby Partz
	LiPo Balance Charger with AC Adapter	48.50	1	48.50	Hobby Partz
	Marker Supplies	40.00	1	40.00	Michaels
Component	Item	Unit Cost	Quantity	Total Cost	Supplier
Mechanical	Corrosion-Resistance 5052 Aluminum	48.77	1	48.77	McMaster Carr
	Steel Ball Bearing	10.25	4	41.00	McMaster Carr
	Wood (Basket)	15.00	1	15.00	Home Depot
	Wood	50.00	1	50.00	Home Depot
	4 WD All-Terrain Chassis	174.95	1	174.95	Pololu
	Shaft	15.00	1	15.00	Tractor Supply
	Nuts	0.35	20	7	Home Depot
	Bolts	0.75	16	12	Home Depot
	Sheet Metal	5.00	1	5.00	Home Depot
	Motor	1,000.00	1	1,000.00	Maxon
				TOTAL	2,005.00