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

Midterm I Report

Robotic Weeding Harvester

Team Number: ECE#16 - ME#11

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Abstract

Jeff Phipps is a local organic farm owner who is in need of extra help in maintaining the weeds on his eight-acre organic farm. This report will outline the plan of action Team 11 desires to take in the design and implementation of a weeding robot that will provide this extra needed help on Mr. Phipps' farm. In addition to this, the report will summarize and explain the product specifications of which we will adhere to in order to develop the best product for our sponsor. Thus far, taking background research into consideration, design ideas have been brainstormed and modeled. The product specifications provided to us by our sponsor in addition to specifications we thought as appropriate aided in the design of certain components that would be possible for our final designs. Proper scheduling and resource allocation have been assigned for tasks throughout the remainder of the semester to ensure our strict timeline is followed. In the upcoming weeks, we hope to have our design ideas approved of by both our sponsor and advisors. At this stage we would like to request funds for the purpose of prototyping to test our preliminary ideas. The group plans to build individual components of these preliminary ideas in order to test their feasibility. By testing the individual key components of this project (locomotion, navigation and weeding methods), the group can unbiasedly determine the best idea for each of these components.

1.0 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.

2.0 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.[1]" 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. The Steketee IC Automatic Hoeing Machine is pictured below on the left.

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"[2]. 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.

Figure 1. The Steketee IC Automatic Hoeing Machine[4]

Figure 2. ROBOVATOR from F. Poulsen Engineering[2]

There are a few noticeable differences between the prototypes previously mentioned and the focus of our project. These examples do not include complete autonomous motion, one of the main objectives we hope to accomplish. The ROBOVATOR from F. Paulsen Engineering is close to success in autonomous motion but in the majority of the testing, the machine does not always maintain linear motion down the rows of crops. This is a huge issue, especially with such large, damaging equipment. This is something we hope to stay away from in our own design. An additional discrepancy seen between the existing technology and what we hope to accomplish is a robot that has very minimal ground pressure. In the previous examples the machines are able to affect a larger amount of rows at once but largely affects the ground pressure and the soil at the far end of the machine where there is contact with the wheels.

Figure 3. Hortibot in action

According to an article in the Ludington Daily News, Michigan, "Danish agricultural engineers have built a robot to help farmers with weeds. The Hortibot is about 3-foot-by-3-foot, is self-propelled, and uses global positioning system (GPS). It can recognize 25 different kinds of weeds and eliminate them by using its weed-removing attachments. It's also very environmentally friendly because it can reduce herbicide usage by 75 percent. But so far, it's only a prototype and the Danish engineers need to find a manufacturer for distribution.[3]" Hortibot is an excellent example of what we wish to accomplish in our design and is pictured to the left.

It can be noted that some of the existing technology, excluding Hortibot, does not completely focus on weed removal but instead on the cultivation and soil preparation aspects of farming. One of the gaps in this technology we would like to fill and improve upon would be the actual weed removal. Instead of merely sifting the top layer of soil we want to focus on affecting and removing the actual root of the weed.

A tool that was developed to make manual labor easier is the Ergonica Weed Twister. "The Ergonica Weed Twister was designed to more efficiently penetrate the soil with a minimum of soil disturbance and extract both new seedlings and deep roots of various shapes and sizes more precisely and efficiently than other hand tools and weeders[6]." The device is pictured to the right and shows the way in which the root of the weed is directly affected. This is something we would like to integrate in to our design that would be an improvement in comparison to existing designs in which the actual weed removal aspect was not completely satisfied.

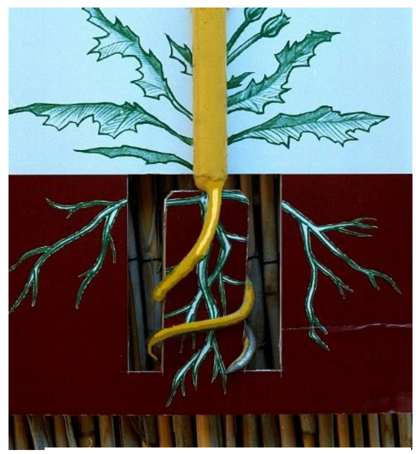


Figure 4. Ergonica Weed Twister

It is imperative that a new technology be developed to assist in this large-scale production of food to balance the ever-increasing population. As with any push in new advancements or technology, not everyone is going to support it or believe it will actually improve mankind. We experienced some of this opposition directly when speaking with the master farmhand at Orchard Pond Organics. The master farmer expressed his concern that with the integration of robots on the farm, people would feel less and less inclined to educate themselves on how to correctly harvest and maintain a farm. He believes it will put many people like himself out of work and result in an ignorant and uneducated group of people relying on technology to feed themselves.

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 & Objectives

Goal Statement: “Design a robot capable of 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 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 3/8th 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.

Table 1. Requirement ranking from 0-5 (least to most)

Requirement	Priority
Movement/Navigation	5
Ground Pressure	5
24/7 Operability	3
Charging Station	3
Waterproof	4
Weeding Capabilities	5

3.0 Design

3.1 Functional Analysis

3.1.1 Frame

Because the designs for locomotion, navigation and weeding methods have not been definitively chosen as of yet, it is difficult to formulate an exact design for the frame of the robot. However, keeping in mind the ideas for these designs, as well as some of the constraints on the project, some general ideas about the frame can most certainly be discussed.

In order to keep the ground pressure as low as possible, the weight of the frame will have to be light. Anodized aluminum 6061 would be the ideal material for this. Aluminum is a light weight material that is readily available. It could be purchased in bars or plates, and is an easily workable material. Additionally, it will be durable enough to withstand the weight of the components. Also, aluminum is still reasonably strong, and it has a reasonable amount of corrosion resistance, which is important since the robot will be operating outside.

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

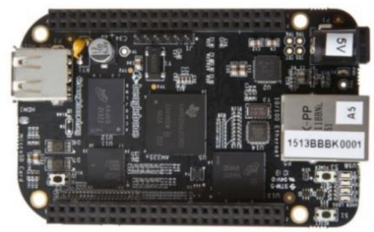
The weeding mechanism will need to not only be light weight, but also durable, cheap and efficient. To handle this we will be using an anodized aluminum 6061. This alloy, like other aluminum alloys, is light weight and fairly cheap. Because of aluminum's characteristics it is also easier to machine than other metals. Finally the fact that it is anodized should ensure that it is corrosion resistance. 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.

3.1.3 Electrical

3.1.3.1 Microcontroller/Computer

3.1.3.1.1 Raspberry Pi B+ vs. BeagleBone Black

Raspberry Pi B+



BeagleBone Black

Table 2- Includes both the Raspberry Pi and BeagleBone Black specifications

Models	BeagleBone Black	Raspberry Pi
Price	$45	$35
Processor	1 Ghz Ti Sitara AM3359 Cortex A8	700 MHz ARM1176JZFS
RAM	512 MB DDR3L @ 400 MHz	512 MB SDRAM @ 400 MHz
Storage	2 GB on-board eMMC & MicroSD	SD
Video Connections	1 Micro - HDMI	1 HDMI, 1 Composite
Power Draw	210-460 mA @ 5V under varying conditions	150 - 350 mA @ 5V under varying conditions
GPIO Capabilities	65 Pins	8 Pins

Peripherals	1 USB Host, 1 Mini-USB Client, 1 10/100 Mbps Ethernet	2 USB Hosts, 1 Micro-USB Power, 1 10/100 Mbps Ethernet, RPi camera connector

3.1.3.1.2 PICAXE 08M2

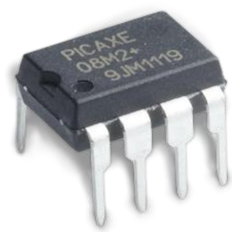


Table 3 - 08M2 Specifications

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

3.1.3.1.3 32 I/O Point Expansion & GPIO Shield Board

Figure 5 - MyPi - Protect Your Pi - 32 I/O Point Expansion & GPIO Shield Board

- Increases the Raspberry Pi GPIO pin count from 8 to 32 pins
- Has an added feature to protect the board from damage caused by GPIO inputs.

3.1.3.2 Camera

3.1.3.2.1 Logitech C310 USB 2.0 HD Webcam

Figure 6 - Logitech C310 USB 2.0 HD Webcam

- Linux Compatible
- 5 ft. USB
- Sleek design that can be altered to make waterproof with the addition of epoxy to seal unwanted openings.
- 5MP camera 720 P HD

3.1.3.3 Ultrasonic Ranging Module

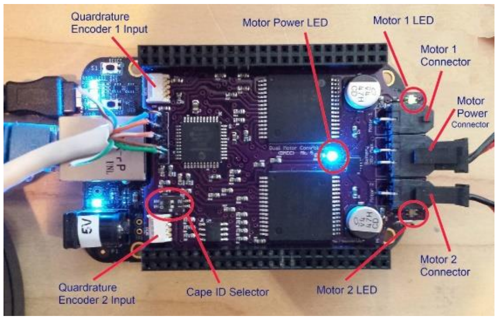
3.1.3.3.1

Figure 7 - Ultrasonic Ranging Module

- Voltage DC 5 V , Current 15mA

- Working Frequency 40Hz
- Max Range 4m, Min Range 2 cm
- Measuring Angle 15 degree

3.1.3.5 Motor Control



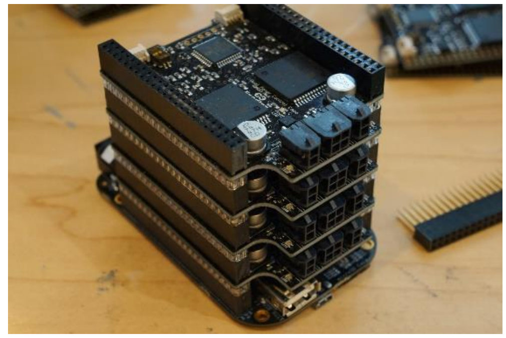


Figure 8 - Dual Motor Controller Cape (DMCC) Mk.6(LEFT), Device can stack to handle up to 8 motors(RIGHT)

- Dual DC motor control (5V to 28V)
- Motor speed and Motor direction (reverse / forward) control
- High Current (up to 7A continuous per motor)
- Stackable, up to 4 DMCCs can be stacked
- Dual Quadrature encoder interfaces on each board
- Built in PID control firmware

Figure 9 - L293D Motor Drive Shield Expansion Board for Arduino which can be interfaced with the Raspberry pi

- This is an Arduino Shield that can be interfaced with the Raspberry Pi B+
- L293D is a monolithic integrated, high voltage, high current, 4-channel driver.
- Can Drive 4 DC motors
- 0.6A average draw with 1.2A peak current

3.1.3.6 Software

3.1.3.6.1 Image Processing Library

- Library of programming functions which are aimed at real-time computer vision

3.1.3.6.2 Kernel

- Open Source operating system which will be used on the Final microprocessor setup

3.1.3.7 Waterproofing Protection

Figure 10 - Waterproof casing Structure

- Air Tight & Waterproof
- Rubber Lining to protect electronic components
- High Strength material used for outer casing to withstand the trials of a life outdoors.
- Dimensions – 9’ x 4.875” x 3”
- Will be modified to attach to the frame of the device. Modifications will also be made to allow for the wires of various peripherals to be handled. All holes will be sealed with high strength epoxy.

3.1.3.8 Battery

Figure 11 – LiPo Battery

- 11.1V 3 cell battery pack
- 8000mAh capacity
- Hard case and waterproof shell for rugged use outside

3.2 Design Concepts

3.2.1 Plot

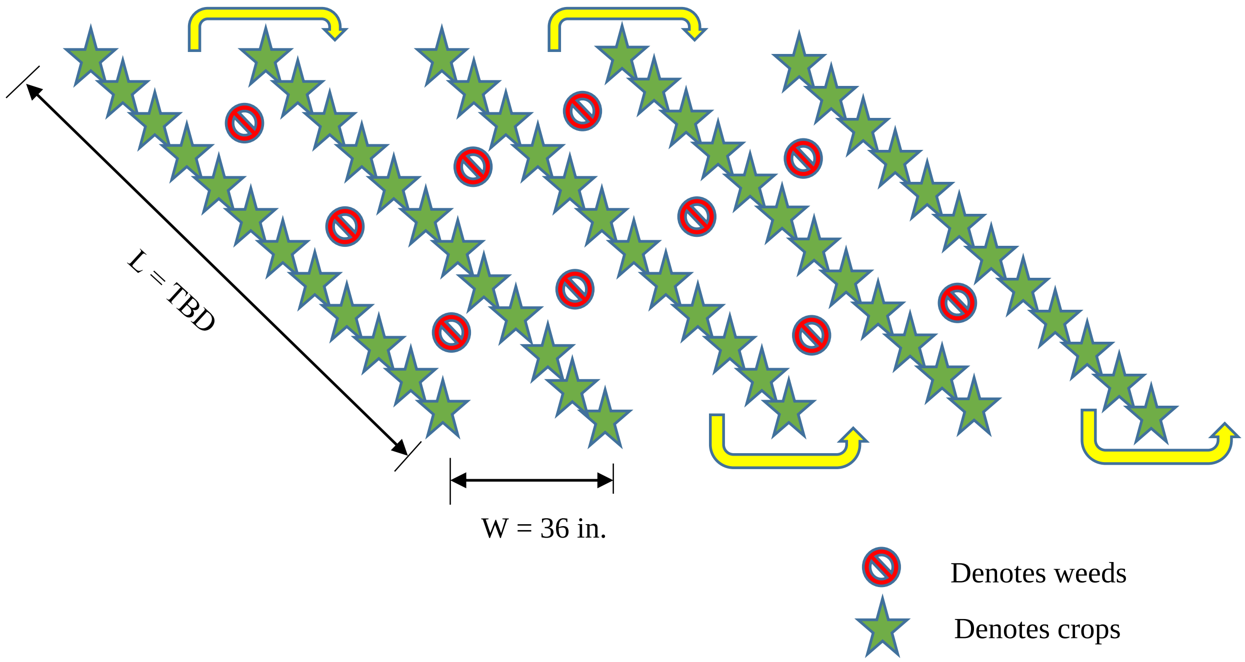


Figure 12 - General schematic of the plot

Under realistic field conditions, the rows of crops will not grow in perfectly straight lines, this must be taken into consideration when the navigation component of the robot is designed. Ideally though, the robot will be programmed to avoid the crops, whether they are in a straight line or not. In between the crops, the dirt will be flat, as it will be easier for the robot to navigate over this type of terrain. The number of rows has not been determined yet, but it should be arbitrary, as the robot should be able to weed any number of rows.

3.2.2 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 13 - Computer vision accomplished by the 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[8] (2009 proceedings, pg 40), 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 14 - Robomow in action

On the other hand, general area methods have been shown to be successful, and even commercially viable. For instance, the Robomow[9] 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.

3.2.3 Weeding Mechanisms

3.2.3.1 Teeth

The teeth concept works by having a layered set of teeth, as seen in figure …, 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 aluminum 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.

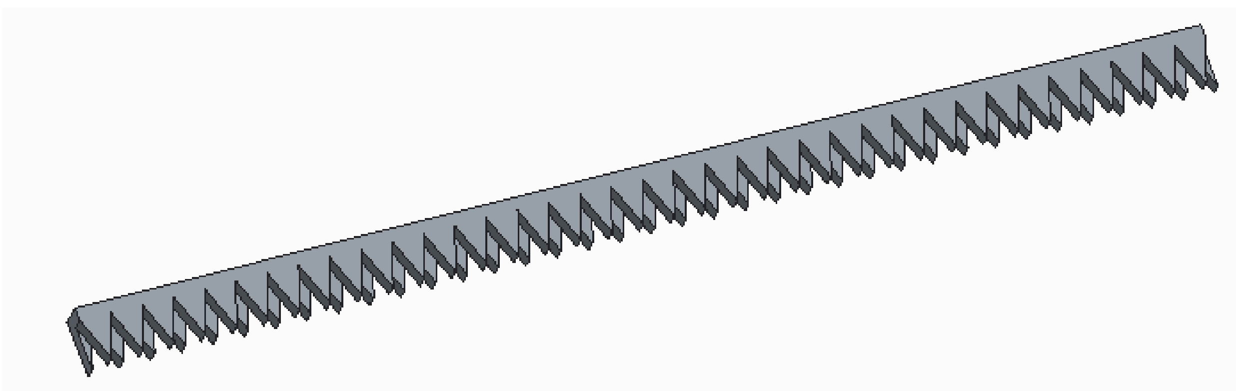


Figure 15 - Weed Removing Teeth Design Concept

3.2.3.2 Revolving Doors

The revolving door concept is shown in figure …. 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.

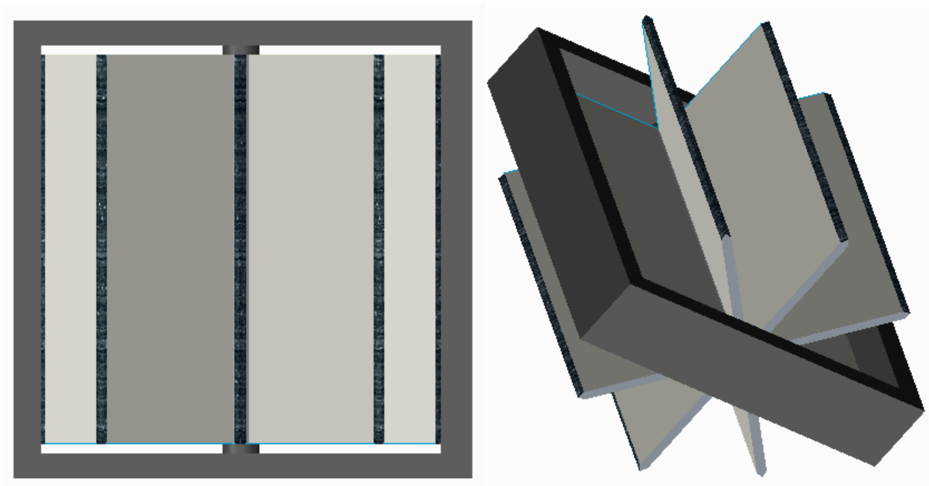


Figure 16 - Weed Removing Revolving Door Design Concept

3.2.3.3 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.

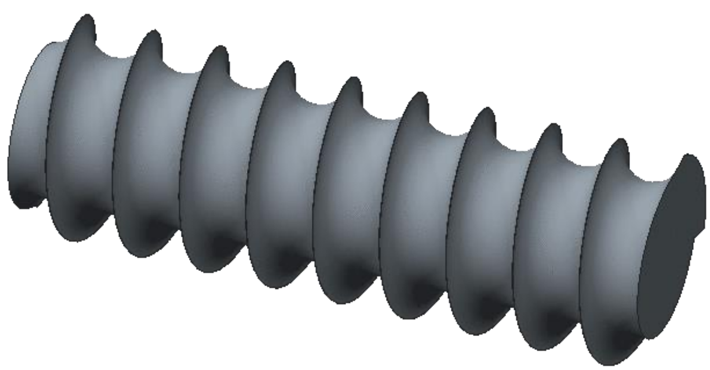


Figure 17 - Weed Removing Helix Design Concept

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.

3.2.3.4 Basket

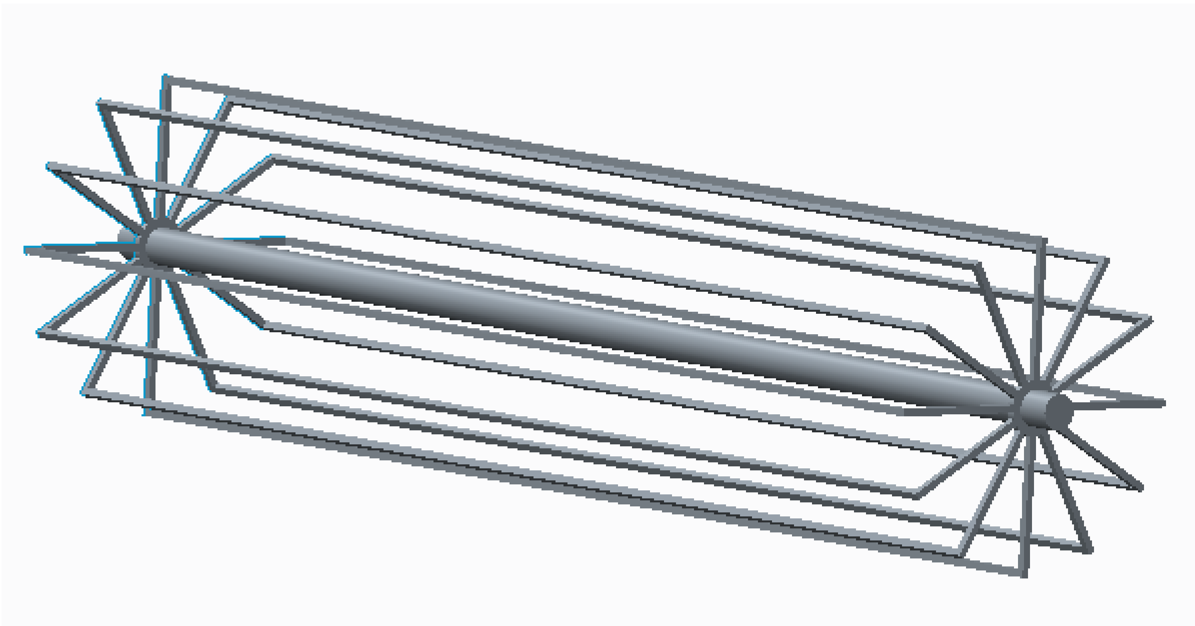


Figure 18 - Weed Removing Basket Design Concept

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.

3.2.3.5 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.

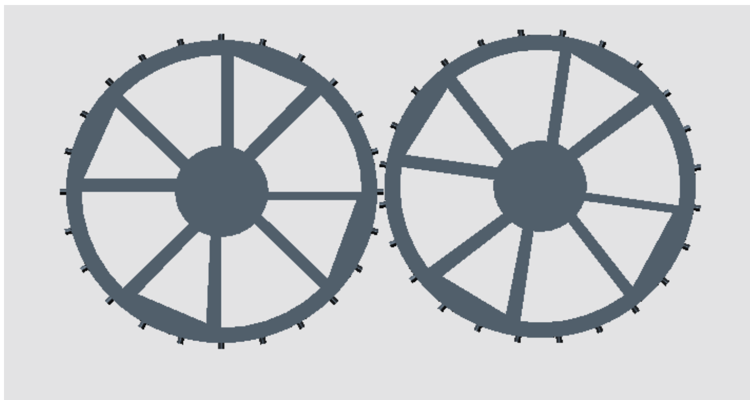


Figure 19 - Weed Removing Pinch Point Design Concept

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

3.2.4 Locomotion

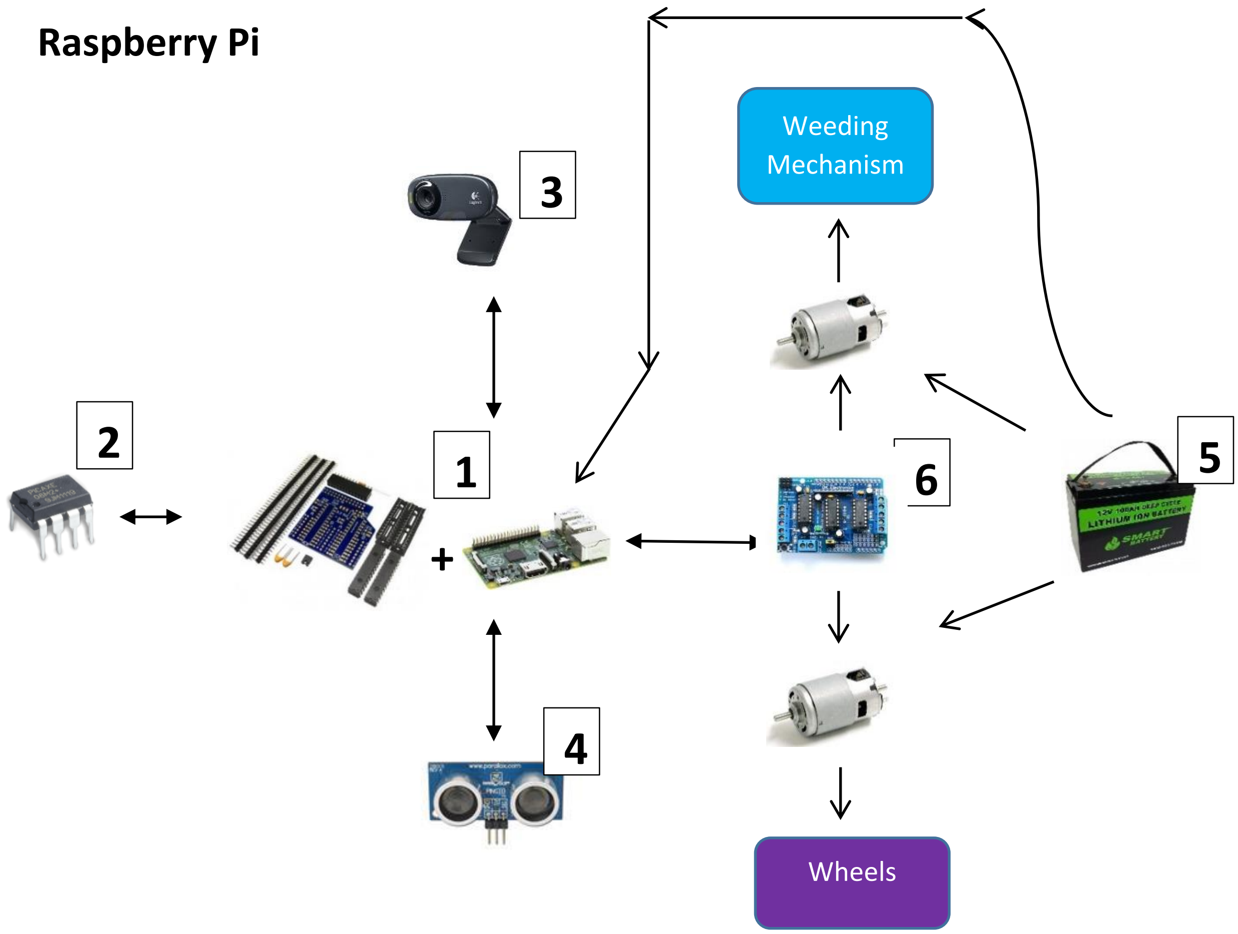
Locomotion is an important aspect to the robot. For this we compared the use of tracks, and wheels because they cause the least amount of ground pressure. When determining between the two of these options the criteria used were balance, construction, cost, maintenance, and control. The track method has 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 4 - Design Matrix for Locomotion Methods

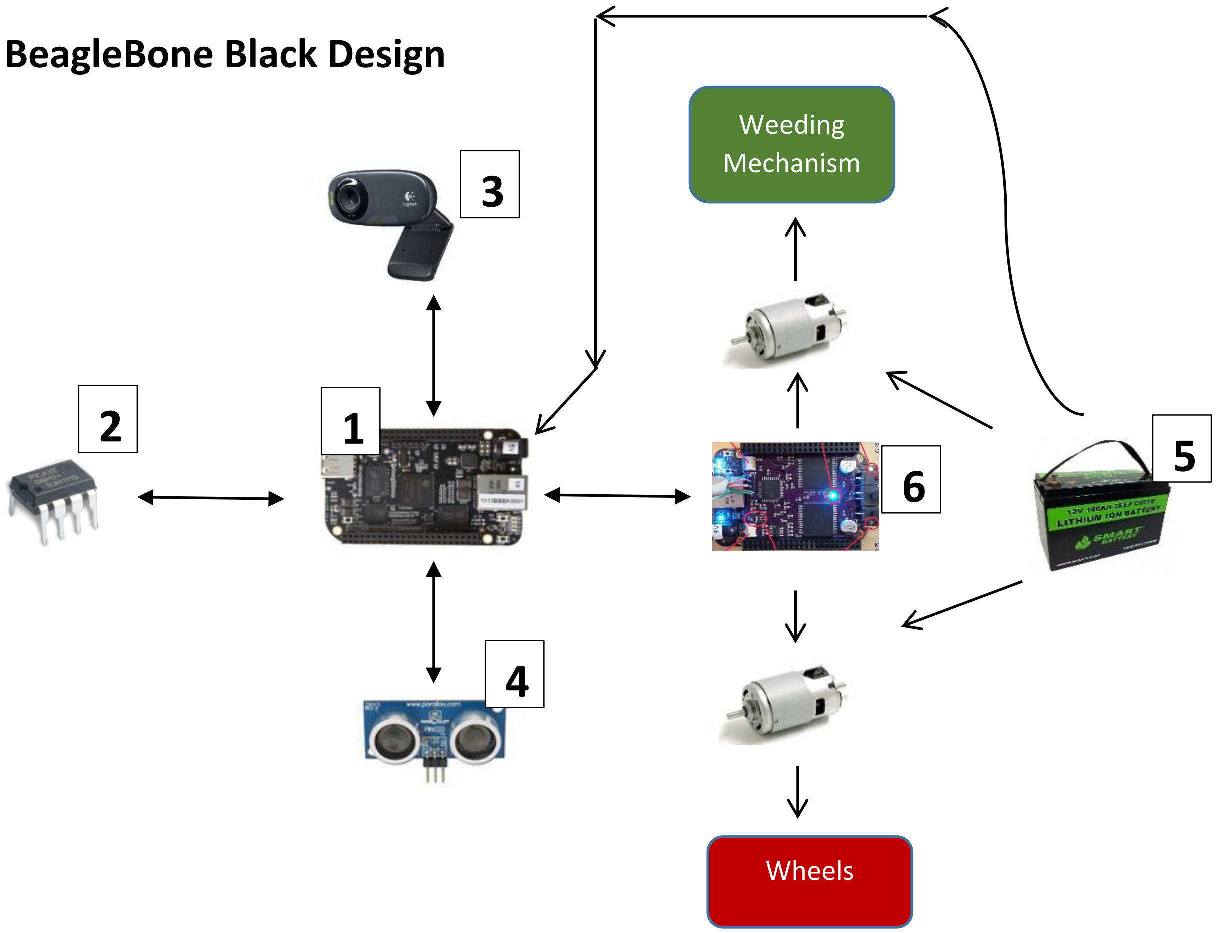
Criteria	Tracks	Wheels
Balance	3	2

Construction	1	3
Cost	2	3
Maintenance	1	3
Control	3	2
Total	10	13

3.2.5 Microprocessor System Designs



BeagleBone Black Design



1. Microprocessor (Each Diagram Above has different Controller Setup)
    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.
    b. Raspberry Pi B+ - This device would not be able to control all aspects of the robot by itself, and would require and expansion shield to meet the GPIO pin requirements. The repurposed Arduino shield would give the device 32 GPIO pins.
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.

3.2.5.1 Design Cost Estimate

Table 5 – Raspberry Pi Design Cost

Raspberry Pi B+ Design		
Item	**Quantity**	**Cost**
Raspberry Pi B+	1	$38.44
Logitech C310 USB 2.0 HD WebCam	1	$49.99
Durable Motor Drive Shield Expansion Board L293D	1	$6.24
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		$499.95

Table 6 – BeagleBone Black Design Cost

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

3.2.5.2 Power Analysis of control system

Table 7 – Power Analysis of Microprocessors

Power Analysis of Designs		
	BeagleBone Black Design	**Raspberry Pi B+**
Current (mA)	460	350
Voltage (V)	5	5
Power (W)	2.3	1.75

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 Evaluation of Designs

3.3.1.1 Weeding Mechanisms

Table 8 - Decision Matrix for Weeding Design Concepts

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.

3.3.1.2 Microprocessor Design

Table 9 - Decision Matrix For final Microprocessor Design

	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.

3.3.2 Selection of Optimum Designs

3.3.2.1 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.

3.3.2.2 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

4.0 Methodology

To accomplish this project the robot will have to be constructed in separate Subdivisions. The robot will be broken up into locomotion, navigation-localization, and weeding. Locomotion will focus on how to move the robot through rough and possible muddy terrain, while maintaining low ground pressure. Navigation-localization will deal with how to get to and through each plot of crops and deal with separating plant from weed. The weeding subdivision will determine the most efficient form of weeding without disturbing the crops or causing large amounts of damage to the soil.

4.1 Schedule

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.

4.2 Resource Allocation

The project has been broken down into several different components, each of which have subtasks that are assigned to each person. It should be made clear that each person will only work on one breakdown at a time, because the project will be in one phase at a time. Each person has a total of 12 hours of work per week.

Table 10 – Resource Allocation Table

Components	***Component Breakdown***	***Member Name***	***Hours/Week***
Frame	Research different designs	Grant	6
	Design concepts	Coen	6
	Design fabrication (CAD)	Grant	6
	Design selection	Coen	6
Locomotion	Research different designs	Grant	6
	Design concepts	Nathan	6
	Design fabrication (CAD)	Grant	6
	Design selection	Nathan	6
Computer Vision	Research different designs	Ian	6
	Design concepts	Jeremy	6
	Design fabrication (CAD)	Ian	6
	Design selection	Jeremy	6
Microprocessor	Research different designs	Jeremy	4
	Design concepts	Ian	4
	Design fabrication (CAD)	Jeremy	4
	Design selection	Ian	4
Navigation	Research different designs	Ian	6
	Design concepts	Jeremy	6
	Design fabrication (CAD)	Ian	6
	Design selection	Jeremy	6
Weeding Method	Research different designs	Amanda	6
	Design concepts	Coen/Nathan	6
	Design fabrication (CAD)	Amanda	6
	Design selection	Coen/Nathan	6
Budgeting	Weekly expense reports	Amanda	6
	Ordering parts	Amanda	6
Webmaster	Design	Jeremy	2
	Upkeep	Jeremy	2
	Total work hour per week per person		12

5.0 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 plans to approach design and construction by splitting up the project into key components. These key components are locomotion, navigation and weeding methods. While there are more desires for the project, such as 24/7 operability and waterproofing, the primary components of the project will be accomplished first. By splitting up the responsibility of the project between the group members, the team has ensured that each task has a primary and secondary accountability for each task. Through the construction of this document, 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. Finally, another lesson learned was that it is difficult to create designs that will fully satisfy the customer, as well as fit into the scope of the project

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7.0 Appendix

Fig. 20: Gantt Chart