FSU/FAMU College of Engineering
Departments of Electrical and Mechanical Engineering

Interim Design Report

Robotic Weeding Harvester
Team Numbers: ECE#16 - ME#11

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Submitted To:
Dr. Gupta
Dr. Helzer
Dr. Li
Dr.Frank
Dr.Clark
Jeff Phipps

Authors:
Ian Nowak (*EE*) – ian10@my.fsu.edu
Coen Purvis (*ME*) – cvp11@my.fsu.edu
Amanda Richards (*ME*) – amr10e@my.fsu.edu
Grant Richter (*ME*) – gmr10d@my.fsu.edu
Jeremy Rybicki (*EE/CpE*) – jnr11b@my.fsu.edu
Nathan Walden (*ME*) – new12@my.fsu.edu

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Acknowledgements—

Mr. Jeff Phipps: Project Sponsor
Dr. Chiang Shih: Project Mentor/Mechanical Engineering Chair
Dr. Scott Helzer: Project Coordinator/Instructor
Dr. Nikhil Gupta: Project Co-Mentor
Dr. Jonathon Clark: Project Advisor
Dr. Micheal Frank: Project Advisor
Mr. Ricardo Aleman: Project Teaching Assistant
Mr. Samuel Botero: Project Teaching Assistant
Mr. Yuze Liu: Project Teaching Assistant

Team Biography—

Ian Nowak: An Electrical Engineering student that attends the FAMU/FSU College of engineering. He works at the Center for Advanced Power systems (CAPS) doing work on a Piezoelectric Disconnect Switch. He also has plans to attend Graduate School for Digital Signal Processing after completing his undergraduate degree.

Coen Purvis: A Mechanical Engineering student who attends the FAMU/FSU College of Engineering. He is on track to finish his undergraduate studies in the spring of 2015. He plans to attend Graduate School to further his education after completing his undergraduate degree.

Amanda Richards: A Mechanical Engineering student who attends the FAMU/FSU College of Engineering. She currently works at Modern Professional Engineering doing HVAC design and calculations. She plans to move to Charleston, SC after graduation to work for Cummins Inc as a Product Validation Engineer.

Grant Richter: A Mechanical Engineering student who attends the FAMU/FSU College of Engineering, specializes in Mechatronics. From Orlando, intends on going into industry after graduation.

Jeremy Rybicki: An Electrical and Computer Engineering student that attends the FAMU/FSU College of engineering. He works part time as an IT consultant for medical ad surgery centers. Has recently accepted a position as Systems Engineering intern at Northrop Grumman for the Summer of 2015. After graduation he is interested in working with embedded systems and software engineering.

Nathan Walden: A Mechanical Engineering student who attends the FAMU/FSU College of Engineering. Interests are in the robotics and controls section of engineering. He is the President of Pi Tau Sigma

Abstract—

Jeff Phipps is a local organic farm owner who is in need of extra help in maintaining the weeds on his eight-acre farm. As of now organic farming is costly due to the amount of man hours needed to make up for the fact that herbicides and pesticides cannot be used. In an attempt to reduce the cost of organic farming an autonomous weeding robot will be built to monitor the fields 24/7 and take out the cost of labor. This projects contains strict constraints that will dictate the direction of the robot design. These include minimally compacting the dirt, navigating successfully through the plot, removing 60-70% of weeds overall. For navigation computer vision will be used, this method will provide the most robust platform to carry out the needed tasks and allow for future optimization and advancement. Research tells us that the final design can be up to 60lb, which will allow for minimal soil compaction as the robot moves through the field. By testing soil compression with various weights and different pressure points this result was found. In order to affect 60-70% of the weeds within the field a general weeding method proved most effective, to perform this a basket weeding mechanism will be used. This project will serve as a platform for future designs that will contain more features and be able to handle an organic farm from planting to harvesting.

1. Introduction

1.1 Objective

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.

1.2 Background

This is the first year this senior design project has been introduced to the FAMU-FSU College of Engineering. Our sponsor Mr. Phipps has been working on developing an automated process to remove weeds from his farm for a few years. In addition to funding this senior design project, he is also funding a local high school robotics club to come up with a functioning design for his farm as well.

1.3 Problem Statement

The farm has to many weeds and is in need of an autonomous robot to remove weeds from the plot to increase farm efficiency.

2 Project Definition

2.1 Background Research

The idea of integrating robotic systems onto farms to reduce the labor and human dependency is not a new one. This application has been researched extensively, especially in European countries like Denmark, the Netherlands and Italy. Many of these ideas are already prototyped and are being used on farmland on a day to day basis.

The majority of these prototypes require a single person to navigate through the crops and typically use cameras or infrared sensors to spot the weeds, which they can differentiate from vegetables by using pattern recognition. The Steketee Machine Factory has developed an automatic hoeing machine that affects ten rows of crops at a time. While this does not remove the weeds, it does agitate the surface of the soil in preparation for planting and allows a consistent and uniform approach to farming.

One example of a working prototype that hits very close to home comes from a Danish engineering company, F. Poulsen Engineering. They focus directly on creating robots for use on organic and conventional farming that provides efficient and economical weed control without the use of herbicides. This machine primarily focuses on cultivating and can affect at most, thirty six rows of crops at one time. It is capable of operating 24/7 and also uses infrared sensors to maintain position between the crops. Currently, the robot is not autonomous but work is continually being done to enable the machine to run on autopilot.

2.2 Need Statement

The Robotic Weed Harvester Team is sponsored by tinkerer and inventor Jeff Phipps. He owns a plot of land spanning 10,000 acres of which 8 acres is set aside for an organic farm. At present Jeff is struggling to make the organic farm viable for the remaining property. The main issue is that organic farming on such a large scale requires a large amount of manpower, that of which Jeff does not have. With the use of modern machines, herbicides, and pesticides a more traditional farm, of a much larger size could be run by a single person. The capability for Jeff to do the same with organic farming does not exist. Without the use of herbicides and tilling to control weeds they become a major issue. Jeff wants to change this by commissioning the DeepDivers (Team 11) to build him a 24/7 autonomous weeding robot to alleviate the workload synonymous with organic farming.

As the world's population increases, farmers have had to produce larger crops yields. This continual need to ramp up yield has led to a farming industry where bigger is king. With large scale farming comes more aggressive farming practices. Farmers employ tilling to control weeds, shape the soil, and create furrows to aid in irrigation. This method is extremely invasive to the soil. Tilling destroys the biodiversity in the soil, microbes in the top layers of soils are killed along with beneficial insects such a worms. Having a large microbe biodiversity in the soil makes food such as nitrogen, carbon, oxygen, hydrogen, potassium and other trace minerals available to the plants. As microbes eat they produce waste which is in the form of plant food. The worms that are destroyed loosen the soil in a way that allows a plants roots to more easily take hold and grow toward the area where large concentrations of food lies. It also causes material in the soil to aerate and decompose faster than normal which releases carbon into the atmosphere. This an environmental issue which is at the forefront of public thought. If a no till method was adopted then farms would act more as a “carbon sink” then an annual carbon release.

The main issue with a no-till organic farm is that it require a large amount of manpower to maintain. This makes them costly to run in the market saturated by high yield farms using traditional techniques. With no till organic farms the main consumer of manpower is the weeding of fields. A solution to this is to build a low impact 24/7 weeding robot that can perform the task of weeding without human input. This would be a tool no till organic farmers can use to achieve all the benefits of this type of farming while driving prices down an enabling competition with more traditional farms.

“Organic Farms require too much manpower to run because the weeds cannot be controlled without continuous care by the farmer in the absence of tilling and herbicide.”

2.3 Goal Statement and Objectives

Goal Statement: “Design a robot capable of autonomously weeding a farm.”

Objectives

- Navigate an appropriate set farm plot
- Be able to properly avoid the crops on each row
- Remove weeds within the rows of crops

2.4 Project Constraints

Since this project is about satisfying the customer's needs, it is imperative that the constraints are carefully outlined. The customer hopes that this robot will be advanced in capabilities, but these constraints will encompass the requirements that the senior design team believes can be satisfied within the allotted time and budget.

The following are primary goals, and these goals will be a measure of success for the finalized product. With all of the equipment on the robot, it should not compact the dirt in the plot by more than $3/8^{th}$ of an inch. Additionally, it must be able to navigate successfully through the plot by avoiding the crops and staying within the allotted area in between them. Most importantly, it must be able to remove weeds from the plot (meaning that the weeding mechanism should affect 100% of the dirt, but needs to at least remove 60-70% of the weeds). Also, this weeding mechanism should not disturb more than an inch of soil. As mentioned before, there is a wealth of biodiversity in the soil and deep disturbances will hurt the health of the client's organic farm. As stretch goals, the robot should be able to run 24/7, operate in any weather, and be waterproof. These stretch goals will be attempted if the primary requirements of the project are satisfied.

3 Design and Analysis

3.1 Mechanical Design Considerations

3.1.1 Frame

Field testing analysis tells us that the total weight of the robot can be a maximum of 60 pounds. With this in mind, we have decided to manufacture the frame of the robot out of perforated steel rather than our original plan of anodized aluminium. This is due to the fact we want to be able to support any force the weeding mechanism might place on the design as a whole and we will still be able to stay under our weight limit without placing too much pressure on the soil.

The perforations in the framing will allow for variation the components attached to the frame and will allow for a multi-purpose autonomous machine if need be. The plan is to perfect the weeding mechanism and have the design available for additional attachments other than weeding mechanisms, like watering or harvesting mechanisms.

The size is also extremely important because it will determine how many the passes the robot needs to do in order to cover each row in the plot. The robot will be half of the size of the row, an approximate 18 inches, it will have to make two passes in each row in order to cover the whole row. Even though this would take more time, this limitation is likely very acceptable; the sponsor has indicated the robot should sacrifice time for efficiency. However, if the robot is the length of the row, it will be able to cover the whole row in one pass. If the width were about the length of the row, the robot would be larger and would weight more.

3.1.2 Weeding Mechanism

The weeding mechanism will need to not only be light weight, but also durable, cheap and efficient. To handle this we will be using carbon fiber steel. All of the weeding mechanisms be about 20 inches wide. This is so the robots weeding path will overlap by a couple of inches. The weeding mechanism will also be limited to half of the height of the robot which will make it have a height of 4 inches. This is so the robot is not thrown off balance under extreme circumstances.

General Area Method

During and up to the midterm presentation, the group a primary decision that would affect the rest of the development of the weeding robot: general area or find and pick weeding methods. The find and pick method involved identifying each weed in the rows and picking each one individually before moving onto the next weed. The general area method is more like a lawn mower; when it passes over an area in the row, it will ideally remove all of the weeds by agitating the dirt or physically pulling the weeds in a line at once.

For some time, this decision prevented forward progress by the group, as it was necessary to choose a method before moving on. This decision would affect all three components of the project: navigation, locomotion and weeding method. By preventing forward progress, developments in the design of the project was hindered, so it was decided that the group needed to make a decision as soon as possible.

Figure 1. Computer vision accomplished by CornStar Project

After some deliberation, it was decided that the general area method would be used. While the find and pick method could have potentially be successful with pulling the weeds from the plot, it was determined that it would be outside the scope of the project. This is because with the find and pick method, much effort of the group would have been spent on the identification and finding of the weeds. This necessarily would have involved computer vision and filtering. While this is possible, it could have turned out to be unreliable or inaccurate. Such computer vision has been accomplished by the CornStar project (2009 proceedings, pg 40) seen in figure 1, but this was a complicated project, and the algorithm was only able to detect bright yellow balls among carefully controlled rows. However, computer vision could be a viable method for navigation, as opposed to weed identification.

Figure 2. Robomow in action

On the other hand, general area methods have been shown to be successful, and even commercially viable. For instance, the Robomow shown in figure 2 is available for purchase in several models. It travels along the contours of a lawn and navigates around the boundaries of the lawn. It is able to mow in strips, and can cover the entirety of a lawn autonomously. This highlights the viability of the general area method, and the group believes that this method is more in the scope of the project.

Teeth

The teeth concept works by having a layered set of teeth, as seen in Figure 3, that will vibrate back in forth which will lead to the cutting the weed or pulling the weed from the ground. One concept with the teeth is to have the material made out of a metal such as aluminium and for the ends of the teeth to be somewhat sharp. This idea is basically the same concept of how a hedge trimmer works. Another idea is to have teeth that are dull and made of rubber that translate slowly in one direction. This in theory would allow for the teeth to trap the weed and pull it out of the ground. For our design we decided the sharp teeth that vibrate back and forth would be a more viable option because each weed is a different length and therefore one would not know how long the rubber teeth would have to translate to pull the weed out of the ground.

Some manufacturing considerations are the teeth will not be allowed to go under more than one inch of soil so this will need to be taken into consideration when designing this concept. The size of the teeth will depend on the size of the robot because the teeth will span the entire width of the robot. Another aspect that needs to be taken into account is that another motor will be needed to drive the teeth back and forth.

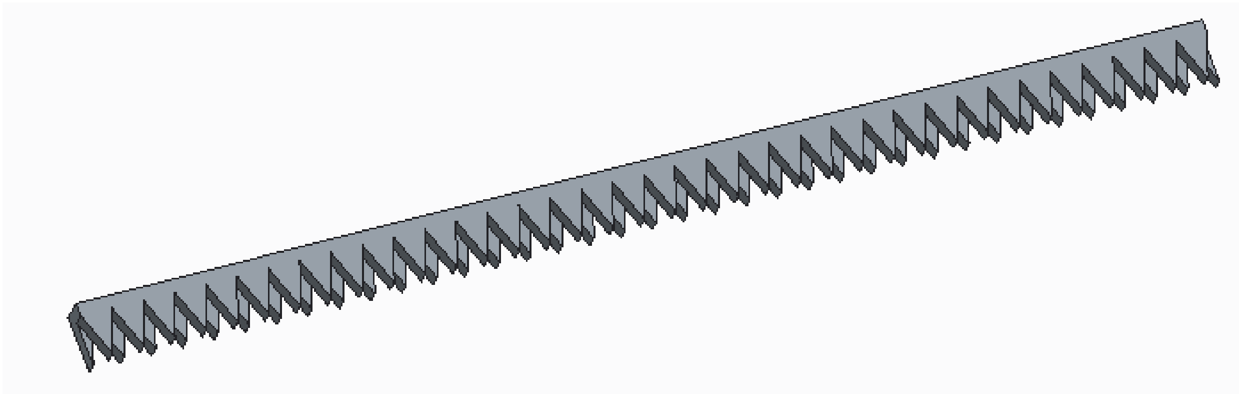

Figure 3. Weed Removing Teeth Design Concept

Revolving Doors

The revolving door concept is shown in Figure 4. The idea is to have the blades work essentially like a revolving door that is constantly spinning. The front blades will push the weed toward to wall where the weed will get trapped between the wall and the blade. Once the weed is trapped the blades keep spinning which will cause the root to be pulled out of the ground and will released out of the backside. For this design concept multiple “doors” will be needed so it can cover the full width of the robot. This is due to the fact that the blades will need to be close enough together to capture the larger and smaller weeds.

Manufacturing components that need to be taken into consideration is the fact that you will need multiple revolving doors. The idea behind this is that the blades need to be small enough and close enough together that they can trap the smaller weeds as well as the larger ones. If the blades are too far apart the weed will not go all the way to the wall and will not be pulled. Also a motor will be needed to drive the individual shafts which will in turn spin the blades and run the weeding mechanism.

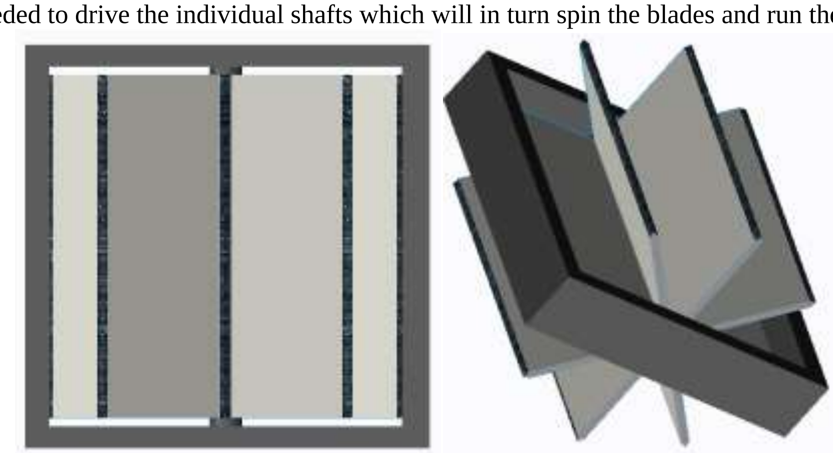

Figure 4. Weed Removing Revolving Door Concept

Helix

The helix concept is an idea that comes from a turning an auger that is normal vertical, to a horizontal orientation. In this way the helix can shift the dirt that in comes in contact with by a specific amount thereby displacing the weeds. This could move the entire root system away from its nutrients and potentially force the roots to the surface where they will do no good. This apparatus will be placed on the back of the robot so that the displaced dirt and weeds do not affect the path of the robot.

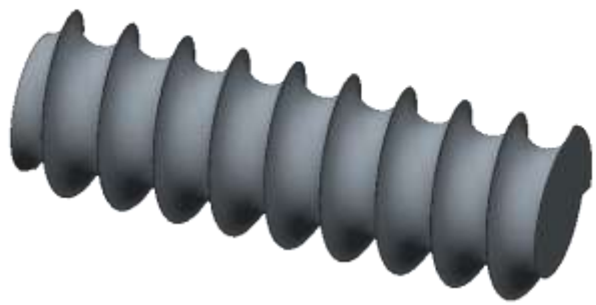

Figure 5. Weed Removing Helix Design Concept

If helix blades where to be bought on line it could cost from one to three hundred dollars. Machining them might cost less because our sponsor says that he knows someone who could do it for us. But the price for that is still unknown. If since there are companies that make helix blades it could be possible to reproduce the idea on a larger scale with only minor changes to already existing auger designs such as how they are mounted and driven. The helix itself will remain almost the same.

Basket

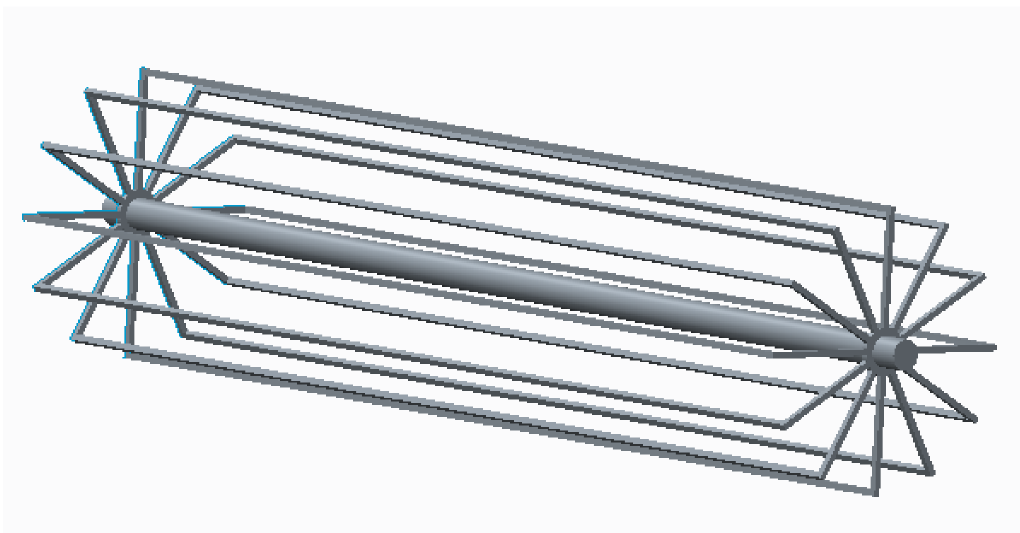

Figure 6. Weed Removing Basket Design Concept

The basket weeding design looks like a cylindrical cage that rotates on the horizontal axis. This basket sits with the edges of the basket digging almost an inch into the ground. There will be a basket that is rotated by the soil and one that is geared from the first basket to move at a different speed. In this way the main weeding basket will be moving at a different speed than the robot. This will allow the basket to sweep roots out from under the plant thereby removing the weed from its nutrients.

Although there are similar designs already in existence, it will be difficult to get them in the size and scale that we are looking for. It may be possible to alter a basket idea that is already in existence, but this will take a deeper look into the current basket designs. Because of this they may have to be machined which will usually cost more time and money. The upside is that the basket requires only a small amount of metal to be able to machine it due to the thinness of each of its parts. Because of the small amount of metal and the simplicity of the design this would not be hard to manufacture on large scale.

Pinch Point

This design concept was inspired by John Deere's Corn Threshing Machine. The pinch point weed removing mechanism is composed of two wheels with spokes. The outer part of the wheel has small extruded rubber ridges to further capture and pull weeds. The idea is to rotate each wheel upwards in opposite directions as to pull up anything in the midline of this wheel contact. Depending on the final design, the wheels will either be aligned along the line of motion or spin perpendicular to the line of motion. If the first option is decided, one of the wheels will need to be back spun and further considerations will needed to be taken to decide on the best method of which this will be done. For the other option, perpendicular motion, we will have to decide the best way to attach this mechanism to the frame of the robot as to minimize the force acting in the opposite direction as much as possible.

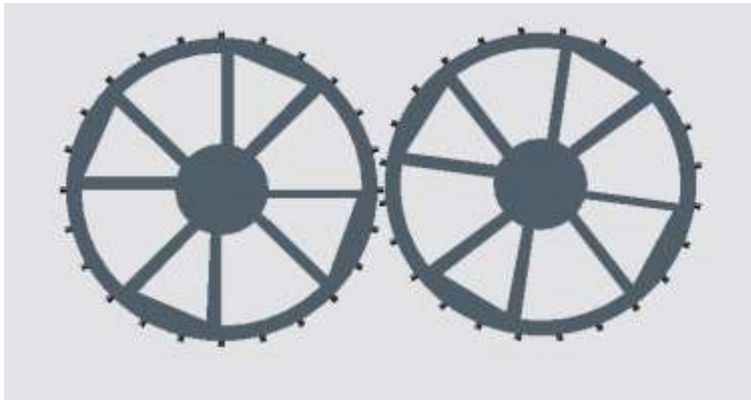

Figure 7. Weed Removing Pinch Point Concept

This design very closely resembles tires with spokes. It is safe to assume there will not be many problems in manufacturing. Additionally, both aluminium and rubber are used on a large scale and are very common materials. Depending on the type of aluminium and rubber used, cost should not be a serious issue.

3.2 Electrical Components and Specifications

Figure 8. BeagleBone Black

TABLE 1
BEAGLEBONE BLACK SPECIFICATIONS

Models	BeagleBone Black
Price	$45
Processor	1 Ghz Ti Sitara AM3359 Cortex A8
RAM	512 MB DDR3L @ 400 MHz
Storage	2 GB on-board eMMC & MicroSD
Video Connections	1 Micro - HDMI
Power Draw	210-460 mA @ 5V under varying conditions
GPIO Capabilities	65 Pins
Peripherals	1 USB Host, 1 Mini-USB Client, 1 10/100 Mbps Ethernet

Figure 9 - OpenCV DSP library (left) and Linux kernal (right)

The BeagleBone Black (Figure 8) will be at the heart of the entire electronic design. It has a powerful 1 GHz processor that is more than capable of handling the image processing required by the visual navigation system. Also the board offers a wide arrangement of I/O ports. These include 65 GPIO pins, USB connection, SD card slot, and micro HDMI. The USB port will be used to connect the camera to the BeagleBone Black. The OpenCV digital signal processing library will be used to perform all the image processing (Figure 9). This library is a powerful tool that will allow the user to perform advanced processing in days, rather than weeks if they were writing custom libraries. Since the libraries being used in the image processing are large the SD extension capabilities of the BeagleBone Black will be needed in order to add additional memory. The BeagleBone Black will be running the "Debian" Linux operating system (Figure 9). This is an added benefit of the system because Linux is compatible with the Logitech webcam chosen. Another benefit to using the BeagleBone Black is the ability to add powerful and versatile motor control capes without sacrificing any GPIO pins.

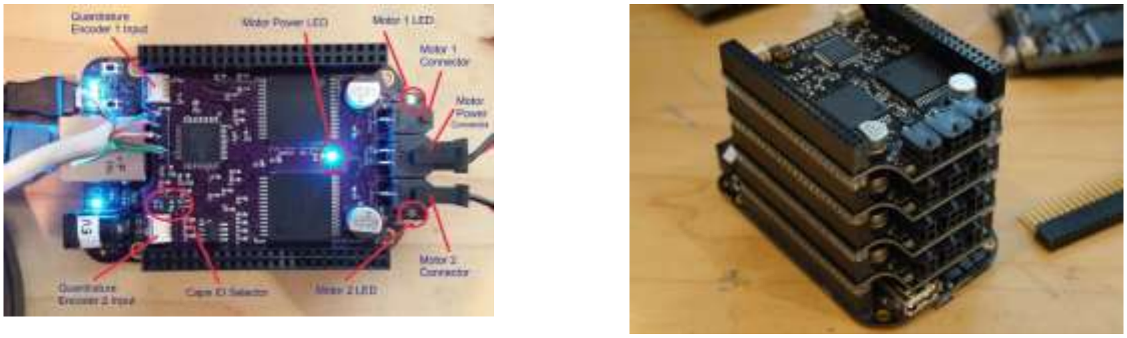

Figure 10. Dual Motor Controller Cape (DMCC) Mk.6 (Left), Device can stack to handle up to 8 motors (Right)

These dual motor control capes can handle anywhere from a 5V to 28V motor with currents up to 7A continuous draw. Each control cape is capable of handling 2 motors. These device are also stackable as seen in Figure 10. With stacking the device can be made to handle up to 8 motors at once.

The weeding robot will need to be able to conserve power when not in use. This will be done by utilizing a second microprocessor that's sole purpose is to take control when the device is not and use. This must be done because the BeagleBone Black has a GUI that will be drawing more power than necessary. A PICAXE-08M2 (Figure 11) chip will be used to prevent unnecessary wasted power. The 08M2 chip draws just 20 mA when in use, in a standby mode it can even draw less. See specifications in Table II for more detail on the PICAXE-80M2.

Figure 11. PICAXE-08M2 Microprocessor

TABLE 2
MICROPROCESSOR SPECIFICATIONS

08M2 Specifications	
Memory Capacity (bytes)	2048
RAM (bytes)	128
I/O (bytes)	6
ADC/Touch Pins	3
Max. Freq (MHz)	32
Voltage (V)	5
Current (mA)	20

A vision system has been chosen to perform the task of navigating the weeding robot through the fields. This will be performed utilizing the Logitech C310 USB 2.0 HD Webcam seen in Figure 12. This device is capable of taking images of up to 5 megapixels. This is far beyond what is needed for the task at hand. These images will have to be reduced in size utilizing the

OpenCV library. This camera also has a sleek design that can be altered to make waterproof with the addition of epoxy to seal unwanted openings.

Figure 12. Logitech C310 USB 2.0 HD Webcam Figure 13. Ultrasonic Ranging Module

In unison with the webcam will be the Ultrasonic ranging module shown in figure 13. This is needed because with only one camera there will be no ability to determine the distances of objects viewed. This ranging module requires a 5 Volt source and only draws 15 mA during operation. The maximum range it can detect is 4 meters and the minimum is 2 centimetres.

Figure 14. LiPo Battery

The entire design will be powered by multiple LiPo batteries (Figure 14). These batteries were selected for their ability to output large amounts of current to the multiple motors. Also these batteries have an 8 amp hour rating each, which is more than enough to power the device for multiple hours upon each charge. Another benefit of these batteries is the rugged casing. This will allow the robot to be exposed to the elements without too much wear on the batteries.

Figure 15. Waterproof casing structure

Finally the entire electronic system will be sealed in the waterproof structure in Figure 15. This container is air tight and water proof with a rubber lining on the rim for extra protection. The entire case is made of a high strength plastic material that will not wear during outside use.

3.2.1 Microprocessor System Designs

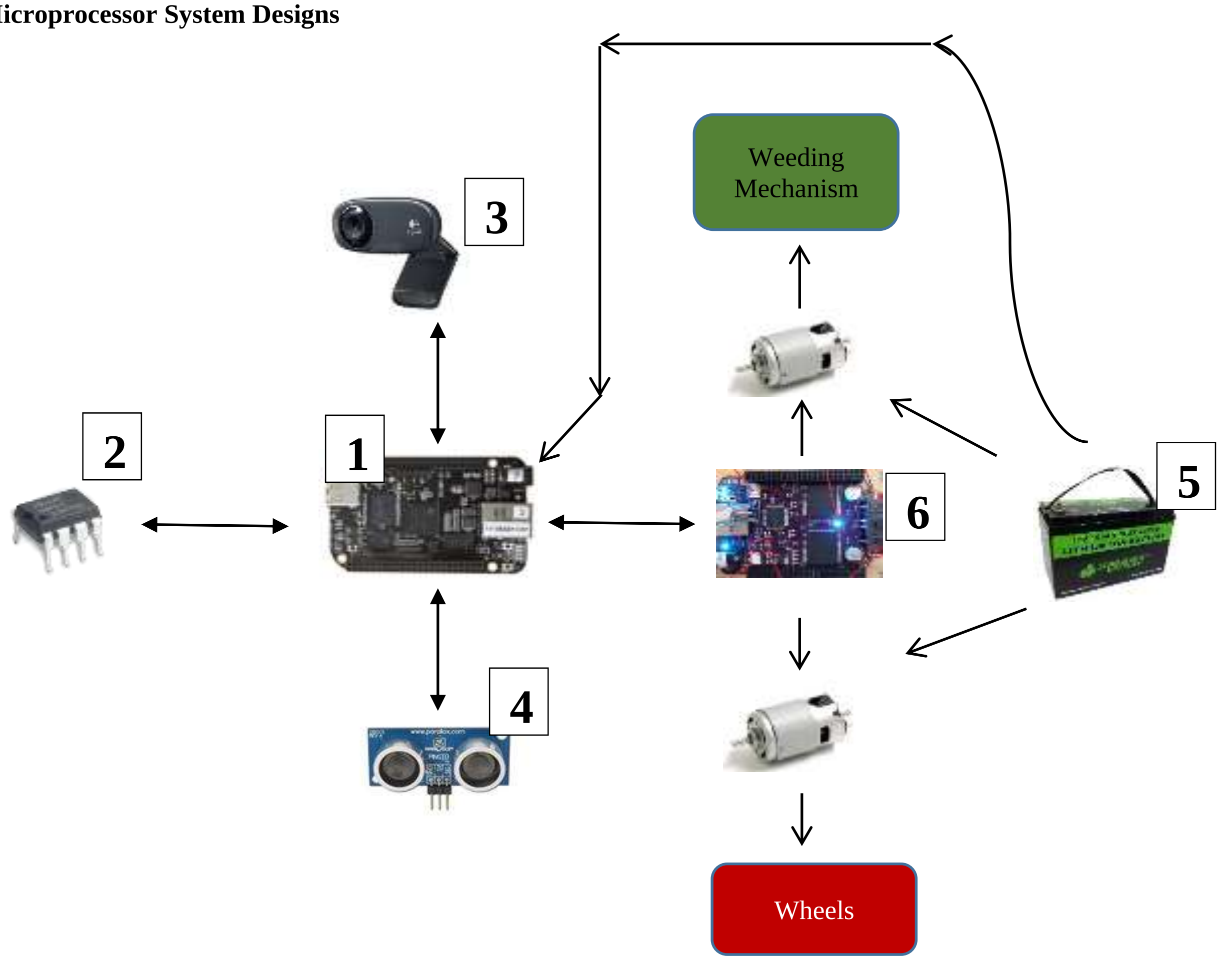

Figure 16. Electrical System Layout

1. Microprocessor
    a. BeagleBone Black – as the main controller for the entire robotic weeder. This device offers a very fast processor coupled with large amounts of memory that will be able to handle the image processing for the camera. This device also has 65 GPIO pins, which is more than enough to handle all the components needed to complete this project.
2. PICAXE 0M82 – A very small microcontroller that can be used to save power and take over control when the robot is in its "stand-by" phase requiring little power which will allow the battery to run longer. Since the Beaglebone runs an operating system it will utilize much needed resources if kept "ON" in the standby phase.
3. Logitech C310 USB 2.0 HD Webcam – This is a small lightweight USB 2.0 webcam that can be customized to make it water resistant. This camera has USB 2.0 interfacing and is Linux compatible. At 5 MP and 720p at 30 fps this camera is more than adequate to handle the task at hand. Also the camera is equipped with a 5 foot USB cable allowing for easy placement at an elevated position for better field view.

4. Ultrasonic Sensor HC-SR04 Distance Measuring Module – This unit will be used in tandem with the Computer Vision to detect precise distances of objects within the Robotic Weeding bots field of view. Since only one camera will be used to detect the colors of the rows, the Ultrasonic ranging module is a necessity to accurately navigate through the field since you need to cameras for depth perception.
5. 11.1V 8000mAh LiPo Battery – By using 2 LiPo RC battery packs the robot will be able to maintain longer operability times while still being able to power a 4 wheel drive system and the microprocessor. The LiPo hobby batteries are lighter than a larger golf cart or motorcycle battery and will fit the design specifications better.

6. Motor Control
   a. Dual Motor Controller Cape (DMCC) Mk.6 – This motor controller would be more than adequate to deal with as many motors as needed. This device also excels in the fact that it can handle motors with high peak currents up to 7 A.
   b. Durable Motor Drive Shield Expansion Board L293D – This motor controller would be able to handle the amount of motors needed to complete the project. This device lacks in its ability to handle higher power motors. Also the interfacing of this device would be complicated.

Design Cost Estimate

TABLE 3
BEAGLEBONE BLACK COST ESTIMATE

BeagleBone Black Design		
Item	**Quantity**	**Cost**
BeagleBone Black	1	$52.95
Logitech C310 USB 2.0 HD WebCam	1	$49.99
Dual Motor Controller Cape (DMCC) Mk.6	2	$136.00
PICAXE-08M2 microcontroller	1	$1.89
SainSmart HC-SR04 Ranging Detector Mod Distance Sensor (Blue)	1	$8.42
1450-00 Small Polycarbonate Waterproof Case	1	$14.99
11.1V 8000mAh LiPo Battery	2	$379.98
Sum		$644.22

Power Analysis of control system

TABLE 4
BEAGLEBONE BLACK POWER ANALYSIS

Power Analysis of Design	
	BeagleBone Black Design
Current (mA)	460
Voltage (V)	5
Power (W)	2.3

All the electronic devices will be run off the chosen microprocessor, making the power analysis based off the maximum power usage of the given microprocessor.

3.3 Electrical Design Evaluations

3.3.1 Microprocessor Design

TABLE 5
MICROPROCESSOR SELECTION MATRIX

	Cost	Power Consumption	Board Connections	Microprocessor Speed	Microprocessor Architecture	Shield Expandability	Setup Difficulty	Total Score
Raspberry Pi Design	5	5	2	3	3	4	3	25
BeagleBone Black Design	4	4	5	5	5	3	5	31

The main difference between these two concepts is the microprocessor at the center of each design. The first design uses the BeagleBone black microprocessor from TI, whereas the second design uses the Raspberry Pi microprocessor board. In order to pick between these two designs, we used a decision matrix to compare certain aspects of each design. The Raspberry Pi is a simpler board than the BeagleBone, which is slightly cheaper and consumers less power. Although this is a difference, it is not a huge difference because both microprocessors are relatively cheap and consume at max less than 500mA at 5V.

The first major difference between the boards is the amount of GPIO pins on the board itself. The BeagleBone has 65 and the Raspberry Pi only has 8. This is a huge factor in the project because the board will need to interface with multiple sensors and a motor controller, so even though the Raspberry Pi could accomplish this, the BeagleBone has a large advantage.

Another huge difference between the boards is the processor on the microprocessor boards. The Raspberry Pi uses and older ARM architecture which is not supported by newer Linux distributions, and runs at a slower clock rate of 700MHz. The BeagleBone runs on a more modern ARM 8 architecture, which is supported by newer Linux distributions, at a clock rate of 1 GHz. Since the Microprocessors will be used for Real-Time DSP, the faster processor will be able to process more frames per seconds giving a more up to date and accurate data to the robot.

The final part of the decision matrix is the setup and expandability of the microprocessor boards. Since the Raspberry Pi is a slightly more accessible board and has been out for longer, there are more shields and attachments. It is also able to interface with a number of Arduino microcontroller shields, which the BeagleBone cannot. However since the BeagleBone has more GPIO pins, this is not a huge concern. The final consideration was the ease of setup and use of the microprocessor boards. The Raspberry Pi does not come loaded with an operating system and requires a separate monitor for display when programming. The BeagleBone Black comes pre-installed with an operating system, and a console window can be brought up through a regular desktop window through a USB connection. It also has onboard memory instead of using an SD card.

3.4 Mechanical Design Evaluation

3.4.1 Locomotion Evaluation

Locomotion is an important aspect to the robot. For this we compared the use of tracks, and wheels because they cause the least amount of ground pressure. When determining between the two of these options the criteria used were balance, construction, cost, maintenance, and control. The track method has better balance than the wheel method, because tracked robots usually have a lower center of gravity. The down sides to tracks are that they are more complex to construct due to their excess of moving parts and because of this they have higher cost. Another problem with having so many parts is that the maintenance cost for tracks is higher than that for wheels, but the tracks do allow the robot more options for control and maneuverability.

TABLE 6
LOCOMOTION SELECTION MATRIX

Criteria	Tracks	Wheels
Balance	3	2
Construction	1	3
Cost	2	3
Maintenance	1	3
Control	3	2
Total	10	13

3.4.2 Weeding Mechanisms

TABLE 7
WEEDING MECHANISMS SELECTION MATRIX

Criteria	Teeth	Revolving Door	Helix	Basket	Pinch Point
Simplicity	2	2	3	3	1
Effectiveness	2	2	1	3	2
Speed	3	1	2	2	2
Cost	2	2	1	3	3
Construction	2	2	2	2	2
Durability	2	3	2	2	2
Total	13	12	11	15	12

Teeth

Categories of importance to our group which will help us make our decision to what design we will use are simplicity, weeding effectiveness, speed, cost, construction, and durability. The design would be fairly simple to design however we would have to take into to consideration a motor that will drive the motion of the teeth which may complicate the design. The teeth would be effective at cutting the weeds but may not be able to destroy the root system of the weed so the weeding effectiveness is moderate. The robot could operate at higher speeds if this design were used because no matter how fast the robot is moving the teeth are still going to affect the same amount of area. This design would also be fairly cost efficient because aluminum is not an expensive material but a motor to drive the teeth would also have to be purchased. Construction of the teeth would also be fairly easy because the aluminum just needs to be cut in a patterned fashion with sharp teeth edges. Since the teeth have to operate underground they could run into something hard in the soil such as a rock causing the teeth to be susceptible to damage.

Revolving Doors

Simplicity, weeding effectiveness, speed, cost, construction, and durability are the main categories of concern to rate our design. This is one of the harder concepts to design because all of the dimensions would have to be perfect in order to have the blade trap the weed on the wall and pull it out of the ground. In theory, if the product were to work it would be effective in picking weeds because it would pull all of the weed out, including the root. This design require the robot to move slowly because the door would need to go through the whole process of trapping the weed and pulling it out. This design might also be a little more expensive because there are multiple components to the design and there will be multiple doors. Also a motor will have to be bought that will drive each shaft. Construction might also be a little tricky due to the fact that there are multiple parts and the dimensions will have to be cut perfectly to size so that the apparatus will trap the weeds effectively. This system will however be very durable because it does not have to go underground so will not be affected by any hard objects in the soil. Also the apparatus will be water resistant and will not be affected by the rain.

Helix

The important criteria that we are judging are simplicity, weeding effectiveness, speed, cost, construction, and durability. On the subject of simplicity the helix design gets high marks. The only thing this design needs to came it work is proper gearing.

The down side though is that the design does not directly affect the weeds. Since the design only shifts the dirt it is possible that the weeds will remain planted in the soil. The design itself does not hinder the speed of the robot directly but the design is more driven by the speed that the robot travels. The cost on the other had could be a restricting factor. The helix design might require a higher grade metal due to the excess force placed on it by the earth. The assembly of this design after being machined should be simple because of its small number of parts. This and its sturdy materials will cause this design to have a fairly high durability even though it will have a large amount of wear.

Basket

For this design, simplicity, weeding effectiveness, speed, cost, construction, and durability are the major criteria that are being judged. On the matter of simplicity, the basket design it probably the best. This design is self-driven and does not contain complicated motion. In addition to this the design is highly effective. Because the bars do sweep under the plant by a small margin, it is likely to pull or cut the weed from the ground. Similar to the helix design, the basket design's speed will be directly related to the speed of the robot, and will not cause much hindrance on its velocity. Because we may be able to modify something already in existence and the materials that will be used will be a cheaper metal the cost for this design should remain lower than some of the other ideas. Its construction will also be easier since we may be able to repurpose something that is already in existence. The one down side to this design is that the bars on the basket are susceptible to being bent by large force. This could compromise the effectiveness of the design but should not completely hinder its weeding capability.

Pinch Point

Rotating wheels are not a new concept. Therefore, this concept is very simplistic in its design. Using upward motion and a capturing contact point, this design would be easy to execute. As for the weeding effectiveness, this could depend on how wide each wheel is, and if the clearance between each is sufficient enough to capture weeds but also avoid frictional losses by touching. With the speed of this mechanism, there is a lot of freedom in how fast the wheels should rotate. This now becomes dependent on the method of navigation that is chosen. The materials to make this design are easily obtainable, simple, and would be cost efficient. The construction of the wheels would also be simple, but one thing that may be difficult is ensuring the rubber ridges are securely fastened on to the outside of the wheel and will not become damaged or fall off due to the strength of the root of a weed. Additionally, all materials are waterproof, but the durability is highly dependent on the method with which the system is connected to the frame. This design is desirable because of its simplicity. Instead of using some type of advanced technology to grab the weed and pull it out of the ground, a naturally occurring material would be used that seemingly does the same thing.

3.5 Optimum Design Selections

3.5.1 Weeding Mechanism

The basket weeding method has been chosen to be most effective design, as prescribed by the discussion and decision matrices. It is favorable because of its weeding effectiveness and because it does not require an addition motor to power it.

3.5.2 Microprocessor Design

Based on research and much deliberation the final design for the Robotic Weeding Device will be based off the *BeagleBone Black*. This setup ranked high on the decision matrix based on the ease of use, speed of the processor, number of GPIO pins, and the microprocessor architecture. These factors outweighed the fact the Raspberry Pi design was cheaper.
Final Control System Design: BeagleBone Black Design

4 Risk and Reliability Assessment

For this weeding robot, there are aspects of the risk and reliability assessment that fall under both physical risks and project risks. As for physical risks, the basket weeding mechanism may have sharpened blades. It is obvious that, as an autonomous robot, safety precautions should be taken. These precautions, for instance, could include protocol that stops the blades if a person is detected to be approaching the robot during operation. Additionally, safety training, safety warnings and other informative documentation should be included with the robot in order to prevent injury to the operators. In general, the spinning movement of the mechanism has potential to cause injury as well, and similar precautions should be taken for this as well. Another precaution that can be taken to prevent injuries of this nature is to ensure that the navigation systems functions as intended. If the robot veers off of its path, it could begin to damage crops, other property or even people. If this system is perfected, the risk of injury will be further minimized.

In addition to this, there are also risks to the success of the project, and with careful planning and testing, these can be avoided. One such roadblock that could cause failure for this project would be the failure of the basket method. This could come as a failure of the prototype, or failure to make a reliable basket. If the prototype fails, then the basket weeding method may not be proven to be a successful weeding method. If the basket fails, then the group might not be able to deliver a reliable product on the prescribed deadline.

5 PROCUREMENT

5.1 Purchase orders and machining

Thus far, a few of the electrical components have been ordered through various vendors through the FAMU-FSU College of Engineering. These materials are presented in the table below. The materials needed to prototype the mechanical aspects of the design were purchased on our own at the Home Depot in Tallahassee. This allowed to us to work with those materials as soon as we could and allowed for more efficient prototyping. The remainder of the materials will be purchased within the next few weeks after we have finished all testing on the prototypes and are confident in all aspects of our design.

TABLE 8
PURCHASE ORDER REQUESTS

Vendor	Item	Part Number	Quantity	Price	Total Cost
Amazon	Logitech HD WebCam C310	NA	1	$29.99	$40.46
Adafruit	BeagleBone Black Rev C - 4GB	1876	1	$55.00	$55.00
Exadlers Technologies	Dual Motor Controller Cape Mk.6	NA	2	$68.00	$136.00
PICAXE	PICAXE-08M2 Microcontroller	AXE007M2	4	$2.35	$15.67
STREAMLED	UltraSonic Module Distance Sensor	NA	1	$8.99	$16.99
				Total	$264.12

Additional electronic components that will be purchases in the next few weeks are shown in the table below. Other materials needed such as the perforated steel for the frame, the treaded wheels and various parts for coupling are still being considered for purchase to ensure the best products are used.

TABLE 9
FUTURE PURCHASE ORDER REQUESTS

Item	Quantity	Price	Total Cost
SainSmart HC Range Detector	1	$8.42	$8.42
1450-00 Polycarbonate Waterproof Case	1	$14.99	$14.99
11.1 V 8000 mAh LiPo Battery	2	$189.99	$379.98
		Total	$403.39

5.2 Budget

The total budget for our design project is $3,000 provided by our sponsor, Jeff Phipps. Of this total, $264.12 has been spent, 9% of the total. After the remaining electrical components have been purchased, we will have spent 18% of the total budget. This leaves us with a large amount of money to buy the best materials for manufacture and gives us some breathing room in the case that something goes wrong and additional parts are to be ordered.

6 Communications

This team has communicated effectively with the advisors, sponsor and professors as well as within itself. Each member has identified his/her strengths and weaknesses and as a team the work load has been divided to meet those specific skills of each person. Communication has been mainly through weekly Monday evening meetings, a group messaging system, and emails. Communication with the sponsor and advisor has followed the same manner in addition to attempting weekly conference calls with our sponsor.

7 Environmental and Safety Issues and Ethics

There are some environmental concerns with this project. The main environmental concern here is that robot is electronically powered it needs to have a battery source. Although these batteries will be well contained, there is a chance that could be punctured or the seal could be broken and they could leak poisonous chemicals into the soil of the rows of the plants, potentially killing the plants. This is a problem with LiPo batteries and especially the Cadmium in NiCad batteries[3]. In order to try and prevent this from happening, the batteries purchased will come with hard shells and be placed in a place of the robot which is not easily punctured. The only reason for these batteries to leak would be them overcharging, which if used properly with our charging system should not be possible. The battery charger will have a fail-safe so that when the battery is fully charged the charger turns off as to not over-charge the battery.

The rest of the parts on the robot pose very little environmental concern, the main issue here with the robot is safety in general. Since the robot is going to be using rotating baskets, possibly with blades on the edges of the spokes, and operate autonomously, it needs to be able to stop in case of an emergency situation. This ranges from anything to a person trying to touch the spinning basket mechanism to an animal or child getting in the way of the robots path. This is a huge issue to overcome since the robot drives itself, there needs to be an interrupt where the robot knows to stop forward motion and the weeding mechanism. This will possible through the use of the robot's computer vision. Since the robot is already using computer vision to navigate down the rows of the crops, it will also be able to detect large foreign objects if they are in the front of the robots path. If the camera picks up on an object in the front of the robot due to a sudden change in picture, it will stop operation of the motors in order to make sure that it does not come into contact with the object in front of it.

This robot is being designed for local inventor and farm owner Jeff Phipps. He is providing all of funding for the project, and has a vision of a similar device as what is being produced for this senior design project as a marketable product. All of the students working on this project are designing and building parts with this in mind, taking into consideration all safety factors which could arise by cutting corners in the design phase. In order to prevent any safety issues with this product, although it is only a prototype, it is being designed with safety as a major factor. In addition, the scope of the project for the year has been changed from what it was originally. This will allow for more time to be spent on what it is reasonable to finish in one year of work. This will eliminate the chance of a need to exaggerate or lie on what the robot's capabilities will be since it is certain the tasks which were chosen for the year are capable of completion.

8 Schedule

8.1 Gantt Chart

The Gantt chart is broken down into three parts. The first part is understanding the project. This part includes sections that revolve about getting to know the project better. From getting a better understanding of the needs of the sponsor to identifying the resources and finally elaborating on the specifications as the project continues. The second part is developing solutions. This part takes information that is being learned from the first part and applies it to creating solutions that meets the needs of the sponsor. This section includes coming up with strategies for the robot, prototyping those strategies, selecting the concept that works the best, and finally breaking that concept down into something manageable and delivering a solution. The final section is a summary of how our time is being spent on the different components of the project. Locomotion, navigation, and weeding are the different modules that the weeding robot will be broken up. These parts will each go through background research, design specification, generation of ideas, concept selection, and reviewing with the sponsor. These are a summary of what is being shown in the first two parts of the Gantt chart and are just used to help understand how everything is connected.

8.2. Resources

Another important aspect of this project is the budgeting of resources, both educational and scheduling wise. As before, each member should be scheduled for 12 hours of work per week. The Electrical/Computer Engineers are budgeted time to work on navigation of the robot, microprocessor functions and computer vision. The Mechanical Engineers are budgeted time to work on prototyping, motor selection, and final CAD designs for machining. Additionally, the team has used outside resources for working on this project. For instance, the team is able to use the senior design lab, which has provided a work area for practicing presentations and working on prototypes. The senior design team has also received good advice from professors and advisors, much of which will be included in the fabrication of the product.

One resources that will be really helpful next semester will be the Machine Shop for manufacturing purposes. The FAMU-FSU College of Engineering Machine Shop has a lathe, drill press, laser cutter and other very useful tools for the assembly of our design. In addition to this, if the Machine Shop is ever too busy or there is not ample time for our parts to be manufactured, our sponsor has mentioned another machine shop in Thomasville, CNS Machines, which could also manufacture any parts needed.

9 Results & Discussion

From what we have seen from our field testing, a conclusion can be reached about how much our robot can weigh. Knowing that a 10 lb round weight creates a depression of .25" over a surface of 2.5" x 1.5" we can determine that it takes 2.67 psi to create a .25" depression. Using a ratio of .375"(3/8) to .25"(1/4) we can see that it would take 4 psi to create a .375" depression. If we assume that the robot has 4 tires that create the same surface area on the ground we have determined that the maximum weight of the robot should be 60 lbs. From just running a rake into the ground we determined that it will not take a lot of force to scrape the weeds from the ground. In fact it the spokes of our basket weeding method are thin enough the force will be further reduced. The final result that came as a result from our field testing was that there are a large number of weeds per foot. It was estimated that on average the weeds numbered 30 per foot. This was just another example as to why weeding over a general area was a more practical idea vs finding individual weeds.

10 Conclusion

In order to satisfy the sponsor, Jeff, the group has devised a compromise between his desired goals, and the scope of the project that can be accomplished in the limited budget and time frame. The team has approached the design and construction by splitting up the project into key components. These key components are locomotion, navigation and weeding methods. One of the major aspects of our project that would guide our design throughout the rest of the project was the decision between a general area method and find and pick method of weeding. Our team decided to go with the general area method because of the weed density of the plot and felt this approach would be much more efficient. Once this decision was made the other components could be designed to agree with this method. For locomotion our robot will be using wheels rather than tracks due to the fact that tracks require maintenance and the sponsor would like minimal human interaction with the robot. Also with the results from the field test it was determined that wheels would not cause as high of a ground pressure as originally expected. For the main component of the design, the weeding mechanism, the team has decided to go with the basket weeding method due to its ability to affect every weed in its path and not foul as it is doing so. For navigation the team will be using color vision, as described in the electrical components section of the report, which will allow the robot to stay in between the rows of crops as it removes the weeds from the plot. As of now this is the only aspect of the project where parts have been purchased because more prototyping and testing is needed before the purchase of mechanical parts can be done. Throughout this semester the team has learned some valuable lessons. When the customer presents a set of goals, there is a tough compromise between the idea that the customer has and the product which the team can deliver. Also, it is necessary to allocate time to each and every task, no matter how small, in order to ensure that it is accomplished.

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Appendix

Figure 17. Gantt Chart