

Robotic Lawnmower Design

ION Robotic Lawnmower Competition

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Abstract

The project objective is to design and build an autonomous lawnmower that will compete in the Eighth Annual Robotic Lawnmower Competition. This is the first year that CSU will compete in the competition and it will take place 2-4 June, 2011 at Siebenthaler's Beaver Valley Garden Center near Dayton, OH. A short summary of the design plan is presented. This report describes the design of the physical aspects of the lawnmower.

I. Introduction

1.1. Design Team

The process of creating an intelligent lawnmower requires the design of several component subsystems that must be fully integrated into the completed machine. The design team consists of three mechanical engineers and three electrical engineers. The project is set up into two different categories, electrical and mechanical. The electrical engineers are responsible for providing the electrical components; the batteries, the motor, the computer and programming the control systems. The mechanical engineers are responsible for the mechanical components, the deck, the chassis, wheels, mounting brackets, and the wheel adaptors. A majority of the electrical components have been sponsored by Invacare Products, while the mechanical items have been sponsored and manufactured by MTD Products Incorporated. Throughout the design process projects are assigned according to the engineering discipline required. It is important to take a system approach to this project to ensure all subsystems are accurately integrated into a complete unit.

1.2. Description of Competition

The Eight Annual Robotic Lawnmower Competition is sponsored by The Institute of Navigation - Satellite Division and The Air Force Research Laboratory - Sensors Directorate. The Institute of Navigation (ION) is the world's premier non-profit professional society dedicated to the advancement of the art and science of positioning, navigation and timing (PNT). The purpose of the ION - Satellite Division is to encourage the development, operation, and use of navigation and position determination systems incorporating satellite based elements. The objective of the Air Force Research Laboratory's Sensors Directorate is to provide sensor and countermeasure technology enabling complete freedom of air and space operations. Their mission is to lead the discovery, development, and integration of affordable sensor and countermeasure technologies. These sponsors present this competition as a way to challenge students to design and operate a robotic unmanned lawn mower using the art and science of navigation.

The competition will take place June 2nd through the 4th, 2011 near Dayton, OH. The main requirements of the design competition will be defined by rules and regulations set by the judges of the competition. The lawnmower is designed to meet all the competitions guidelines and produce the neatest and cleanest cut possible in the allotted time.

1.3. Competition Requirements

A. Competition Deadlines

- April 21, 2011 - Application forms and Qualification Video due
- May 12, 2011 - Reports are due by 5:00 PM EST

- June 2, 2011 - Presentations in the evening
- June 3, 2011 - Robotic lawnmower safety and autonomous operation check
- June 4, 2011 - Mowing competition
- June 5, 2011 - Rain date for competition

B. Description of Course Options

In the autonomous lawnmower competition, there are two different categories in which teams may choose to compete. These categories are based on different mowing fields: the basic mowing field or the advanced mowing field. The basic mowing field, referenced in Figure 1, is a rectangle 10 m by 15 m in size and has a 2 m safety border surrounding it. The basic field will have some type of static obstacle within it, such as a trash receptacle, which each mower in the competition will be expected to maneuver around.

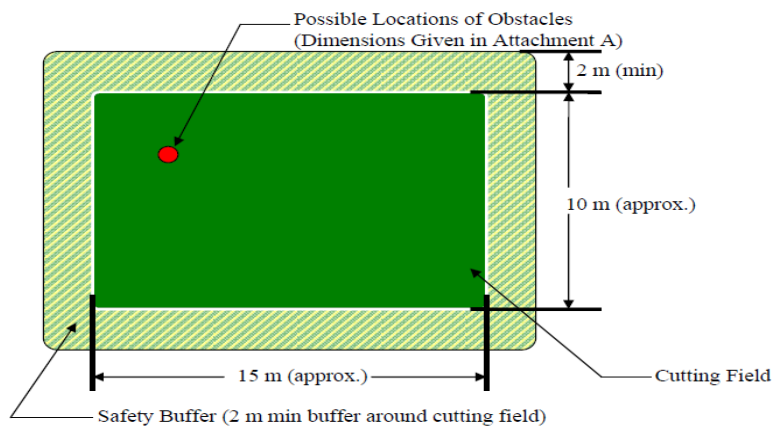


Figure 1: Basic Course

The advanced mowing field, referenced in Figure 2, has an irregular shape and like the basic field, has a 2 m safety border surrounding it. Not only is the shape of the course more complicated in this advanced field, but the obstacles are more complicated as well. There will be two obstacles. The first obstacle will be a stationary flower bed, while the other obstacle will be

a moving one. The moving obstacle will test how safe the mower is by providing a measure of what might happen if an animal or even a person was in the path of it.

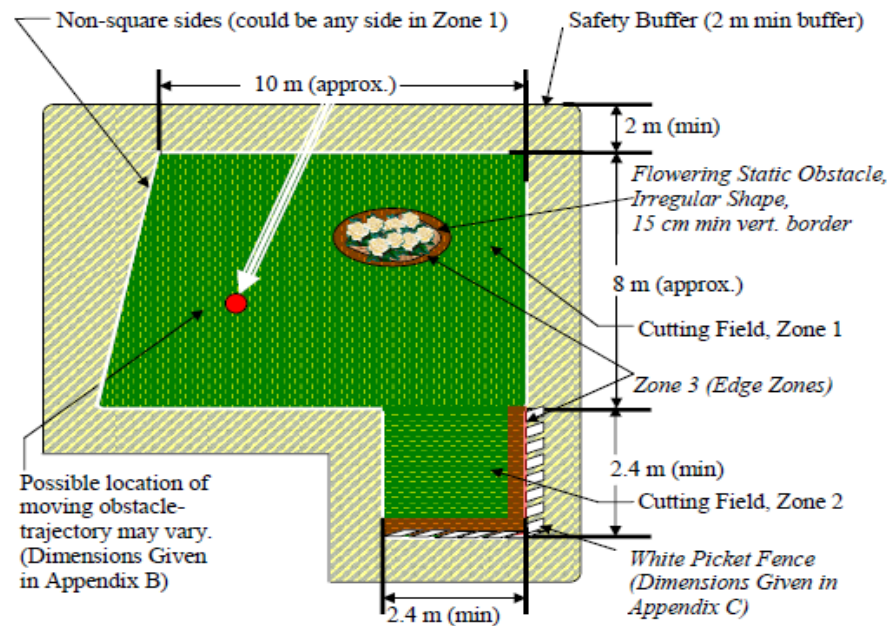


Figure 2: Advanced Course

Each team chooses which field category to compete in and the design for the mower will be based off of this decision. The Cleveland State team will compete in the basic competition. The particular cutting field that will be assigned for each team for the competition will be done at random, and the teams will not be permitted to enter their assigned field prior to their competition start time.

C. Safety Rules

- Maximum speed of 10 mph
- Emergency stop: mowing to cease in less than 3 seconds and 2 meters in distance
- Wireless emergency stop
 - Must be effective over entire field plus 10 m in all directions

- Manual emergency stop button
 - Must be red in color and at least 40mm in diameter.
 - Must be easily accessible by a standing operator behind the lawnmower.

D. Scoring and Awards

Scoring for the competition will be made up of three different factors:

- 10% Technical Presentation
- 10% Technical Report
- 80% Mowing Competition

The mowing competition will be scored on the percentage of grass mowed of the field in the basic competition and in the advanced competition; it is based on the percentage of grass mowed in three different zones. Zones are visible in figure 2, and the more difficult the zone is to mow; the more points will be added to the score for mowing that zone. Equation 1 will determine percentage of the grass mowed.

$$P_{GM} = \left(\frac{A_{CA} - A_{SB}}{A_{TA}} - 0.10N_I \right) \times 100\% - N_{RS} \times 15\% \quad (1)$$

Where:

P_{GM} = Percentage of the grass mowed (score)

A_{CA} = Area of grass cut in the cutting area

A_{SB} = Area of grass cut in the safety buffer

A_{TA} = Total area of the cutting area

N_I = Number of Impacts which move an obstacle

NRS = Number of Restarts

In the event of a tie, the team that mows the lawn in the shorter amount of time will be declared the winner.

Last year's awards for placing in the competition were as follows:

1.) Advanced Competition Awards

- First Place: \$15,000
- Second Place: \$10,000
- Third Place: \$5,000

2.) Basic Competition Awards

- First Place: \$2,500
- Second Place: \$1,500
- Third Place: \$500

This year's awards have not been posted yet and depend upon the number of sponsors. In order to qualify for the total prize amount, the team must mow at least 50% of the field. If less than 50% of the field is mowed, the team will only receive 25% of the prize amount. [1]

II. Background

2.1. Importance of Automated Technology

In undertaking this design project, it is important to have a solid understanding of the current state of robotic technology. There are many industries that are in constant pursuit for the latest in robotic technology. The main reasons for this are time and cost savings. This demand is what has driven the continued advancement of this technology. One of the first places that robotics had a major impact on is the automated assembly line. In which product is moved down

an assembly line with little to no human interaction. The success of robotics in industrial applications has led to the progression of robotics for use by consumers. The main goal of automated technology for consumers is time saving. The ability to have something accomplished without having any interaction with the process can save significant time. An example of this is a product called the **iRobot Roomba®**. This automated product is designed to vacuum carpeting while navigating itself around the room making sure to cover the entire carpeted area. There are autonomous lawnmowers that are currently being produced such as the Toro iMow® shown in figure 3 that are based on many of the same principles as that of the as that of the Roomba®. An example of where automated technology is headed is the new Google car. The Google car is an autonomous automobile that is in the process of being tested. The car has been able to run unmanned on public roads for one thousand hours, and 140,000 hours with only occasional human interference. Currently, the only accident the car has been in was a rear end collision [3]. As shown by these advancements, automated technology is a growing field and is an important part of product design.



Figure 3: Commercially available I Mow® from Toro

2.2. Study of Past Competition Designs

It is important to understand what was successful and unsuccessful in the competition and why. Successes and failures were observed from previous groups that competed in the competition for the years of 2008- 2010, such as Case Western Reserve University, Auburn University, and the University of Florida. Case Western Reserve's "CRU Cutter" and Auburn University, "MOE" shown in figures 4 and 5 were two designs that had some success in last year's competition. Chief Engineer Jim Green provided some additional insight from MTD Products Incorporated, who provided knowledge from his many years of experience in working in the outdoor power equipment industry. He has also had some experience in working with other groups who have been involved in the autonomous lawnmower competition in previous years.

There were many observations made when viewing last year's competition. Due to the competition being done in the early morning the dew caused the grass to be wet and caused many of the rear drive wheels to slip when starting from a complete stop. The wheels with a more aggressive tread design or more weight near the driven wheels fared better on the wet grass. Auburn University's design proved to be too light and the small wheels not adequate for the wet grass or the rough surfaces. The smaller wheels were either got stuck in holes, or failed to cut a straight line due to the field conditions.

The grass was also significantly long at the competition and many teams struggled to cut the grass due to the height of the mower and the height of the grass. It is recommended by landscapers to only cut up to an inch and a half of grass at a single passing of the lawnmower.

Another obstacle of the course that the design must be able to overcome is the rough surfaces, the rocks, and the holes in the field. It was noticed that if the sensors and other vital

components of the electrical systems are too close to the ground or not properly mounted, the rough surfaces caused interference and vibrations that led to failures in the sensors as well other sensitive equipment.



Figure 4: Case Western Reserve, CRU Cutter



Figure 5: Auburn University, "MOE"

III. Design Plan

3.1. Design Overview

The design of the overall system will be broken down into three fundamental areas: the mechanical platform, the electrical system, and the software implementation. The mechanical platform will consist of a sturdy steel base that is driven by four wheels using differential steering from the rear.

The electrical system will be created in two independent sections. The first will consist of the electronics portion of the robot hardware. This includes the sensory devices (i.e. infrared sensors, encoders, etc.) and their controller interface as well as, the on board computer that will

handle processing of the received data. The second section will be made of the motors and motor drives.

The software associated with this project will be designed into multiple subsystems. Separate systems will be created to handle information being relayed from the machine. This includes a higher-level manager that will determine state situations of what will be controlled.

There were many factors to weigh in deciding on the design approach of the autonomous lawnmower. The most important factors in this design are time and resources. With only ten months to build and operate an autonomous lawnmower it is imperative that the design is composed of already existing lawnmower parts. There is just not enough time to build the frame and not enough money to buy the materials. Sponsors like MTD have donated a mower deck with blade and electric blade motor, front castor wheels, rear drive wheels and the chassis of an existing walk-behind lawnmower.

Another valuable design aspect is the drive motors. The drive motors drive the rear wheels drives and steers the lawnmower by varying the electrical current and differentiating it from wheel to wheel. The motors are intended for wheelchair wheels so a motor to wheel adaptor was machined and connected to the motor. The motors are mounted to brackets that provide added support for the chassis. This configuration of the rear wheels and motors results in a tighter turning radius, having one rear wheel static while the other is moving forward or backwards to help the lawnmower maneuver in tight places and to avoid obstacles.

One sensor used in the design to generate a mowing path is a web cam that detects the white line surrounding the course. Navigation control on many commercially available autonomous lawnmowers uses a wire to define the perimeter of the area to be mowed. The rules of the competition forbid the use of any kind of perimeter wire. To counteract that, computer

vision was incorporated. In order to develop a viable autonomous lawnmower it is important that it is understood what has been done in the past and how improvements can be made on previous designs and technology employed.

3.2. Design Components

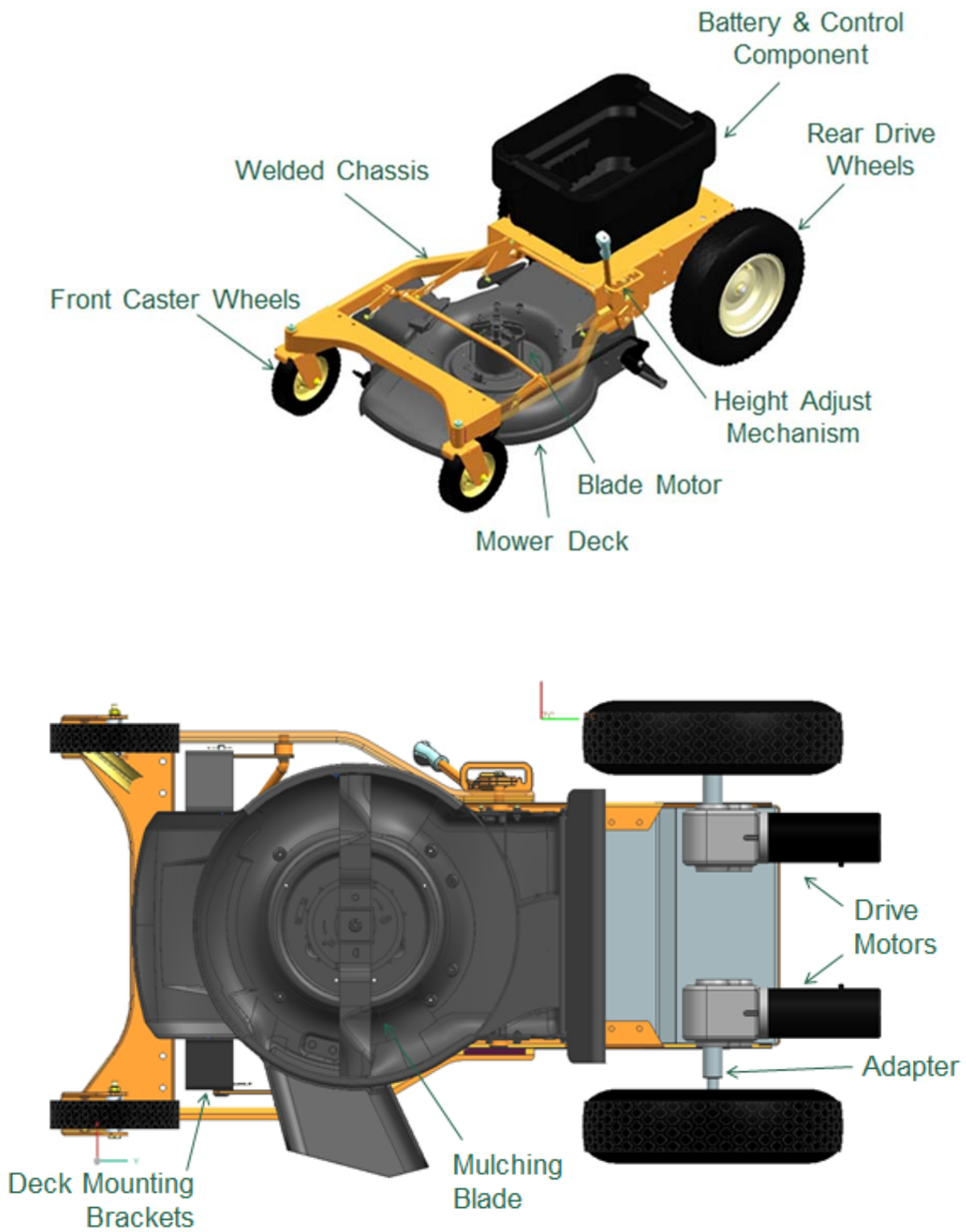


Figure 6: Design and location of the components

3.3. Mower deck and Chassis

A main component of this system is the lawnmower provided by MTD Products Incorporated. The mower deck is from a 19 inch Remington electric push mower. The chassis was provided by MTD as well, it started out as a Cub Cadet 33 inch gas powered walk behind mower that was stripped of all the pulley components, the engine, and the transmission. The chassis is composed of steel that is welded together. An FEA analysis has been done ensuring the design is able to handle the stresses and strains under the given loads. The chassis is already equipped with a height adjustment mechanism that the mower deck is rigidly mounted to. The height adjust mechanism is manual and ranges from 1.375 - 3.75 inches. The electrical items that have to be incorporated are bolted on, ensuring that if anything fractures or doesn't work properly, then new equipment can be interchanged in a reasonable time frame.



Figure 7: Chassis

3.4. Blade and Drive Motors

The blade motor used is a 24-volt electric motor, which is included with the lawnmower provided by MTD shown in figure 8. The blade motor is a permanent magnet motor that operates on the 24-volt battery, which gives the motor enough power to turn the steel blade at high speeds. The design of the blade motor will remain consistent to that of other electric mowers except that the microcontroller with a relay onboard will control it.



Figure 8: Mower Deck and Blade Motor

The drive motors are Invacare Pronto 24-volt electric motors. A motor to wheel adaptor was designed and machined to attach the drive motors to the wheels (figure 9). The adaptor is used to connect the keyed end of the motor shaft to the open hub of the drive wheel. The wheel is driven using two flat faces that protrude into the diameter of the wheel hub. The adaptor matches these flat surfaces and allows the motor to drive the wheels. A stress analysis was completed on the wheel adaptor to ensure that adaptor could handle the weight and any other

forces acting on the lawnmower. The analysis was performed using SolidWorks Simulation. A 200 psi normal load was placed on the bottom half of the shaft and the face that mates to the motor was held fixed. From this set up the stress acting on the shaft was obtained (figure 9). A maximum stress concentration of 16,097 psi was shown at the base of the smaller shaft. The alloy steel chosen as the material for the adaptor has a yield stress of 89,985 psi, which is well above the maximum calculated stress. The factor of safety for the adaptor was also calculated and determined to be 5.66, which is in a safe range for this application (figure 10).

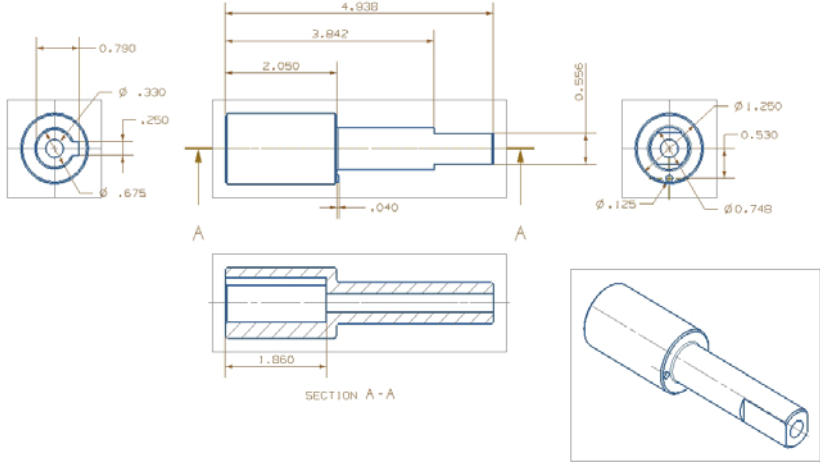


Figure 9: Motor to Wheel Adaptor

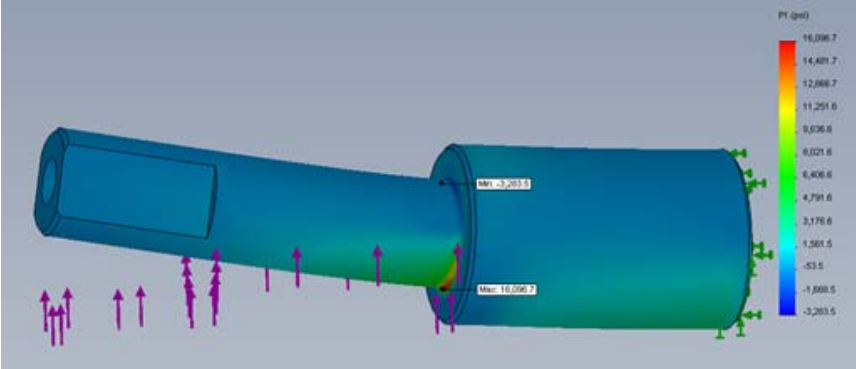


Figure 9: Adaptor Stress Analysis (16,097 psi max principle stress)

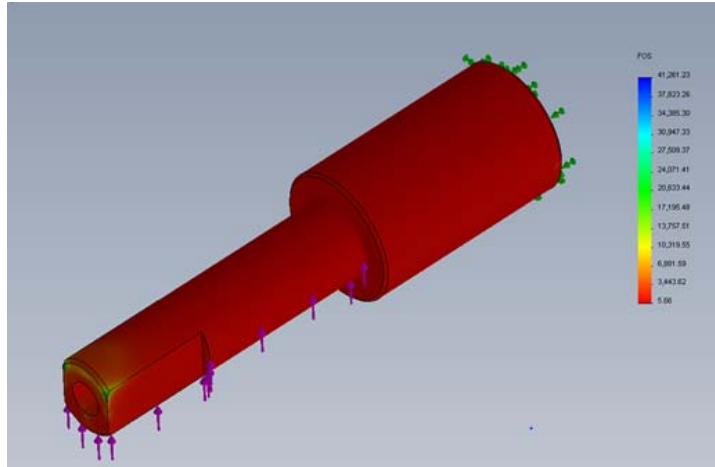


Figure 10: Factor of Safety (5.99 min)

3.5. Front and Rear Wheels

An analysis of torque and friction requirements for the drive wheels ensuring the proper diameter and width were done. The rear wheels chosen are the wheels that came with the Cub Cadet lawnmower. They have an aggressive tread to neutralize the rigorous mowing conditions and to stabilize the lawnmower, giving it a strong base. The rear wheels diameter is 16 inches and the width is 5 inches. Due to the nature of differential steering in the rear wheels, the only choice was to use a heavy duty lawnmower tire. The front wheels are caster wheels, 8 inches in diameter and 1.75 inches wide. They are also the original wheels on the Cub Cadet lawnmower. The front castor wheels are able to rotate 360 degrees without interfering with the mower deck or any of the sensors in the front of the lawnmower.

3.6. Motor Engage/Disengage

The drive motors contain an engage/disengage lever that engages the gears in the drive. This makes the mower immovable without power to the motors. Once the mower was assembled, space was very limited and levers were difficult to reach without disassembling parts

of the mower. A solution was created which allows the user to pull or push handles located at the rear of the mower frame as a means of shifting the engagement lever. This system is shown in the figure 11 below.

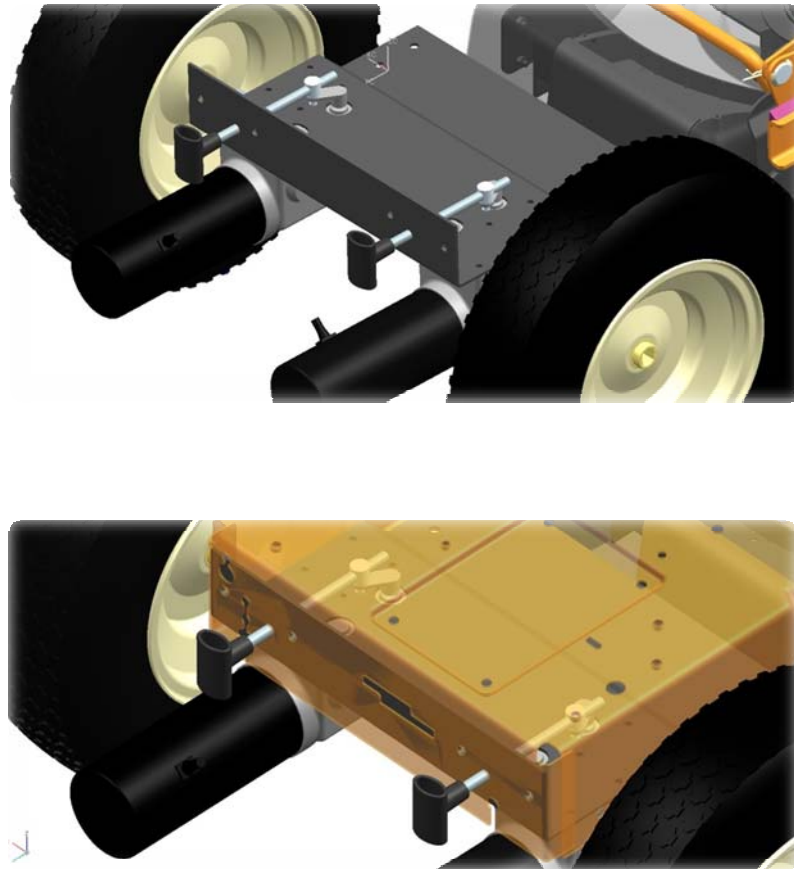


Figure 11: The design of handles to engage drive motors

3.7. Encoders

An important electrical component is used to detect the direction of the wheels by keeping track of every rotation is the encoder. The encoders were mounted to the frame. A small pulley was tightened around each encoder and a larger pulley was tightened around each wheel

axel. The pulleys act together with a timing belt to eliminate the possibility of slippage. This system is shown in the figure 12 below.

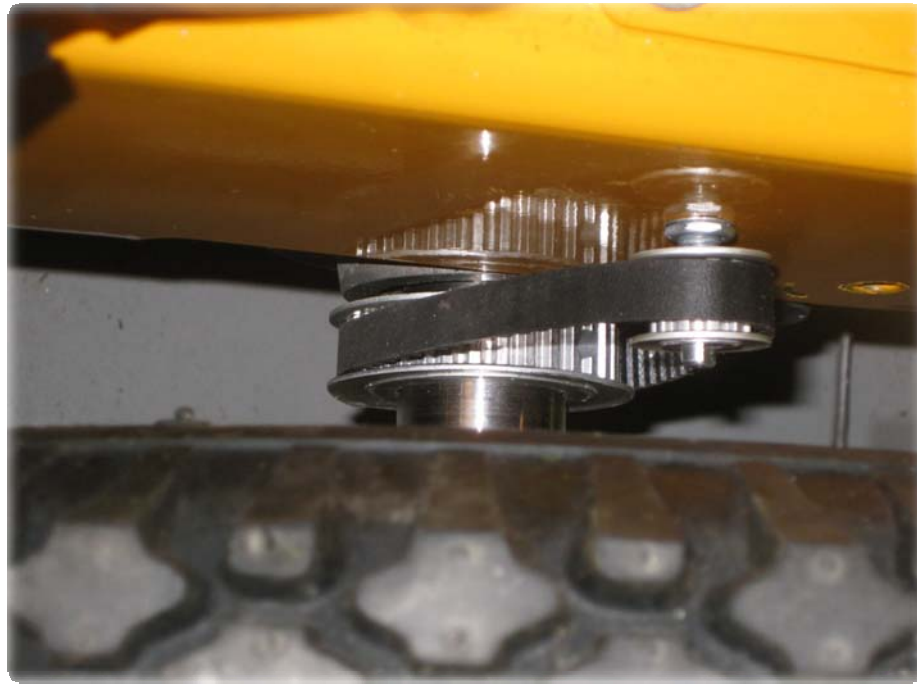


Figure 12: The motor and the encoder

The mechanical rotary encoders that we use have two signal pins and a common ground pin. As the encoder shaft turns, the signal pins are alternately left floating and shorted to ground. Figure G1 shows a circuit model of the encoder. By using pull-up resistors to keep the voltage on the signal pins high when the encoder leaves them floating, one can produce a digital signal from these encoders. The signal produced on the first encoder pin leads the second pin's signal by a phase of 90° . The mapping of these signals to the shaft angle of the encoder is called quadrature encoding. One of the most useful aspects of the quadrature-encoding scheme is that the direction of rotation of the encoder shaft can be determined by the order in which the signal transitions occur. We have chosen to use 18 pulses per revolution (PPR) encoders as these have

sufficient resolution for our needs. Timing belts and pulleys were used to rotate the encoder shafts at a rate proportional to the drive wheel shafts. The ratio of the motor shaft to encoder shaft pulley diameters, which in our case is 3:1, causes the encoder shaft to rotate 3 times for every true wheel rotation; this effectively increases the encoder resolution by a factor of three.

Figure 13 depicts the encoder signals as the encoder shaft rotates at a constant

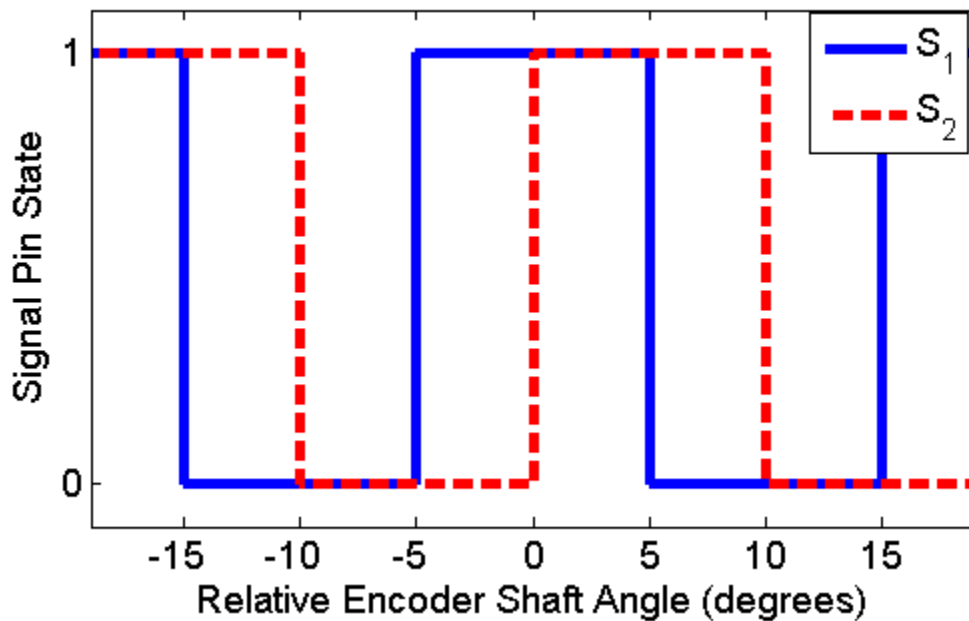


Figure 13: Signals produced by an 18 PPR encoder as its shaft rotates.

Rotary encoders for the lawnmower's drive wheels enable us to keep track of the position, velocity, heading, and other variables of the lawnmower's kinematic model. The use of sensors like encoders to calculate current position from previous position, velocity, and acceleration is known as dead reckoning. While dead reckoning is easy to implement, errors in the calculated position value will accumulate over time. For this reason, sensor precision is very important if we wish to use dead reckoning for any extended period of time.

Our lawnmower does not totally rely on dead reckoning for navigation. The lawnmower makes major navigation decisions when it detects the border of the field (i.e.: the painted white line) using image processing tools in the MATLAB(R) Image Processing Toolbox. We use dead reckoning techniques only to compute the angle of heading of the lawnmower. This angle can be used as feedback in a closed-loop control algorithm. In our implementation, we use the angle as the input for a PID controller. The output of the PID controller is a PWM duty cycle value that is applied to the left and right turn digital input pins for the OEM Invacare motor driver. If the controller output is positive, the PWM signal is applied to the left turn pin, likewise, if the output is negative, the PWM signal is applied to the right turn pin. Our navigation algorithm requires that the lawnmower make two motions; it must be able to go straight, and it must be able to make 90 degree rotations. The same PID controller can be used for both of these motions; the only thing that must be changed is the lawnmower angle set-point. In the case where the lawnmower must go straight, the set point would be a relative angle of zero degrees and the forward driving digital input pin for the Invacare motor driver is asserted. In the case of the 90-degree rotation motion, the set point is set to a relative angle of +/- 90 degrees, and the forward driving pin is not asserted.

The lawnmower's kinematic model is called the differential steering model, and is very common in robotics for its ease of use and versatility. In the differential steering model, the difference of velocity of two drive wheels produces a rotation. If the two wheel velocities are the same, the lawnmower will drive purely straight. If one of the wheel velocities is the negative of the other, then the motion of the lawnmower will be purely rotation. Any other combination of wheel velocities will produce both a rotation and a translation of the lawnmower.

3.8. Control Component Housing

The navigational and control components are crucial to the mower being able to accurately mow the field. Selecting housing for these components must be done carefully. Considerations to be made are regulating the temperature, keeping the components dry, and making sure that they are well secured. An assembly structure was designed with wooden mounts that were bolted inside the box. The mounts are designed in a way so that they will hold sheets of Plexiglas in which all of the components are mounted to. This allows for easy removal of the components by just sliding them out of the wooden slots as seen in figure 14.

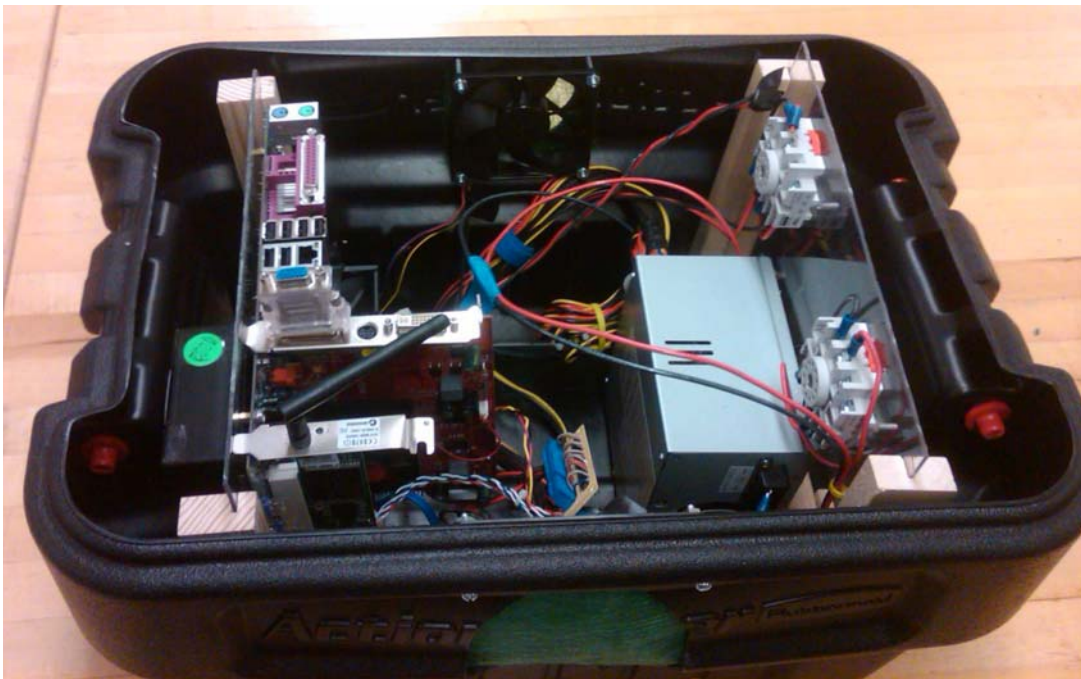


Figure 14: The design of the electrical components' box

Two fans were installed on each side of the component box as shown above. One fan acts as an inlet fan while the other acts as an outlet fan to blow out warm air that is generated by the electrical components. A flow analysis was ran on the component box using SolidWorks

flow simulation, assuring electrical components will be cooled properly and kept within the desirable temperature ranges. The results are shown below.

Average Velocity	35.7 in/sec
Average Inlet Velocity	238.9 in/sec
Average Exit Velocity	238.9 in/sec

$$\Delta P : +0.1034 \text{ lbf/in}^2$$

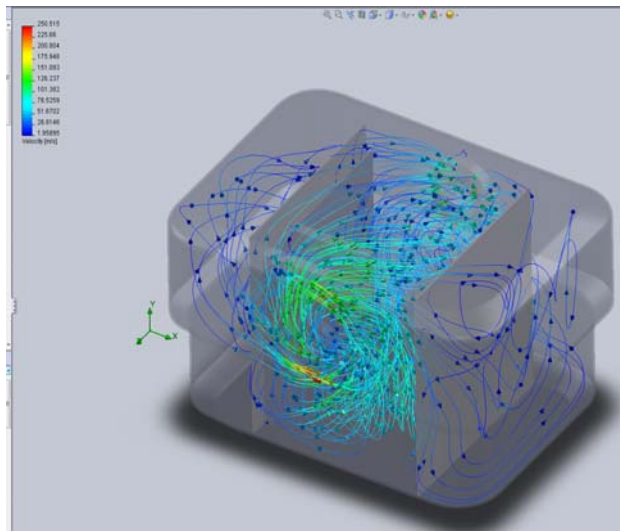


Figure 15: Flow analysis of the airflow

Average Temperature	72.8°F
Inlet Temperature	71°F

Outlet Temperature	75.3°F
Max Temperature	150°F

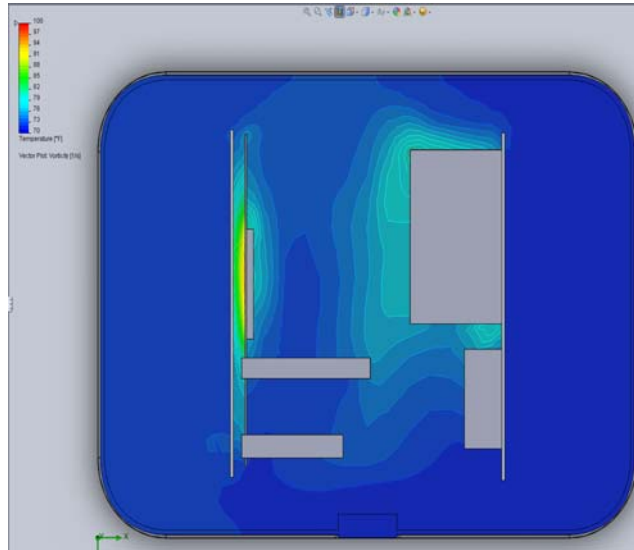


Figure 16: Cooling analysis

Another consideration that had to be made when deciding on the best option for cooling is that grass, dirt, and other debris as well as rain is kept out of the box. Placements of the fans were also limited to where there was room within the box so that they would not get in the way of wires or any electrical components. Filters were used to cover fans to ensure that minimal debris will get into the box.

IV. Design Implementation

Components acquired are a 19 inch lawnmower deck equipped with a 24 volt blade motor and blade, two independent Invacare wheel chair motors, three 24 volt rechargeable batteries, Chassis, front and rear wheels, and all of the electrical components. The mower is attached to the

chassis by rigidly mounted brackets at the height adjustment points. Brackets had to be fabricated in order to connect the two. The rear wheels are attached to the drive motors and are attached to the chassis by a bracket that bolts to the flanges on the bottom of the chassis and expands the whole width of the rear of the chassis.



Figure 17: Complete model of the Autonomous Lawnmower

V. Main Control Board

5.1. Relays

The general-purpose I/O pins of our PIC18F4580 microcontroller only are capable of sinking or sourcing 25 mA of current at 5 V. The relays that we use require 120 mA at 12 V to switch. To solve this, we used an NPN power transistor in the common emitter configuration. A digital output pin drove the gate of the transistor on the PIC; the collector was connected to 12V

Vcc (from a MOLEX connector from the PC power supply) through the relay input. A back-EMF reducing diode was placed in parallel to the relay.

5.2. IR range finders

This section describes one way to convert the non-linear voltage output of a Sharp analog infrared range finder into a usable distance measurement. The technique may be applied to controllers that only support integer math. Due to geometry within the triangle between the receiver and transmitter of the sensor, the output of the sensors is not linear as shown in figure 18 below.

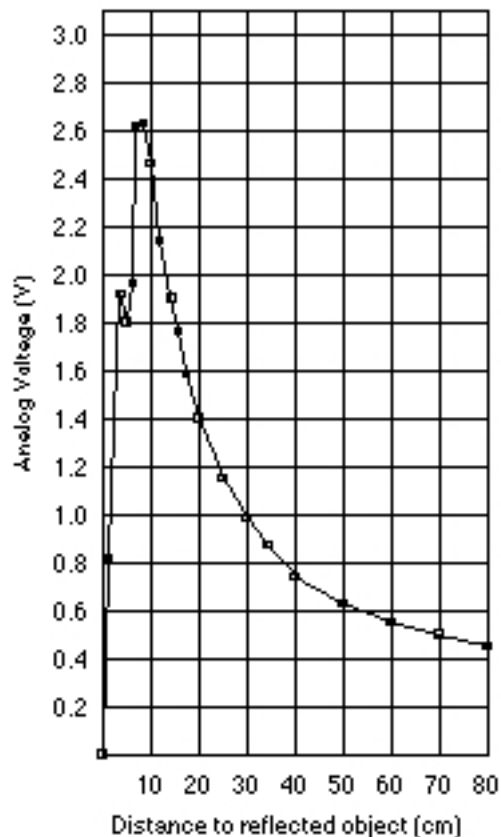


Figure 18: Non-linear output of the IR rangefinders

The figure 18 shows the logarithmic output of the rangefinders within the distance of 80

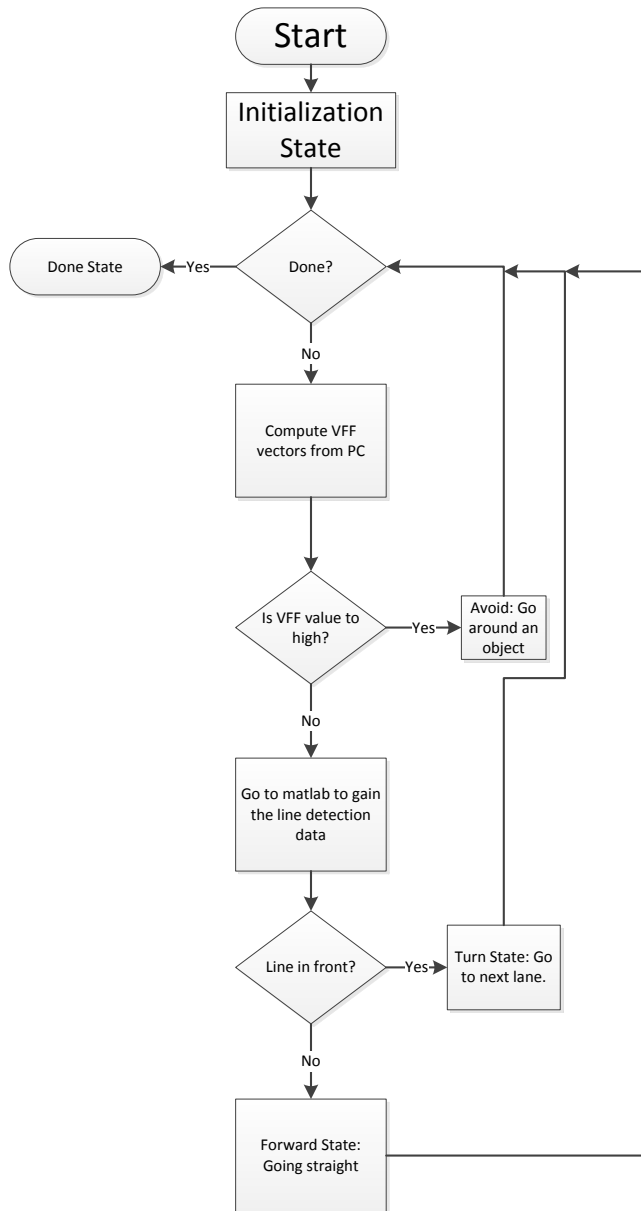
cm. These rangefinders were all very similar and consistent in the output. Therefore, we normalized the output with a lookup table after testing each one of them. Another thing to notice from the graph is that if the rangefinder detects the object that is closer than 10 cm, it will give the same analog value as it would for an infinitely far object. We could crossfire the rangefinders to avoid such situation but we did not need to do that for this project. The beam width of these detectors is up to 16 cm at 80 cm range respectively. This quality makes these sensors very useful in robotics for object detection.

Since these sensors are analog and fire continuously, they don't need clocking to initiate a reading. Therefore, they are easier to interface but use more power. By drawing more power, sometimes it caused the microcontroller to reset due to higher need in current. To fix the problem, 10uF capacitor was installed in between 5V and GND on the sensor.

VI. Intelligence

The first step in the decision making process was to establish a working flow chart. This system flow can be seen in the figure below. The system begins by initializing the all the system components necessary for operation. Next, the program checks that the conditions for the goal state have not been achieved. If this is not the case, the mower begins evaluating sensor data. It will calculate force vectors on this data. Should it conclude that the vector force threshold for obstacle recognition has been exceeded; an avoidance routine will be chosen and performed.

Once complete, the loop will restart as the goal state is again evaluated. If it is determined that we are not in an avoidance state, the control loop will continue on to calculate the force vectors for edge line detection. If this threshold is exceeded it will perform the appropriate routine. This loop continues until the goal state is achieved.



6.1. PC Controller

The Software running on the PC is the main logical control of the system. The design consists of a stack implementation, which consists of four subsystems. This allows for the functionality of the system to be separated for simplification. The first subsystem has the responsibility of communication with the microcontroller over an open serial port. This allows the system to request sensory data from the PIC as necessary. The data obtained is then stored

for use by other subsystems. This connection is also used to make routine requests from the PIC. Once a course of action is determined by the system, the appropriate routine is passed to the microcontroller to perform.

The second subsystem is responsible for monitoring information gathered from the cameras. Because the video processing for this project leverages the MATLAB(R) Image Processing Toolbox, this system monitors data within the MATLAB(R) workspace. This is accomplished by making use of the exposed COM interface that MATLAB(R) provides. The COM interface allows these programs to interoperate by sharing binary data. This data is then recorded for use in the system.

The third subsystem manages collision detection. It does this by using an implementation of a virtual force field. This method assigns a force vector to objects in the path of the mower. This force is monitored by the system using the data received from various sensors. Once a threshold has been reached, the system will request that the appropriate avoidance routine be performed.

The fourth subsystem performs the mapping and path planning duties of the system. The mower is designed to traverse the field using a parallel swath pattern. The logic for this path is executed in this subsystem. In addition, a matrix is maintained that contains the theoretical field coverage.

6.2. PIC Microcontroller

PIC 18F4580 is in charge of controlling the motors and switching the relays. Since our motor driver required a digital signal to drive the motors, a slow manual PWM signal was created by the PIC. Since one digital pin was provided for each output to drive the motors (forward, backward, left, right), manual timing was created to implement PWM method in the

PIC code to control the motors.

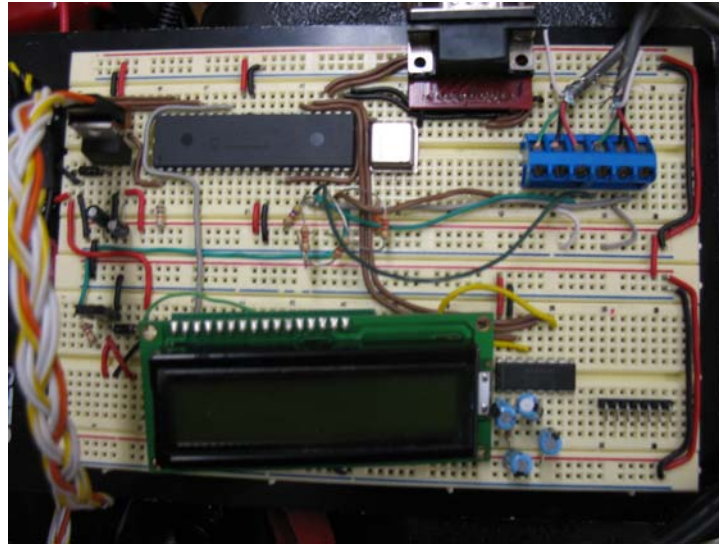


Figure 19: PIC 18f4580 Microcontroller

6.3. Path Planning

Several path planning techniques were considered for this design. It was decided that a parallel swath of the field would be suitable. For simplification, the mower will always be placed in the same reference corner initially. This allows for some assumptions to be made in the control logic.

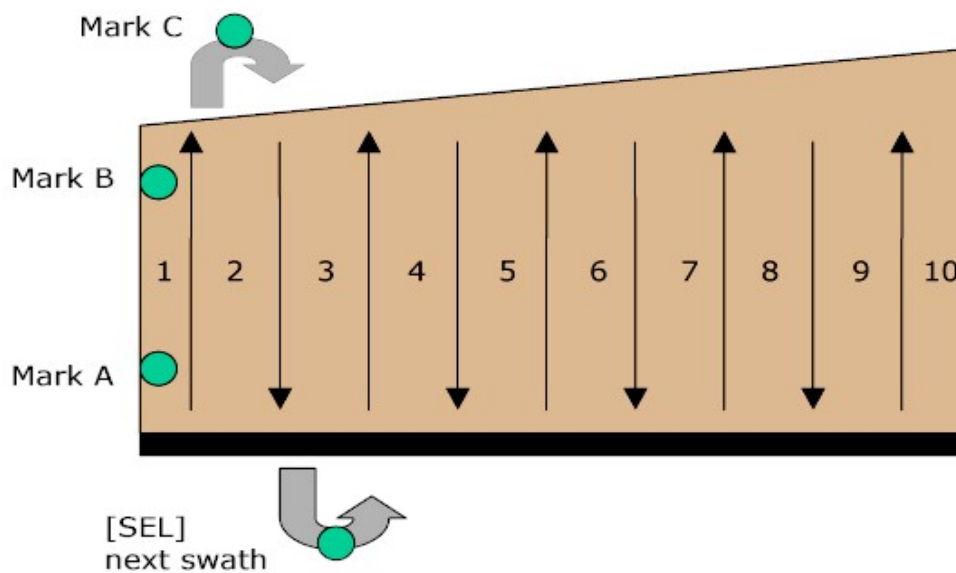


Figure 20: The path of the Lawnmower

6.4. Obstacle Avoidance

The obstacle avoidance for this system was implemented using a modified virtual force field method. A force field is created by the mower based upon information provided by sensory input. This field ID constantly changing due to environmental factors. If the mower approaches obstacles or the boundary, it will begin to perceive a repulsive force. This force will grow to a threshold that will cause the system attempt to reduce it. The calculation is given by the equation below. A certainty value is included to compensate for inaccurate data measurement.

$$F(l, j) = \frac{F_{max} C_1}{d^2} \left[\frac{x_r - x_0}{d(l, j)} x + \frac{y_r - y_0}{d(l, j)} y \right]$$

VII. Safety

One of the most important features of an autonomous machine is that it be designed with safety in mind. A lawnmower is inherently dangerous because of the blade spinning beneath it. Therefore, the safety issues are very essential to consider when planning this project. To combat this issue, we recognize three types of emergency shutdown conditions. In the first, the user has control and decides to stop the machine. Second, the system is encounters a particular situation that make it difficult to continue to keep up with its task. When this occurs, the machine will attempt to reset on its own or enter and idle state until the user manually resets it. And finally, the state in which all control has broken down.

The Bumblebee is equipped with two shutdown methods. The first is a main emergency stop button that has the ability to cease the current flowing to the drive wheels and the blade motor.

This is controlled with a relay that is directly in the power chain. There is also the ability to shutdown the mower remotely using software.

Expected Expenses/Parts Needed

A list of parts needed as well as our expected costs was made:

Drive Motors	\$1,000
Blade Motors	\$400
Frame Parts	\$1,000
55-Ah 12-V Batteries	\$200
Wires and Accessories	\$200
Encoders	\$200
DC Motor Controller	\$600
PIC32	\$150
Ultrasonic Sensors	\$400
Relays	\$200
Computer Hardware	\$1,000
Inertial Measurement Unit	\$150
Range Finder	\$800
Video Cameras	\$300
Compass Module	\$100
Total Expected Cost	\$12,240

Table 1: List of expected expenses

Schedule

- Project Research: **August - October**
- Defining Resources: **August - January**
- Mechanical Design: **October -February**
- Electrical Design: **October - February**
- Build/Program: **December - March**
- Test/Revise: **March - May**
- Competition Application Due: **April 21**
- Reports Due: **May 12**
- Competition: **June 2 – 4**

Testing/Competition Qualification

Testing on the lawnmower started in April when it was first radio controlled. In order to qualify for the competition, a three-minute video displaying the lawnmower's capability to run and quality of cut was required by April 21. This video can be seen at the following link:

<http://www.youtube.com/watch?v=LmQyuAIFPAo>.

References

[1] Anonymous "ION Robotic Lawnmower Competition" **2010**(11/2/2010).

[2] Anonymous "Lawnmower.PDF (application/pdf Object)" **2010**(11/2/2010).

[3] Markoff, J., 2010, "Smarter than You Think: Google Cars Drive Themselves, in Traffic," NY Times article, http://www.nytimes.com/2010/10/10/science/10google.html?pagewanted=1&_r=3.