Autonomous Lawnmower

Max Lesser
Vincent McMasters
Jonathan Poulose
Josh Samaniego

Final Report

Table of Contents

AUTONOMOUS LAWNMOWER

Max Lesser
Vincent McMasters
Jonathan Poulose
Josh Samaniego

CONCEPT OF OPERATIONS

REVISION – 3
29 April 2021

Concept of Operations
for
Autonomous Lawnmower

Team 30

Approved by:

Team Member	Date
Prof. S. Kalafatis	Date
Pranav Dhulipala	Date

Change Record

Rev.	Date	Originator	Approvals	Description
-	9/6/2020	Max Lesser		Draft Release
1	9/20/2020	Vincent McMasters		Revision 1
2	11/24/2020	Vincent McMasters		Revision 2
3	4/29/2021	Jonathan Poulose		Final Report

Table of Contents

List of Figures

1 Executive Summary

We are designing a proof of concept for an autonomous lawnmower system. The system is to receive information about the area to be mowed from a user, interfaced wirelessly through an android app. The mower is then to mow the indicated area completely autonomously, for a duration of at least one hour, before recharging. The system shall use inertial guidance and GPS to navigate based on starting location and shall identify objects and obstacles in its path and avoid them using internal sensors. The system will include safety features, components and protocols to ensure safety of any and all bystanders.

2 Introduction

2.1 Background

With the emergence of automation and robotics in the 21st century, it is imperative that common household products become smarter as they increase in functionality while the future approaches. As smartphones become a necessity, more hardware and software is being created to complement the simplicity of using a mobile device.

Cutting the grass has always been a dreadful task. Overtime, more and more technology has been created to aid customers cut their grass. The first lawn mower was designed and built in 1830. This was an early cylinder (reel) mower which was very popular back then. In 1859, the first chain-driven mower was created, which reduced the amount of effort it took to cut your lawn. In 1902, the first ride-on mower with a gas engine was created. All new types of lawnmowers had one goal in common; to make cutting grass easier for the customer.

An autonomous lawnmower will allow one to cut grass with a press of a button on their phone. This is a valid application of home automation. Many homeowners do not have the time or energy to keep their grounds as neat as they may like, and would be customers of this autonomous system.

2.2 Overview

The following design problem, as stated below was posed to our team.

"You will start with a lawn mower shell, add motors to propel the wheels, microcontroller to control everything, comms to a wifi network where area to be covered and route will be entered, and a power mechanism (docking station or other)"

In order to accomplish the task we propose the following system: a battery operated lawn mower vehicle, equipped with appropriate sensors to discern its environment, a means to connect to a WIFI network to obtain user input, an android app or web service based user interface allowing for navigation input, scheduling, usage statistics and feedback from the mowing unit, a solar panel and docking station for charging, as well as traditional lawn mower components to accomplish the mission.

In the user interface (android application), the user will select the corners of their lawn to choose where the grass will be mowed. The mowing unit will use the corner coordinates and calculate distances from each corner and essentially navigate in a shrinking rectangle. If the mower detects an obstacle using the proximity sensors, then it departs from its navigational path and goes around the obstacle, avoiding any collision. Once the area to be mowed is completed, or the battery depleted, whichever comes first, the mowing unit will return to its starting position for recharging and its next assignment.

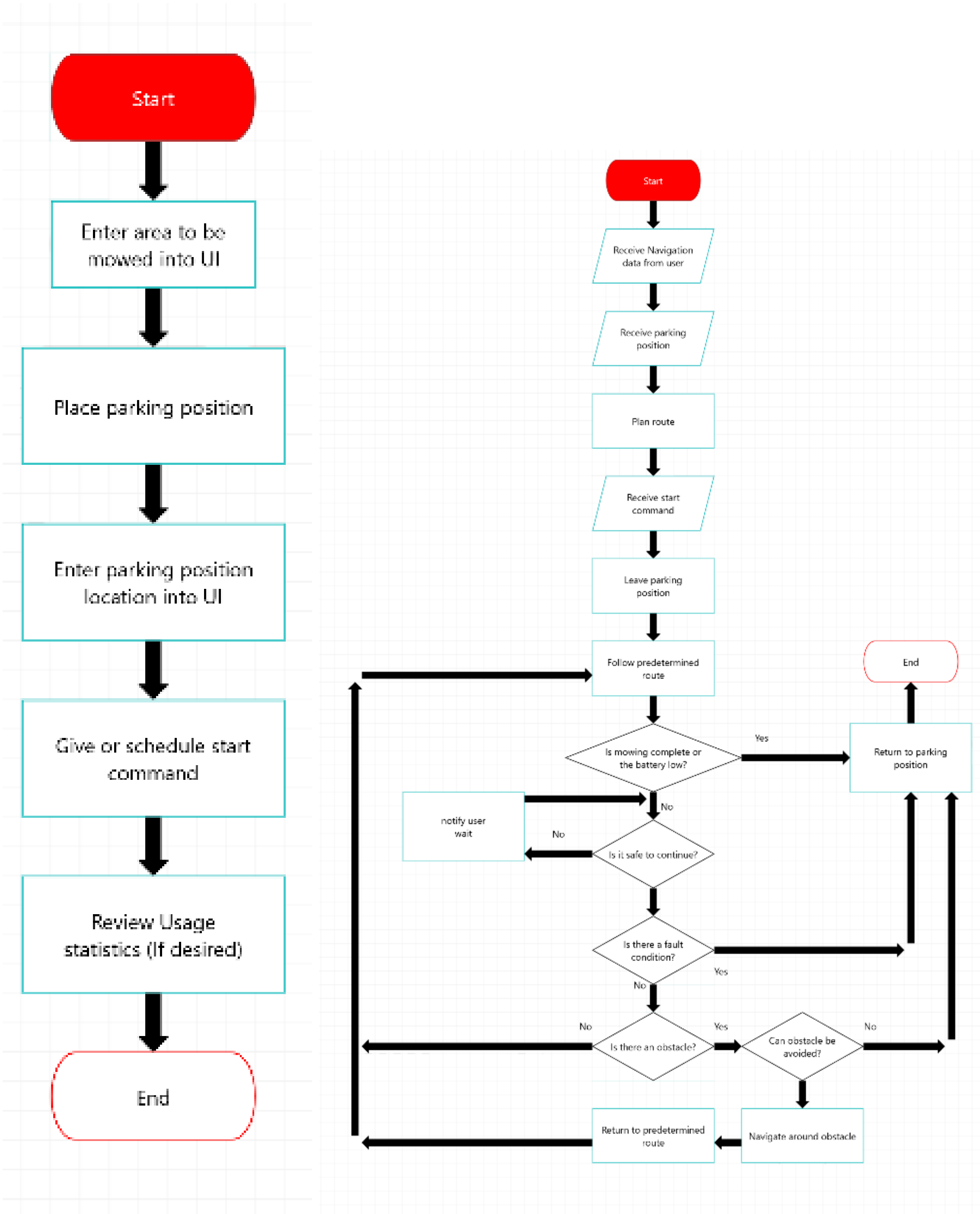


Figure 1: Overview of User and System Actions

2.3 Referenced Documents and Standards

List of standards and references that may apply to some or all systems, depending on future design decisions

- ANSI/OPEI 60335-2-107-2019
  - Particular requirements for Robotic, battery powered electric lawn mowers with batteries of less than 75V
- IEEE 802.11 Standards for WIFI networks and connections
  - Local Area Network Protocols for implementing wireless local area networks (WLAN)
- IEC 61000
  - Requirements for generic EMC standards with motors
- UL-2111: Standard for overheating protection of motors
  - Max heat requirement for a motor NEMA B electric motors
- UL 2595 -UL Standard for Safety General Requirements for Battery- Powered Appliances
  - Requirements for appliances incorporating detachable, integral or separable battery packs with a maximum rated voltage of 75 VDC
- UL 61800-5-1: UL Standard for Safety for Adjustable Speed Electrical Power Drive Systems
- Rechargeable Batteries: http://www.epectec.com/batteries/battery-standards.html
- *"UL and ANSI specification regarding various systems components"*, Global Spec Engineering 360, https://standards.globalspec.com/

3 Operating Concept

3.1 Scope

This design is intended to use an existing Lawn Mower platform consisting of the body, wheels and blades and modify it with electric motors for the blade drive and wheel drive. It will also add an electric power source to supply motors, controller and sensor systems. In order to charge the power supply a docking station that can switch between Solar and wall power will be included. Additionally the system will be outfitted with sensors to discern its environment such as an ultrasonic sensor, accelerometer and gyroscope, as well as shaft encoders on drive wheels to determine distance and movement direction. This will allow the mower to maneuver safely and effectively. All sensor components of the system will be controlled using a microcontroller which will be connected to another microcontroller that controls navigation and connects the system to WiFi. The mobile application allows the user to input lawn area information as well the ability to control the lawnmower wirelessly.

3.2 Operational Description and Constraints

The system is to operate autonomously in lawn mowing activities for at least 1 Hour, relying only on navigation input and a start command, which may be scheduled in advance, from the user through the mobile application. Once the start command is received the mower departs its parking location and follows the determined optimal route in a shrinking quadrilateral as efficiently as possible. The mower shall be capable of avoiding obstacles in its path and returning to its original route accordingly.

The area to be mowed shall be specified by the user through a mobile app. The primary interface mode is an assisted approach, where the user specifies an outline of their lawn in a map screen and the mowing unit will rely on shaft encoders to measure distance traveled as well as turning radius. In order to facilitate inertial guidance, the docking station will act as a navigational anchor. In boundary cases where obstacles are present or conditions are unsafe the mower will go around the obstacle and continue on its path. In case the mower is not able to return to the docking station it shall alert the user and shut down. Finally, if the safety of users or bystanders is in question the mower shall immediately stop the blades and stop all movement until a safe course of action can be determined.

The navigation of the mowing unit will be handled by one of the microcontrollers that will connect to WiFi as well. Lawn area and scheduling information will be provided by the user, after which the controller exerts control over motors and, using sensor information, begins the mowing process. The controller will continuously evaluate sensor data to ensure safe mowing conditions, as well as compare to navigation solution to follow the optimal route. The resulting constraints from this operational description are:

- The system is constrained in its ability to maneuver through exceedingly difficult terrain
- WiFi signal is needed for mower to be controlled
- Navigation logic is constrained to lawns with a rectangle
- Solar panel docking station needs to be placed in an area which receives a lot of sunlight
- Obstacle detection logic is limited to one obstacle at a time

3.3 System Description

To accomplish the mission, 4 subsystems have been identified as necessary, listed below. A high level block diagram, indicating information and powerflow between the systems is given at the end of this section.

- Power/Docking Station
- Motors/Navigation
- Microcontroller/Sensors
- User Interface/Server/WiFi

These subsystems will be broken into 3 separate units, the Mower, Docking station and the User interface, with distinct tasks outline below

3.3.1 Mower Unit

The mowing unit is the primary component of the system, engaging in actual lawn care activities. As such it will include all components needed to operate autonomously in a safe and efficient manner. These components include, but are not limited to, drive and blade motors, power supply, sensor suite, microcontroller unit, WIFI communications and safety system. Some high level requirements of the mower unit are given below.

- The mower shall mow the specified area
- The mower shall mow autonomously without user interference, aside from giving start commands and specifying the area to be mowed.
- The mower shall consist of separate motors for the blade drive and for steering, to allow for maneuvering without running the blade.
- The mower shall be able to orient itself and navigate exclusively with onboard sensors and the original user input.
- The mower shall have an on board power supply allowing for a minimum of 1 hour of continuous operation.
- The mower shall determine the optimal route to follow from user input, given perturbations from terrain and or obstacles.
- The mower shall determine whether mowing activities are safe, and act to ensure the safety of bystanders
- The mower shall avoid obstacles and mow as much of the specified area as possible given unexpected obstacles or terrain limitations.
- The mower shall alert the user incase of malfunction, obstacles or unsafe conditions.
- The mower shall have an emergency stop button incase of any emergency.
- The mower shall automatically return to the docking station upon completion or early termination.
- The mowing unit shall communicate with the user device running the UI wirelessly
- The mowing unit shall be able to initiate the charging process, autonomously

3.3.2 Docking Station

The Docking station shall house the solar panel and connect to commercial power. It shall include the components necessary to switch between wall and solar power, depending on Solar output. It shall also serve as storage for the mower

- The docking station shall charge to onboard power system
- the docking station shall switch between solar and wall power as needed
- the docking station shall house the mower
- the docking station shall provide protection against weather

3.3.3 User Interface

The user interface shall run on existing android mobile devices, such as smartphones or tablets. It provides the user with a means to enter navigation and scheduling information and transmits this information to the online Firebase Server which will be connected to the ESP32 microcontroller via WIFI network. The UI may additionally provide the user with statistics about mowing activities and the mowing unit, such as battery level, mowing completion level, estimated mow or charge time remaining, among others. A high level system description and requirement list is again given below. The application's most important information being sent to the mower is the start_status variable which makes the mower start and stop as well as the coordinates that will be used to calculate the distances.

- Allows user to login through Google Account
    - as many google accounts as you want
    - saves information for each account
- Allows user to add multiple lawns using Google Maps API
    - Select Default Lawn
    - Select current location
    - Unlimited markers/corners for each lawn
    - records coordinates for each marker and sends to server
    - Numbered each corner from one to desired amount
    - Add lawn name
- Scheduling
    - Add time
    - Days of the week
- Control of Lawnmower
    - Start
    - Stop
    - Go Home
- Lawnmower status
    - Battery level
    - Other statistics

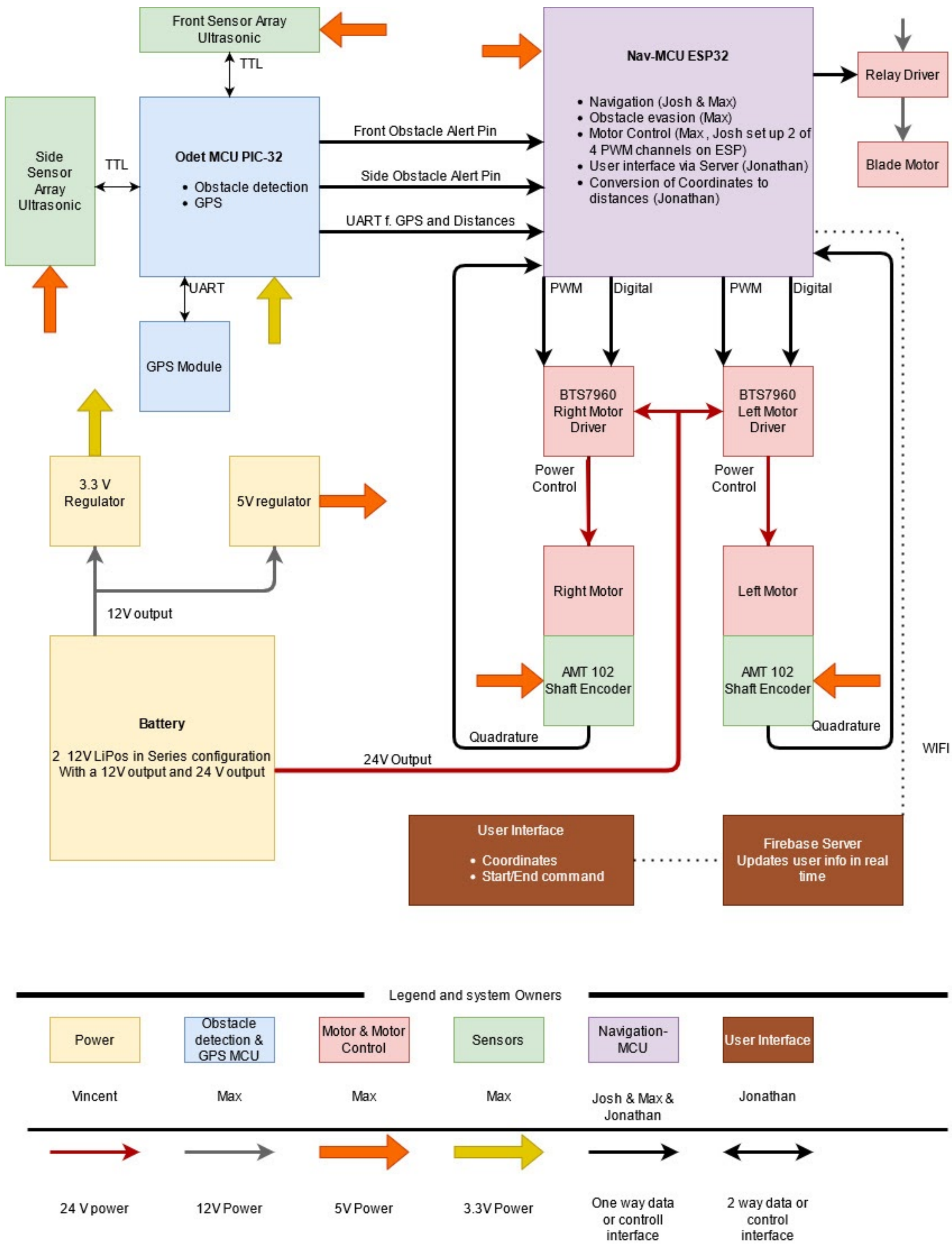


Figure 2: High Level Block Diagram for Signal Flow

3.4 Modes of Operations

In order to operate as efficiently as possible the system had one primary mode of navigation.

> Primary Mode: This mode used the user inputted lawn area coordinates to go in a counterclockwise direction, navigating in a shrinking rectangle at an average speed.

Given evaluation of system constraints through the design process, specifically available power and motor performance the system may include a rapid mode

> Rapid Mode: This mode is intended for users who need a quick cut and do not care about the precision of the cutting or obstacle detection

3.5 Users

The intended users are homeowners and anyone who needs a small to moderately sized lawn mowed with a mowing interval no more than 1 mow per week. The majority of customers will only have one lawn to mow and map out. For those who mow multiple lawns, we have an option to add and save lawns through the app. Since the majority of users will only have one lawn, it will be easy to operate after the lawn is mapped out.

3.6 Support

Help and support will be available through the designed application, while also being in the user manual. This user manual will include instructions on how to set up the lawnmower, as well as describe the user interface of the app. Hardware components will be described in detail, as well as troubleshoot information for each subsystem in the lawnmower. The app will go over the general points of setup installation, and necessary tips to ensure a smooth setup. It will also include the user manual and software files available for download if needed. If questions arise that aren’t covered in the manual or app, contact information will be available for the user to reach out to technical support for assistance.

4 Scenarios

Following is a list of possible usage scenarios, with the expected behavior of the system. The list includes normal operating situations as well as boundary cases, but is by no means exhaustive. As new scenarios become apparent they will be added here.

4.1 Homeowner Use on Single Property

The primary use of our product is for homeowners to utilize on their own property. In this case the user will be able to set it up in a single lawn location and have their google account set this as the default lawn location.IThis will save time and allow for the mower to be able to maintain the same route as before to keep the lawn in the same pattern.

4.2 Corporation Use for Different Locations of Customers

The secondary use of the autonomous lawnmower is for use by landscaping corporations that consistently change the locations they are working on. In this event the starting location would simply have to be set up and a start command issued. The user interface allows the user to add an unlimited amount of lawns and select a default lawn (the lawn being cut at the time). If the user cuts the same lawn again, he can go back into the app and select whichever lawn they are cutting and set it as their default.

4.3 Obstruction of Solar Panel or Insufficient Sunlight

In cases where the mower fails to charge from solar during its rest cycle it shall switch to commercial on its own.

4.4 Lawnmower Contacts Foreign Object and is Dispositioned

For individuals with children or pets it is not uncommon for someone to leave something out in the yard unknowingly. In the event an object is blocking the mowers' path, it may alert the user that a large, unexpected object has stopped the lawnmower from maintaining its preferred path, and maneuver around the object. During the initial learning run the user is urged to clear all non-permanent obstacles, such that the mower has a reference for the area it is supposed to mow. If new objects are added the user will be given the option to include these in the permanent map.

4.5 Lawn Mower Loses Connection to Wireless Network

In cases where the mower loses connection to the wireless network, that is it becomes unable to communicate with the user, it shall continue mowing the predetermined route as it was entered, assuming it is safe to do so. Once it has completed its route or depleted its battery it shall return to the parking position, where it remains until the network connection has been restored and it receives new input from the user. The system shall not engage in scheduled mowing activities unless it has received user input since the last network outage.

4.6 System or Subsystem Failure, Leading to Loss of Control of System or Component

In cases where a subsystem fails or malfunctions the mower shall, if possible depending on which system failed, stop the blade drive, inform the user immediately and return to the parking position. If the unit becomes entirely unresponsive or unable to maneuver, due to critical system failure, it shall initiate emergency shutoff, where the power supply is terminated from the blade. In case emergency shutoff fails, the mower shall have a clearly marked, safely reachable shutoff button, that cuts off power.

5 Analysis

5.1 Summary of Proposed Improvements

The biggest improvement of our design from the traditional gas powered lawn mower is its ability to mow the lawn autonomously and according to a predetermined schedule, without need for real time control from the user. Because the mower is programmed to be able to sense objects around it, and moves according to a set path, the user puts in minimal effort towards getting their lawn mowed. The application that is integrated with the design allows you to set a concrete time for the mower to cut the lawn every week, so you don’t have to worry about forgetting to cut your lawn. This is a luxury item for people who just don’t have the time to take care of their lawn routinely. It’s also for people who don’t have enough energy to put in the manual labor to push a lawnmower around. It also cuts the lawn in a timely manner, so energy costs are saved in the long run.

5.2 Disadvantages and Limitations

Limitations and disadvantages of this design are for the most part a direct consequence of the proposed improvements. For the purpose of this design the advantages and disadvantages have been weighed and it was determined that our proposed system provides a distinct advantage over traditional lawn mowing systems for residential and small area comercial users. Nonetheless some disadvantages are inherent to the design and not avoidable.

5.2.2 Energy density Limitations

Due to the system being able to operate autonomously and according to a schedule, without operator intervention, its power source must be electric, to allow for autonomous charging. The Disadvantage of electric power systems is their lower energy content, according to the US Energy Information Administration. This Limits the continuous operating range and time compared to a fossil fuel power system. The electric power system also reduces possible duty cycles, as battery recharge times are much greater than refueling times for fossil fuels. The electric power system does however allow indefinite scheduled operation under normal conditions. It also removes the need for the user to handle, store and obtain hazardous fossil fuels. Summing these reasons it is clear that our proposed system is intended for use in limited areas with limited duty cycles, and is not ideally suited to mow large areas in short amounts of time, or to operate at high duty cycles.

5.2.3 Navigational Limitations

As this lawnmower system relies on user input and onboard sensors to maneuver around obstacles it will do so less efficiently than traditional pedestrian operated lawnmowers. As the system needs to be on the side of caution when encountering obstacles, and lacks the decision making speed and reasoning abilities of human operators when deciding how to proceed near obstacles, it will perform slower and more cautious than a human operator. As such the system may have to leave extra room around obstacles, or avoid them altogether in certain cases, when a human operator could simply maneuver over them, for example by propping up the lawnmower. Additionally the power constraints limit the lawnmower's ability to maneuver in exceedingly complex terrain, such as areas filled with tree roots, or extreme slopes. These areas may either reduce operating range or prohibit autonomous mowing entirely, depending on their complexity. Therefore the system is not ideally suited for extremely challenging terrain, or lawns with large amounts of obstacles that require a fast, precision mow.

5.2.4 Limitations Due to Network Requirements

The system requires connection to a Wireless network to receive navigation and scheduling input form the user. As a safety feature the system will not engage in scheduled mowing activities unless it has received input from the user since the last network outage. This is to prevent scheduled mowing in situations where the user is unable to exert remote control over the mower if needed. As such the system is not suited to operate indefinitely, unattended in situations where network outages are common. Additionally, at least the parking position needs to be within range of a wireless network, and as such special care needs to be taken for installations on large properties, or properties with many obstructions to wireless signals.

5.2.5 Operating Speed Relative to Large Commercial/Riding Mowers Limitations

Due to size, power and charging limitations of the system, the operating range of the system is restricted. Maneuvering speed is additionally limited due to safety concerns. For these reasons the total effective area and the speed at which the system may mow are reasonable but limited. Users that require a large area be mowed, or high speed mowing may find the proposed system too limited to suit their needs.

5.2.6 Summary of Disadvantages, Limitations, and Recommendations

The system may experience limits to range, speed, complexity of terrain, ability to connect to user devices and onboard power storage. All these Limitations are consequences of choices made to reach the design goals: the proposed system is intended for moderate residential or light commercial use. Users that require performance in large areas or difficult terrain may be better suited using existing commercial size fossil fuel mowers, or need to take special care and consideration if they wish to employ the proposed system.

5.3 Alternatives

The alternatives to our product would be lawn mowers that require someone to be present at all times. This includes the original push reel mower, walk behind power lawn mower, ride-on lawn mower, and the hover mower. These alternatives all cut grass slightly differently but all share the burden of physical activity. These types of lawnmowers excluding the ride-on lawn mower needs to be pushed throughout the whole process. The ride-on lawn mover is a little easier to use because it can be used sitting down but is extremely expensive and bulky. All the other methods of cutting grass do not have the capability to run on its own. Our product saves users time because it runs autonomously and money because it is fairly inexpensive and no money needs to be spent on oil or gasoline.

6 Implemented System

Some of the requirements and specifications listed here have not been met. Details are provided in the FSR and system validation. A quick overview will be presented here. The App currently only sends Coordinates specified by the user to the mower, only one mode of operation exists and no feedback from the mower to the user is currently implemented. The mowers onboard GPS works but is not implemented, the Gyroscope and Accelerometer sensor is not working properly. As such the mower relies only on shaft encoder readings to navigate. Due to a late change in Motors requiring a new battery, the docking station is not currently implemented. The failsafe mechanism currently implemented is blade and drive motors shutting down when power to their microcontroller is lost, on/off button from the user interface as well as manual On/Off switches and fuses for all components.

Time constraints and component and system failures during 404 prevented us from adding more functionality. Details are outlined in the Subsystem reports.

7 Impacts

7.1 Ethical Impacts

One ethical dilemma that our team faced was partitioning work through our subsystems. If we had planned better initially, we could have split the work more equally depending on the amount of work that was required for each subsystem. Some subsystems were a lot more work than others and we might have been done earlier if workloads were divided evenly across all 4 team members. This caused a lot of stress and time for certain members of the team.

Ethical impacts of this system itself, were it widely adopted is minimal. While autonomous lawn mowing may remove the need for some commercial lawn care companies, this system would only do so in a small way due to its limited scope. As discussed below, proper testing can prevent safety concerns, and operation is more environmentally friendly than traditional gas lawn mowers. Weighing removal of some jobs against reduced environmental impact and improved safety, we see that autonomous lawn mowers produce more good than bad. Following a utilitarian approach, there would then be no issue with producing autonomous lawnmowers.

7.2 Economic & Environmental Impacts

Since the mower was solar and battery powered, there is no need for oil and gasoline and there are fewer emissions to the environment.

7.3 Health & Safety Impacts

With all the safety protocols implemented, the autonomous lawnmower is theoretically safer than traditional lawnmowers. Not having to be in proximity to the lawnmower during operation is also a benefit. These safety features need to be tested and validated in extensive trials, to ensure proper operation. Providing a customer with a product luring them into a false sense of security due to not properly tested systems violates informed consent and is thus highly unethical. The benefit to being autonomous is also that there is no physical energy required to mow a lawn. This means that elderly and disabled people have less of a risk to their physical health.

7.4 Social Impacts

The autonomous lawnmower will allow more social interaction to occur due to the ability to multitask while the lawn is being cut. A proliferation of autonomous lawn mowers may however lead to job loss for those persons working in residential lawn care. Given the limited scope to only small residential lawns, leaving large or commercial lawn care companies undisturbed, this impact is minor. In addition autonomous lawnmower may allow lawn care companies to operate more efficiently if they choose to use our product. In all the automation concern may reduce some jobs, but only insignificantly so.

7.5 Unintended Uses

As for any technology, unintended uses can bring about unintended consequences from the product. The mower is designed to mow residential lawns. As such it has the ability to follow a predetermined path and includes a blade and sensors. Different uses of the product in its Lawnmower configuration are hard to envision. One could replace the blade with a brush and use it to sweep streets or other areas, no downsides of this are apparent. One could also use mower to mow fields of say protected plant life or to destroy animal habitats. Destroying the living space of sentient life violates its right to existence, if one follows senteinism or Holeims. This would clearly be unethical. Nothing prevents one from doing this with current technology, so this isn't so much an ethical concern for our system as lawn mowers in general.

Since the mower is able to follow a predetermined path, one possible unintended use, with potential ethical ramifications would be Military use in mine clearing applications. Replacing the blade with an implement to trigger land mines, say a heavy chain, would allow this mower to be used in such a fashion as a single use device. While military use of landmines can be hotly debated, their clearing less so. Many humanitarian organisations concern themselves with removal of landmines. And providing them with efficient technology to do so is clearly in the best interest of the public, and hence ethical by Utilitarianism. Improving a militaires combat effectiveness by better means to remove mines may be more questionable. Since many other means of removing landmines exit, the use of our mower in this fashion would hardly alter ethical reality by much.

Outlined above are some possible unintended use scenarios. As they are unintended, they can be hard to convince for the design team. Nonetheless, after consideration we are hard pressed to arrive at any unintended scenario where our system may be used to cause substantial harm that could not have been caused without this system.

Autonomous Lawnmower

Max Lesser
Vincent McMasters
Jonathan Poulose
Josh Samaniego

Interface Control Document

REVISION – 3
29 April 2021

Interface Control Document
for
Autonomous Lawnmower

Team 30

Approved by:

Team Member	Date
Prof. S. Kalafatis	Date
Pranav Dhulipala	Date

Change Record

Rev.	Date	Originator	Approvals	Description
1	9/20/2020	Vincent McMasters		Draft Release
2	11/24/2020	Vincent McMasters		Revision 1
3	4/29/2021	Max Lesser		Final Report

Table of Contents

List of Tables

List of Figures

1 Overview

The Interface Control Document (ICD) for the entire Autonomous Lawnmower will provide more detail on how the subsystems layed out in the Concept of Operations and the Functional Systems Requirements will be interconnected and produced. The ICD will include physical descriptions, such as mass and dimensions, as well as the electrical interfaces, power requirements, and sensor information.

2 References and Definitions

2.1 References

Refer to Section 2.2 of the Functional System Requirements document.

2.2 Abbreviations and Acronyms

A	Amp
A&G	Accelerometer and Gyroscope (unit)
Ah	Amp hour
DC	Direct Current
FSR	Functional System Requirements
GPS	Global Positioning System
UI	User Interface
I2C	Inter-IC
ICD	Interface Control Document
IP	Ingress protection rating
MCU	Micro controller Unit
lbs	Pound weight
mA	Milliamp
mW	Milliwatt
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
SPI	Serial Peripheral interface
TTL	Transistor-Transistor Logic
USB	Universal Serial Bus
V	Volt
VDC	Volts DC
VCC	Positive input voltage level of device in question
VSS	Negative input voltage level of the device in question (typically ground)
W	Watt
WiFi	Wireless Fidelity

2.3 Definitions and Naming Conventions

The term header pin or pin header connector, both male or female, refers to friction fit pins on devices that resemble header pins used in raspberry pis' or other breadboarding applications.

The term pin, as used in section 5.4, refers to the connection point of one wire or signal to a connector or board.

The term MCU, Main controller unit, Controller, Controller board or MCU board are used interchabalby to refer to the PCB that will include the Pic-32 controller, WIFI and GPS module, as well as all connectors and components incidental to their operation. In cases where only the MCU chip, that is exclusively the IC, is referred to the term pic-32 or pic-32 MCU will be used.

The term Bystander is used to describe a person in the vicinity of the lawnmower that is not actively attempting to perform, or engaged in maintenance or operation of the device.

Subsystem owner refers to the person responsible for that subsystem, see table in FSR for subsystem owner names. The subsystem owner carries ultimate authority over their subsystem and all items not specified within FSR or ICD, as well as responsibility to conform with these documents, as outlined in 2.4.

2.4 Boundary Cases and Subsystem Non-Compliance with ICD

The interfaces and connections lined out in this document form the standard basis of performance and interconnection of subsystems. All subsystems are expected to interface with each other, and perform under the requirements specified herein. In case the requirements are not met by any subsystem or component the requirements may be changed only with explicit consents form all subsystem owners implicated by the change.

In case any component or subsystem cannot meet the Interface requirements specified, a reasonable attempt by the subsystem in compliance shall be made to accommodate the offending subsystem or component. Ultimate responsibility to resolve the issue however lies with the offending subsystem.

3 Physical Interface

3.1 Weight

3.1.1 Weight of Autonomous Lawnmower

The autonomous lawn mower will weigh less than 70 lbs. This allows for most people to be able to carry the device, should it need to be moved manually. The Final weight of the unit came in at 35 lbs, well below the stated maximum. A rough breakdown of its makeup is presented below. Note that table entries are approximate weight, but total weight is accurate.

Component	Weight
Blade Motor (1)	6 oz
Drive Motors (2)	2 lbs ea.
Motor Drive	1.41 oz
Proximity Sensor (7)	7 oz
PIC32 MCU + PCB	2 oz
Battery (New)	2 lbs
Accelerometer and Gyroscope	0.07 oz
GPS Module	1 oz
Wheel Encoder	1 g
5 Volt Relay	12 g
Lawn Mower Shell	Estimate: 15lbs
Miscellaneous Hardware, wiring and components	~ 10 lbs
Total:	~35 lbs

Table 1: Autonomous Lawnmower Weight Specifications

3.2 Dimensions

3.2.1 Dimensions of Autonomous Lawnmower

The volume envelope of the Lawnmower shall be less than or equal to 30 inches in height, 25 inches in width, and 40 inches in length.

Component	Diameter	Length	Width	Height
Blade Motor (1)	2 in	2 in	2 in	4.5 in
Drive Motor	4 in	4 in	4 in	5 in
Motor Drive	N/A	4.33 in	3.07 in	0.39 in
Proximity Sensor (7)	N/A	1.8 in	0.84 in	0.6 in
PIC32 MCU	N/A	20 mm	20 mm	1.4 mm
Battery (old)	N/A	7.09 in	3.03 in	6.57 in
Battery (New)	N/A	6.5 in	2.75 in	2 in
Solar Charge Controller	N/A	4.68 in	2.95 in	1.08 in
Accelerometer and Gyroscope	N/A	21.2 mm	16.4 mm	3.3 mm
GPS Module	N/A	25.4 mm	43.2 mm	9.1 mm
Wheel Encoder	N/A	10.6 mm	11.6 mm	N/A
5 Volt Relay	N/A	16.5 mm	21.6 mm	19 mm
Lawnmower Shell		40 in	23 in	15 in

Table 2: Autonomous Lawnmower Dimension Specifications

3.3 Mounting

3.3.1 Mounting of Solar Panel, Controller, and Battery

The solar panel shall be mounted on the docking station, such that it receives an optimum amount of sun on an average day throughout the year. The solar controller will be underneath the solar panel along with the battery inside of a small housing.

3.3.2 Mounting of Sensors

The Ultrasonic sensors were mounted in 2 arrays. A Front array consisting of 5 sensors placed on an aluminum L-iron. The side array was mounted directly to the mower body. All US sensors are attached to custom 3-D printed cases.

The Shaft encoders assemblies have their own housing, consisting of a metal outer shell and a plastic base attached to the motors. The base was super glued to the motors, as bolt patterns did not line up.

The Accelerometer and Gyroscope was mounted in the same box as the Navigation controller.

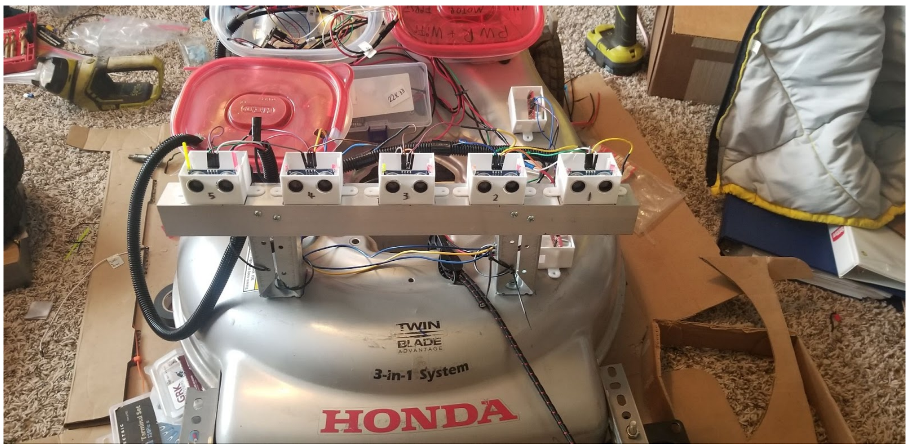


Figure 1: View of Mounted Front Facing Ultrasonic Sensors

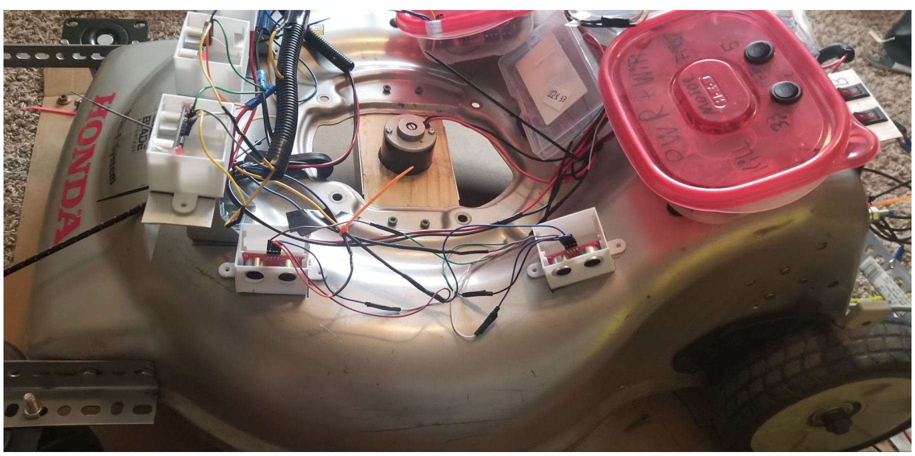


Figure 2: View of Mounted Side Facing Sensors

3.3.3 Mounting of Microcontroller

The two MCUs and GPS unit, as well as connectors and incidental components were mounted in protective plastic cases, one for the ESP and one for the PIC. The ESP case additionally contained the 2 H-bridges. MCU cases are shown in section 3.3.2 and 3.3.6

3.3.4 Mounting of Motors

The 2 Drive Motors were mounted to the frame using 2 L- brackets each. Bolted to the frame on one side and the motors on the other. The blade motor was mounted using a 2x4 with appropriately sized hole to allow the motor to slip through, and L-brackets to hold it in place. The 2x4 was then screwed to the mower. For details on Motor mounts see new Motor subsystem report.

3.3.5 Wire Routing

All wires shall be affixed to the mower in such a way that they do not contact hazardous objects, suffer abrasion from vibration, or interfere with operation in any way. Additionally wires shall be routed such that neither regular operation, contact with external objects, such as foliage or obstacles, nor unintentional interference from bystanders may damage or disconnect them. To accomplish this wires were run in Loom where possible, and attached to the body using wire clamps and zip-ties. Future iteration with more time may use a more purpose full wiring scheme, as we had to adapt to changing components and layouts.

3.3.5.1 Power Cable Routing

Power Cables will be routed clear of any hazardous objects, and in protective shielding. Plastic flexible split loom was used. Only during initial testing may wires be routed without additional shielding or mounting. After initial testing the Looms are to be sealed using electrical tape or similar, with seals no more than 12 inches apart, and mounted to the mower. The wire harness was affixed to the mower using plastic clamps and zip ties, at least every 12 inches. Harnesses shall be fixed to the mower as close to the respective end devices as possible. For wire runs less than 12 inches in overall length at least one clamp to the body shall be used in a suitable location. In boundary cases where mounting of the harness is not possible without considerable reconfiguration or increase in wirelength, unmounted harnesses may be used only if no chance of the wire contacting any hazardous object exists. No Power wire longer than 6 inches, or that may make contact with any metal part or the user may be run without protective loom. Due to last minute changes of the battery, and the need for special connectors, power from the battery had to be run across the unit with minimal attachment. The wire run was clear of outside interference, but would need to be improved in the next iteration.

3.3.5.2 Signal Interface Routing

Signal interface wires shall be run in protective Looms to prevent damage. The same routing requirements as listed in 3.3.5.1 apply to signal wire connections. Due to the small size of signal cables a different means of attaching looms to the mower body may be needed. There wires were zip tied to the unit and each other as appropriate. Looms were used wherever possible.

3.3.6 Case Mounting

No encompassing case was used. However critical components such as MCUs, Motor drivers, and power supplies were mounted in protective cases.

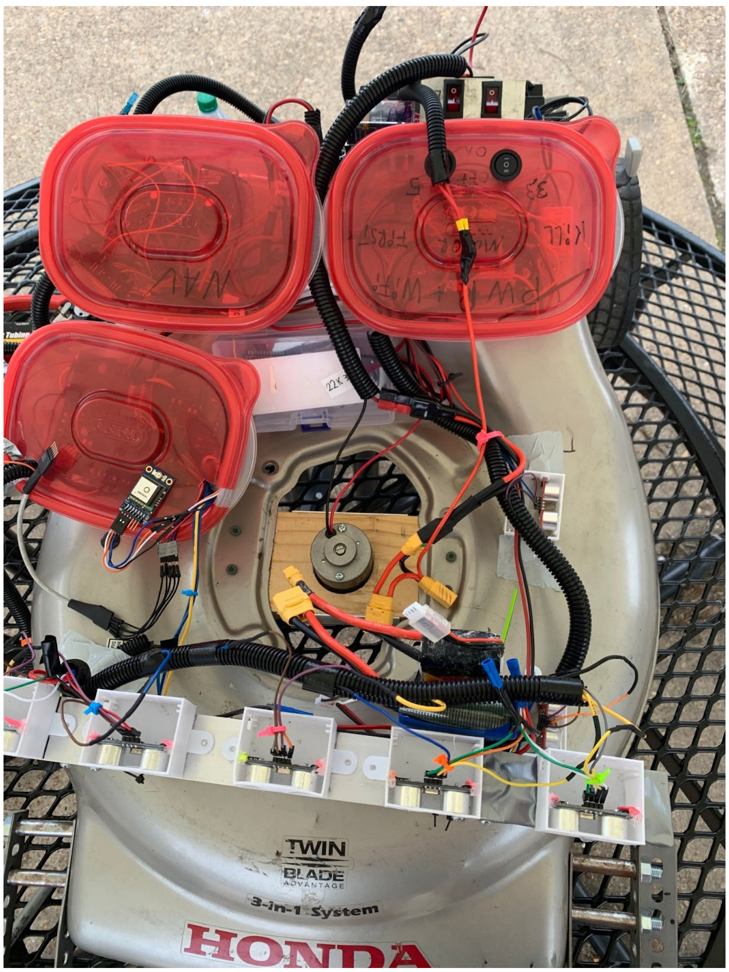


Figure 3: Top View of Casing used to Protect Critical Components

4 Thermal Interface

4.1 Battery Cooling

The heat generated from the battery should be free to disperse on its own.

4.2 Motors

The heat dissipated by the 3 main motors should be able to escape on its own.

4.3 Microcontroller Unit

The Pic-32 MCU and other components on the MCU board shall include a heat sink as needed. The components will not be mounted in direct sunlight, and operating temperature of the unit is not expected to reach or exceed maximum temperature ratings. Additionally the movement of the mower and blade will create considerable air movement. Ambient cooling was sufficient to maintain the MCUs at an acceptable temperature. Additionally after updating to the new H-bridges with heatsinks, its passive cooling was also sufficient.

4.4 Sensors

The amount of heat the sensors will produce will be very minimal and it is not expected to exceed maximum temperature ratings. During operation heat development by the sensors was minimal, and no cooling beyond ambient air was needed.

5 Electrical Interface

Electrical interfaces not specified in the following section shall be determined by consensus of the affected subsystem owners. Additionally, connections that are exclusively internal to their respective subsystems are not listed, and are sole responsibility of the subsystem owner. As The Power distribution system changed toward the end of the semester, we present here first the old diagram, followed by the current “As Built” system.

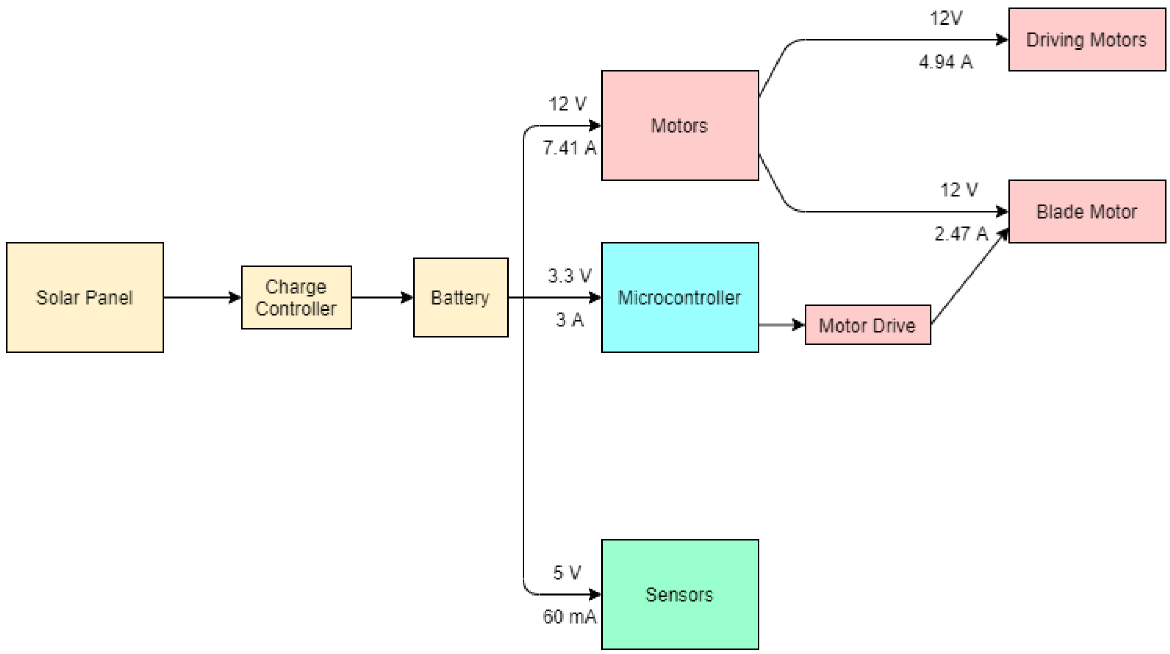


Figure 4: Power Diagram as Designed in 403

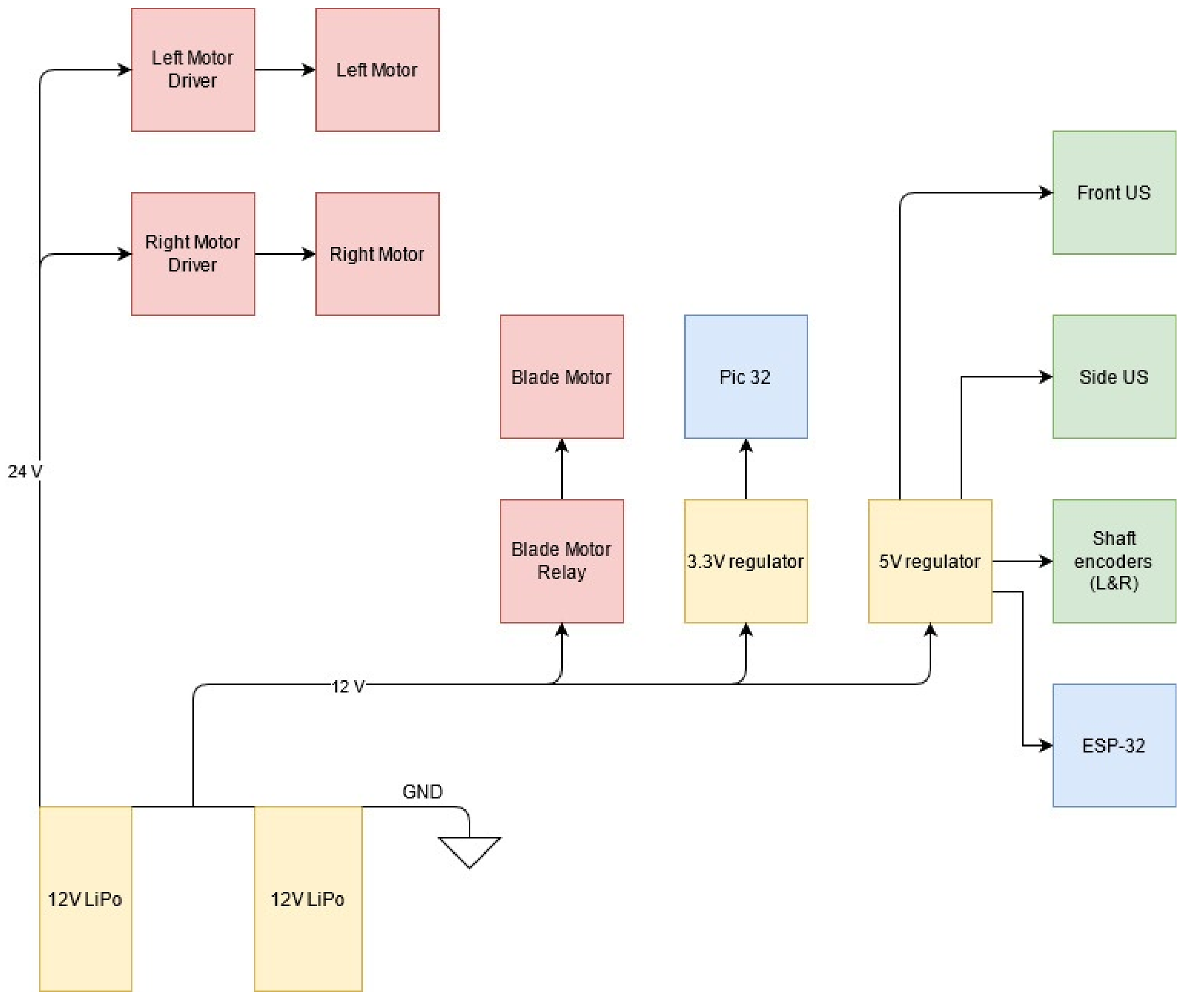


Figure 5: Power Diagram as Implemented on the Autonomous Lawnmower

5.1 Primary Input Power

With the intention of our system being autonomous and self-powered, the entire system will be powered by a 12V battery charged via 10W solar panel that feeds into a solar controller during conditions that facilitate Solar charging, and provisions to charge from Wall power otherwise. The docking station shall be able to switch between the 2 sources as needed. The capacity of the 12V battery will be enough to hold the power required to run the lawnmower autonomously off of charge for a period of at least an hour. The battery will be the only source of power to the system, and will power the sensors, motors, MCU, and all other components.

Due to late changes to the system, the above no longer applies. The mower is now powered by 2 12V LiPo batteries, where the drive Motors receive 24V and all other systems 12V. This change was needed due to new motors. See New Motor Subsystem and Power Subsystem reports for details. Unfortunately this new change rendered the Charging station designed by the Power system incompatible with the remainder of the unti.

5.2 Voltage and Current Levels

5.2.1 Maximum Values

Component	Voltage [V]	Current [A]	Power [W]
Blade Motor (1)	24	3	80.88
Drive Motor (2) (ea)	24	9.6	230 W
Motor Drive	27	43	1100
Proximity Sensor (7)	5	0.035	0.175
PIC32 MCU	3.6	0.2	0.720
ESP-32	5	0.3	1.5
Solar Charge Controller	24	10	240
Accelerometer and Gyroscope	6	0.0039	0.0234
GPS Module	5	0.06	0.3
Wheel Encoder	26	0.006	0.156
5 Volt Relay	30	8	240

Table 3: Autonomous Lawnmower Maximum Voltage and Current Levels

The values in table 3 were all found on the individual parts specifications datasheets. Almost all of these values will not be used but are rather simply for reference purposes in order to prevent us from burning out parts unnecessarily

5.2.2 Typical Values

Component	Voltage [V]	Current [A]	Power [W]
Drive Motor (2)	24	5	120
Blade Motor	12	2	24
Motor Drive	24	10	240
Proximity Sensor (7)	5	0.03	0.15
PIC32 MCU	3.3	0.150	0.495
ESP-32	5	0.1	0.5
Accelerometer and Gyroscope	3.3	0.0039	0.01287
GPS Module	3.3	0.045	0.1485
Wheel Encoder	5	0.004	0.0132
5 Volt Relay	5	0.0794	0.397

Table 4: Autonomous Lawnmower Typical Voltage and Current Levels

The values in table 4 were found on the individual parts specifications datasheets. Are estimates based on consumption during use.

5.3 Power Interfaces and Connectors

All connections specified in this section shall consist of a positive voltage and ground, making for 2 wired connections to each device, unless otherwise specified. Refer to section 5.2.2 for voltage and current levels. And 5.5 for applicable wires.

5.3.1 Battery to Motor Driver Board

Each motor Driver board includes two screw terminals, positive and ground, for power connection to battery and Motors. These will be used to connect the battery to the driver board. The Battery side connection will be made using Anderson Power Poles.

5.3.2 Battery to Blade Drive Motor

The battery to blade motor connection will be made using crimp ring terminals. The connection to the battery will be made using Butt splice ring terminals bolted to the battery. The relay will also be connected using a 2 port screw terminal for battery and motor side. This connection will feed directly into the 12 v power pin of the relay.

5.3.3 Battery to Ultrasonic Sensors (7)

The Ultrasonic sensors shall connect the power supply using the 5V bus bar of the power supply . The connection to the sensors shall be made using female header pin connectors assembled in a custom wiring harness, along with its signal wires.

5.3.4 Battery to Accelerometer and Gyroscope

The Accelerometer and Gyroscope unit is powered directly from the ESP-32, using female header pins.

5.3.5 Battery to Shaft Encoders (2)

Shaft encoders are connected to the power supplies 5V bus bar using spade terminals. The sensor side connection uses a custom connector purchased from the same vendor that supplied the sensors.

5.3.6 Battery Power to MCU board

Battery Power to MCU shall be connected to the MCU using Screw terminal connectors on the PIC, an extra slot for battery status is provided. Female header pins are used on the ESP. The connection to the power supply side shall use the 3.3V and 5V bus bars, respectively.

5.3.7 Charge Controller to Battery Interface

The charge controller shall attach to the battery using screw terminals on the charge controller side, and ring terminals bolted to the battery on the battery side.

5.3.8 Solar Panel to Charge Controller Interface

The Solar panel has wires attached from the manufacturer that output in the form of an SAE connector. An opposing SAE connector with wire leads shall be used to connect the SAE output of the screw terminals of the charge controller..

5.4 Signal Interfaces and Connectors

The signal interfaces, for the purpose of this document, are defined as those interfaces carrying information within the mowing unit, between subsystems, on wires. As such most of these terminate or originate in the PIC-32 or ESP-32 MCU. This section will specify protocols used and physical connectors. The total number of signal interfaces for the Pic is 15, for the ESP 14. All connectors to the PIC are PCB mountable Screw terminals with the specified number of pins and female header pins for the ESP unless otherwise specified.

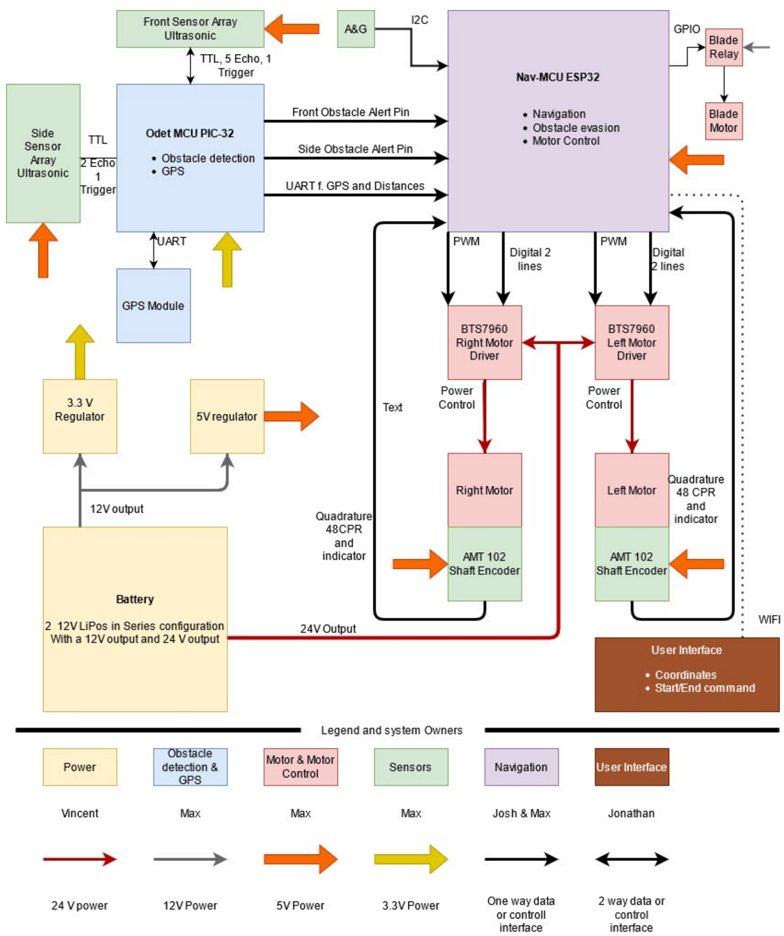


Figure 6: Signal interfaces with MCU, dashed line indicates subsystem boundary. Blue arrows represent incoming , Green outgoing wired signals. Red represents incoming power, thick black arrow represents bi directional wireless signal, small arrows represent internal signals. Incidental components omitted for clarity.

5.4.1 Accelerometer and Gyroscope Unit

The Accelerometer and Gyroscope Unit shall communicate with the ESP Unit via I2C protocol. Connected by female header pins on both sides

5.4.2 Ultrasonic Sensors

The Ultrasonic Sensors shall interface with the MCU using TTL signals. The TTL pulse uses 2 wires per sensor for trigger and echo signals. The front and side array each have a common trigger input, and each sensor has its own echo output. Making for 5 echos and 1 trigger from the front array, and 2 echos and 1 trigger for the side array.

Each sensor shall be connected to the MCU using its own 2 pin connector. The connection on the sensor side shall be made using female header pins.

5.4.3 Wheel Encoders 1 and 2

The wheel encoders shall use AB Quadrature pulse train signals to communicate the number of wheel rotations done by the main motors, as well as an Indicator pulse for full wheel rotations. As only the A and indicator channel were used, each SE has 2 signal lines with the ESP-N.

Each shaft encoder shall connect to the ESP-N MCU using 2 female header pins. The connection on the wheel encoder side shall use custom connectors.

5.4.4 Motor Control 1 and 2

Motor 1 and 2 shall interface with the MCU accepting pulse width modulated signals fed from the controller through the motor driver. This will allow the controller to vary the speed of the motors individually as needed. Each motor driver accepts 2PWM inputs and 2 digital inputs to select operation for a total of 4 signals per motor. The 2 digital inputs require a logic low and high given as 0 and 3.3V respectively. PWM has a frequency of 5KHz with a duty cycle varining for 0% to 65% during operation.

Each motor driver shall connect to the MCU with 4 female header pins, The connections to the Motor control board shall be made using female header pins as well. Power from battery to H-bridges and H-bridges to motors is provided using screw terminals on the drivers, and Crimp connections elsewhere.

5.4.6 Main Blade Control Relay

The relay attached to the blade shall operate at a 5 V signal and interface with the MCU. The MCU shall provide a signal of 3VDC or greater to a relay driver, which then activates the Relay as needed

The Main Blade Relay control connects to the ESP-N via female header pin and uses a screw terminal on the relay driver side. Motor power connection is also made via screw terminal.

5.4.7 Main Blade Status

This interface was not implemented, as the underlying feature was not implemented.

The main blade status shall be interfaced with the MCU. The motor will send a 3 volt signal if the blade is functioning properly, or a off (0 V) signal if it is stuck or not working. See section 5.4.6.

The Main blade status signal shall connect to the MCU on the same 2 pin header as the Main blade control relay. The Blade motor side connection shall be made by attaching a splice crimp terminal to the end of the wire. This will ensure the relay has a sturdy connection.

5.4.8 Main battery status

This interface was not implemented, as the underlying feature was not implemented.
The main battery status shall be relayed to the MCU by means of a direct connection to the battery, in order to read it’s voltage. The signal will directly relay battery voltage. The Maximum voltage level of this signal is 15VDC, with 0VDC minimum.

Main battery status signal shall connect to the MCU via the same 3-pin screw terminal connector as battery power, on a separate pin. See section 5.3.6

The main battery status signal shall connect to the main battery via ring terminal, by bolting directly to the battery.

5.5 Wires

All wires shall be shielded from hazardous parts, unintended contact by the user or external environment. Wires shall be shielded using plastic wire shields or plastic conduit where applicable. Wires shall be routed neatly and affixed to the mowing unit to prevent wires from coming in contact with dangerous parts or abrasion from vibration. See section 3.3.5 for details. In cases where wires need to be spliced to be extended, Butt splice connectors shall be used, with the connection sealed in heat shrink or similar protective material.

5.5.1 Signal Interface Wires

Signal interfaces are made using either 18AWG wire, or breadboard jumper wires. In some cases one or multiple jumper wires were soldered to 18AWG wires in order to multiplex signals and extend wires. Soldered connections were covered either in heat shrink or electrical tape, as appropriate.

5.5.2 Power Supply Wires

All power supply wires shall be routed protective shielding, when coming near hazardous parts, or where bystanders may contact them.

5.5.2.1 Power Supply to Motors

Power supply to motors shall be done with 14AWG copper wire, not to exceed 3ft in overall length for any one run.

The Connections to the motor driver boards shall be fused in accordance with it’s data sheet, 30A fuse for the power input and 15A fuse for each motor output. The fuses shall be inline automotive ATO fuses.

Blade and drive motors have separate power switches, allowing power to be safely disconnected.

5.5.2.2 Power Supply to MCU Board and Sensors

The power to the MCU and sensors shall be delivered using 18AWG or larger stranded copper wires.

5.5.2.3 Power Supply to Regulators

The 5 and 3.3V regulators are connected to the battery using 14 AWG wires, where both regulators are fused using ATO automotive fuse rated for 3A each. Each power supply includes its own switch.

5.6 User Control Interface

The only interface with which the user will be able to interface with the autonomous lawnmower is the android-based GUI which will allow the user to view the status of the mower, and usage statistics as well as provide navigational data and scheduling commands wirelessly. No other user interface is required and no other interface will be designed.

5.7 MCU Debugging interface

Inorder to facilitate debugging and programming the Pic-32 MCU will include a debugging port for use with the MPLAB PICkit 4 debugger. The Debugger will interface with 2 I/O pins and the Reset Pin of the MCU, as well as VDD and ground. The connection will be made using female header pin. The Debugger will attach to a Computer using USB. This connection is not intended to be accessed by the user or any other subsystem, and is purly for internal and development use of MCU subsystems. The MCU-board additionally includes a UART port for debug and demo purposes, giving serial access on a screw terminal. This connection may be used to interface with other peripherals via UART or be reconfigured for final operation if need be.

The ESP-32 includes a serial and debug port accessible via Micro USB.

6 Communications / Device Interface Protocols

6.1 WiFi

The user interface will communicate with the microcontroller wirelessly through WiFi according to the IEEE 802.11 standards in order to send and receive information.

Autonomous Lawnmower

Max Lesser
Vincent McMasters
Josh Samaniego
Jonathan Poulose

Functional System Requirements

REVISION – 3
29 April 2021

Functional System Requirements
for
Autonomous Lawnmower

Team 30

Approved by:

____
Team Member Date

____
Prof. S. Kalafatis Date

____
Pranav Dhulipala Date

Change Record

Rev.	Date	Originator	Approvals	Description
1	9/20/2020	Max Lesser		Draft Release
2	11/24/2020	Vincent McMasters		Revision 1
3	4/29/2021	Josh Samaniego		Final Report

Table of Contents

List of Tables

List of Figures

1 Introduction

1.1 Purpose and Scope

The ability to maintain the appearance of one's property can often be challenging for people who are either simply too busy or are frequently on the go. Rather than having to pay somebody else to maintain their lawn for them, our aim is to provide an autonomous system that will mow the individuals lawn regardless of if they are home. The autonomous lawnmower will receive the information about the area to be mowed from the user, using a wireless interface through an android app. The mower is then to mow the indicated area completely autonomously, for a duration of at least an hour. The system shall use inertial and GPS guidance, as well as internal sensors, to navigate based upon the location of the starting point. The system will have built in safety features and protocols in order to ensure the safety of anyone nearby while the mower runs. The goal of this document is to list and define system and subsystem requirements in order to meet the expectations and goals of the autonomous lawnmower project statement.

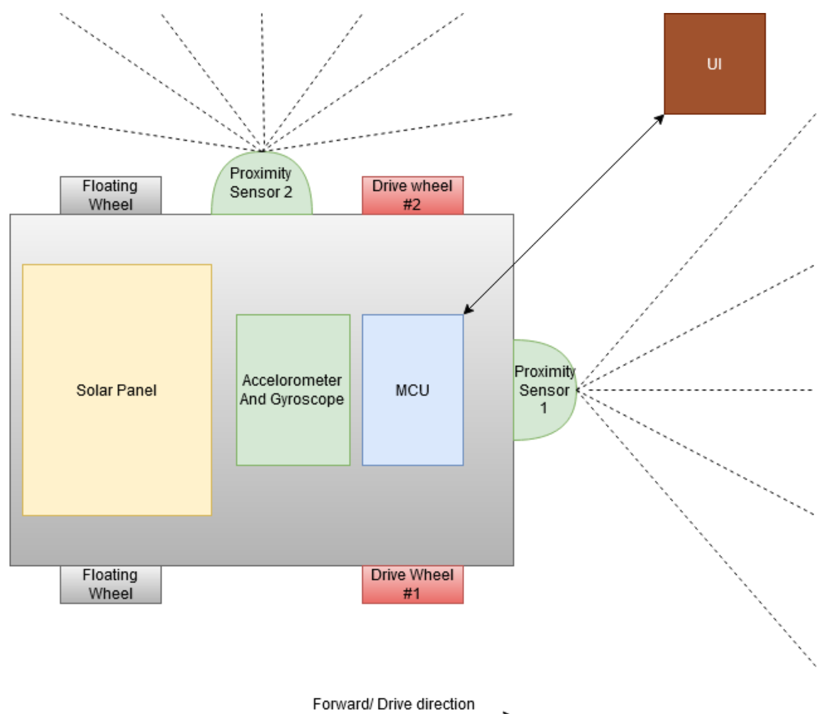


Figure 1: Autonomous Lawnmower Layout, Top View, case omitted for clarity.

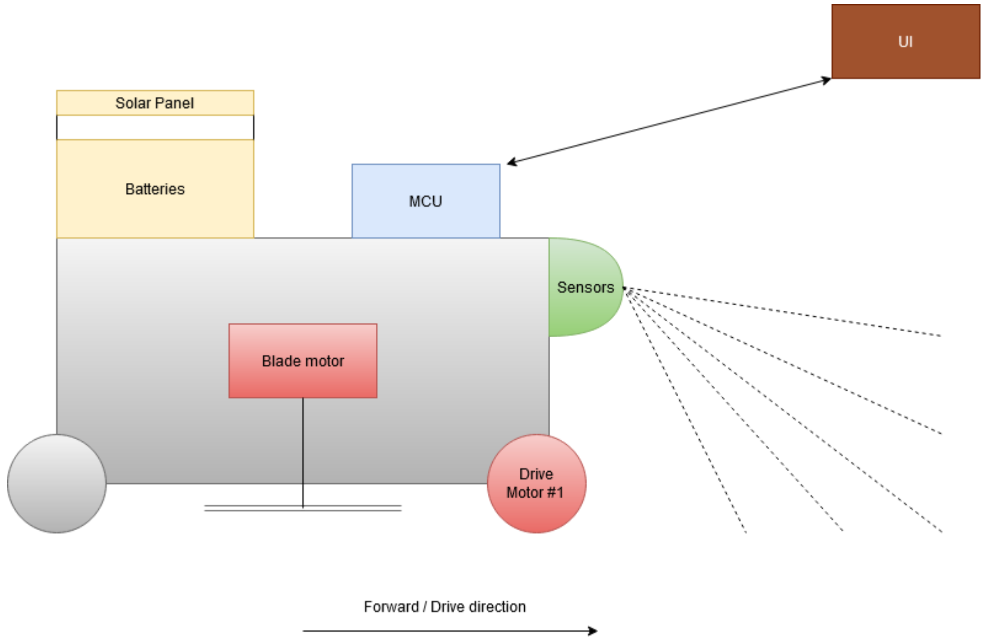


Figure 2: Autonomous Lawnmower Layout, Side View, case omitted for clarity. Final design iterations may place the solar panel elsewhere.

1.2 Change authority

Authority to change the subsystem specific sections lies primarily with the team member responsible for the subsystem in question. Others may only make changes after consultation, or to fix spelling and grammatical errors, or to maintain coherent formatting within the document. General sections may be changed by any team member, in accordance with previously agreed upon style and available outlines. In order to change larger requirements in relation to the project assignment itself consultation with Professor Stavros Kalafatis will be required.

Subsystem	Responsibility
MCU, Sensors, Navigation, Motor Drives	Max Lesser
Power Supply	Vincent McMasters
Navigation	Josh Samaniego
User Interface and Navigation	Jonathan Poulose

Table 1: Subsystem Responsibilities

2 Applicable and Reference Documents

2.1 Applicable Documents

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

Document Number	Revision/Release Date	Document Title
IEEE 802.11	2/6/2012	IEEE Standard for Information technology—Telecommunications and information exchange between systems Local and metropolitan area networks—Specific Requirements
IPC A-610E	Revision E – 4/1/2010	Acceptability of Electronic Assemblies
UL 2595	Editition 2 - 9/2/2015	General Requirements for Battery-Powered Appliances
ANSI/OPEI 60335-2-107-2020	Edition 1 - 6/8/2012	Standard for Adjustable Speed Electrical power Drive Systems
UL 2111	Edition 1 - 3/28/1997	Standard for Overheating Protection for Motors
IEEE 1547.1	Edition 1 - 5/21/2020	Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

Table 2: Applicable Documents

2.2 Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

Document Number	Revision/Release Date	Document Title
PS-MPU-6000A-00	Revision 3.4- 08/19/2013	MPU-6000 and MPU-6050 Product Specification
28015	Revision 2.0 - 2/4/2013	PING Ultrasonic Distance Sensor
28504	Revision 1.0 - 3/30/2019	SIM33EAU GPS Module
70632C	Revision C - May 2013	MRF24WB0MA/MRF24WB0MB
DS60001320G	Revision G - December 2019	PIC32MZ Embedded Connectivity with Floating Point Unit (EF) Family

Table 3: Reference Documents

2.3 Order of Precedence

If there is a conflict between the text within this document and the cited documents, this document and its specifications will take precedence with no exceptions. Specifications, standards, drawings, or other documents are listed as applicable. Documents are used for information with the exception of ICD, which has its own relevant documents incorporated.

3 Requirements

This section defines the minimum requirements for the system and subsystems. An overview and system definition will be given first, followed subsystem descriptions and finally requirements.

3.1 System Definition

The Proposed Autonomous lawnmower system consists of 5 major subsystems: Power, Drive and Blade Motors, Sensors, User interface and Microcontroller Unit.

These subsystems combine in 3 units: the mowing unit, docking station and the User interface. The Mowing unit will combine all systems needed for lawn mowing, namely the Drive and Blade motors, Power system, MCU and sensors. The docking station shall provide a means of charging by either solar or wall power. The User interface will run on a customer device and provide the mowing unit with information about the area to be mowed, schedule commands by the user, as well as allow the mower to give feedback to the user.

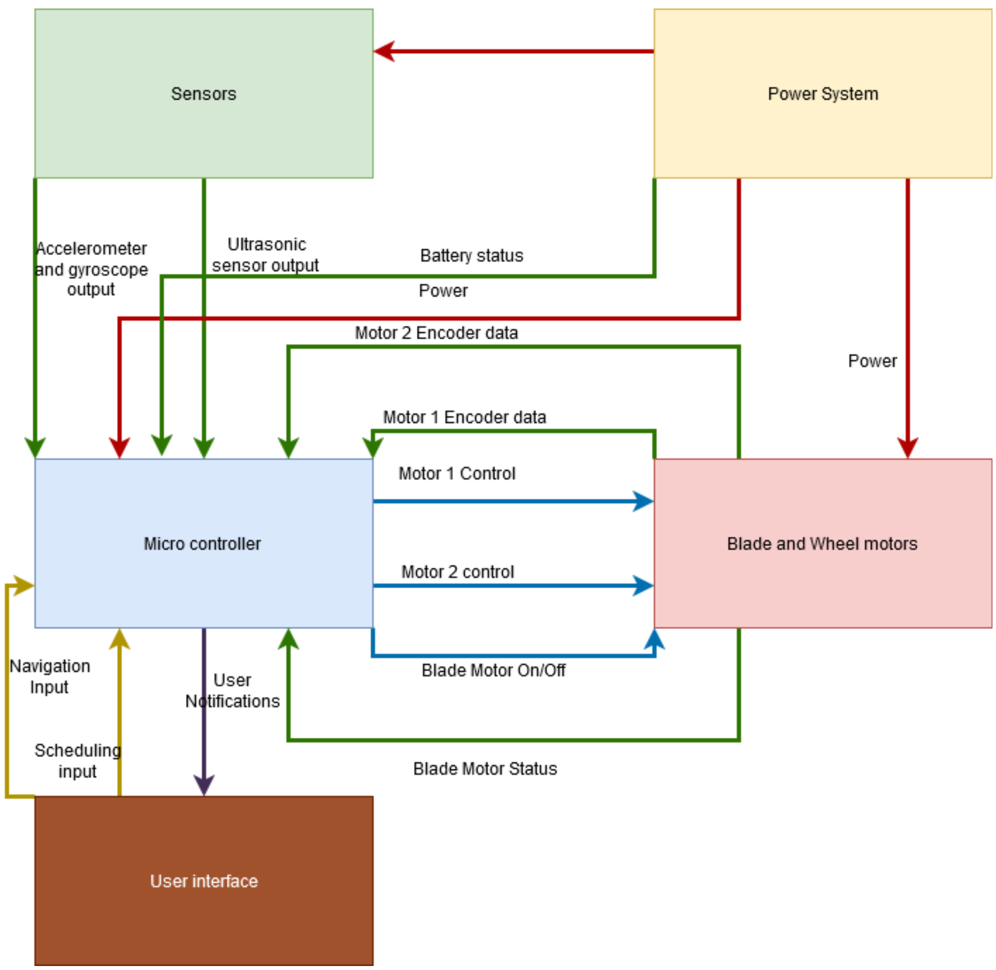


Figure 3: Autonomous Lawnmower Block Diagram

3.1.1 Subsystem definitions

Power supply, Sensors, Motor drives and MCU will be combined on the mowing unit to achieve the mission, interfacing with the user via the UI. While the power subsystem also includes the docking station. A short overview of each subsystem is provided below

3.1.1.1 Microcontroller Unit

The Microcontroller Unit will combine sensor and user information as well as information from other subsystems to control the overall system to achieve the mission. The microcontroller will actuate the motors, control the main blade motor, monitor and control the sensors, monitor battery status, receive navigation and scheduling information from the user as well as notify the user of system status. It will receive power from the power system. The MCU will include a GPS sensor to monitor system position and a WIFI module to communicate with the user, in addition to incidental components to insure connectivity with other systems and consistent power supply.

Update: The MCU does not currently monitor battery status, or inform the user of any sort of system status. The MCU has but does not currently utilize GPS to navigate the mower.

3.1.1.2 Power system

The Power system will utilize a solar panel and a wall plug in order to charge the battery to the system. The solar panel and wall plug will input to a PCB that will take the solar panel output only when it is between 6 and 12V. The selected power will be sent through a disconnecting circuit to the charge controller and battery which will be stationed on the mower unit. The battery will directly power all of our systems from the mower itself.

Update: The docking power system designed worked with our old motor system that ran on significantly less power. Because the new motor system requires much more power and hence new batteries, the docking station was not utilized.

3.1.1.3 Sensors

There will be five total sensors attached to the device. Two of the five will be distance sensors that are ultrasonic rangefinders. These will be attached to the front and side of the device to see the surroundings and to make sure the lawnmower does not run into anything. Another sensor that will be inside the device will be a 3-Axis Accelerometer and Gyroscope sensor to measure the acceleration and speed as well as the direction of the device. The other two sensors are shaft encoders that will be used to count the number of times the motors have rotated and to double check that the wheels are turning in the right direction.

Update: The mower now has 5 front facing and 2 side facing Ultrasonic sensors. The readings from the side sensors are not currently used. The accelerometer and gyroscope unit is not used due to component failure.

3.1.1.4 Blade and Wheel motor drives

The blade and wheels will be driven by a total of three DC motors. The two front wheel motors will allow the lawnmower to turn in any direction, or speed up/slow down, all made possible by the microcontroller. The blade motor will be supplied with a constant voltage, and will be configured so that when the blade gets caught on an object, the blade will stop rotating. All three of these motors will be able to operate under a 12 V supply for an hour without overheating.

> Update: The old wheel motors did not have enough torque to move the mower so new wheel motors and motor drivers (250 W each) were used to drive the lawnmower from the rear wheels. The blade motor currently does not shut off when blocked, but will shut down when power to the microcontroller is lost.

3.1.1.5 User interface

The user interface will run through an android phone or a tablet and will be available on the google play store. This application is necessary for the lawnmower to work due to the transmission of data to and from a WiFi network. The application will provide the user several operation modes starting from the learning mode to the normal mode. During the learning mode, the application will allow the user to specify the area to be mowed and will decide if objects are meant to be mowed on. The interface will allow the user to schedule mowing times and to enter navigation information. It will also notify the user with statistics such as battery level, completion level, and estimated time remaining and reminders before and at the start of operation.

> Update: The application does not currently notify the user of any battery or completion statistics, nor allow specification of obstacles. There is only one mode, allowing a user to enter coordinates.

3.2 Characteristics

3.2.1 Functional / Performance Requirements

3.2.1.1 Operational stamina requirement

The system shall mow grass continuously for no less than 1 hour in flat, obstacle free terrain.

Rationale: This is a requirement that was given to use by Professor Stavros Kalafatis. 60 minutes is also the average time spent mowing one's lawn by a typical person.

Update: The lawnmower was tested for hours on end in incremental time periods. It is shown that the lawn mower can mow for an hour on concrete.

3.2.1.2 Duty cycle

The system shall perform operations at least every 7 days.

Rationale: The most common time frame in which someone mows their lawn is once a week or longer. Hence our system will meet or exceed duty cycle requirements for residential lawn mowing.

Update: The lawnmower does not have a feature that performs a routine cycle of mowing every 7 days, however battery charge rates certainly permit operation every 7 days.

3.2.1.3 Obstacle Avoidance

Obstacle avoidance will be performed based on the data collected from the two distance sensors attached to the device. Obstacles include walls or any miscellaneous objects that need to be avoided. The mower shall navigate to avoid any obstacles in its path that can prove harmful to the mower. Small objects, such as small branches or pebbles may be undetectable in tall grass and will be mowed over. These objects shall not damage the overall system, and may only impact blade sharpness and mower appearance.

Rationale: It is often that people will mistakenly leave things in their yard so it is critical that we detect and avoid them. Small objects such as sticks or small rocks often blend into the grass and as such are commonly run over in lawnmowers .The only impact these cause in traditional lawnmowers is a dulling of the blade or external scratches and dents. Therefore our system shall handle these objects similarly.

Update: The mower currently uses 5 distance sensors in the front and 2 on the side. The side sensors are not utilized. Front obstacle detection and evasion works.

3.2.1.4 Navigation

The user interface shall use GPS to determine navigational boundaries and transmit them to the mowing unit. Navigation boundaries will be decided through the application by placement of markers on a map of the users yard. These markers will be placed on the corners of the lawn and will set the boundary for the lawn. The mower shall then use its internal GPS to follow a clockwise spiral pattern connecting the markers, moving towards the center of the yard. With possible deviations to avoid permanent or temporary obstacles.

Rationale: The GPS coordinates will form a grid in order to make it the simplest path possible for the mower to take. allowing the user to set GPS markers makes the navigation selection simple and robust.

Update: The user interface does send GPS coordinates to the mower, where they are converted to distances. However these values were not used during the demo due to issues with the code. The mower has a functioning GPS unit, however its data was not implemented due to time constraints.

3.2.1.5 Obstacle detection Range and Threshold

The Mower shall be aware of any object extending more than 2 inches above the ground, inside of the hypothetical box extending from the widest point of the mower to a distance no less than 2 meters from the front most point of the mower. For this purpose width dimension is considered to be dimension perpendicular to drive direction and parallel to the ground, while the front is the drive direction. The mower shall be aware of any object within 2 meters perpendicular distance of its left side.

Rationale: The mower needs to be aware of objects to its front to avoid them, as well as objects to at least one side, such that it can safely mow along physical boundaries. No detection to the opposite side is required as the mower follows a clockwise spiral and only needs to approach boundaries on the outside path of this spiral. No detection to the rear is required as the mower does not normally engage in backing maneuvers. The only case where the mower may reverse is in an attempt to free itself when stuck. In these cases the immediate rear of the mower is assumed clear as it was just scanned by the front facing sensor.

Update: Because the mower only utilizes the front facing sensors and not the side facing ones, the lawnmower can only detect obstacles in front of it. Due to sensor failures at demo time front detection reaches only ~90cm.

3.2.2 Physical Characteristics

3.2.2.1 Mass

The mass of the systems added to a traditional lawn mower shell shall be less than or equal to 20 lbs. This results in an overall maximum weight of the mowing unit of 70 lbs.

Rationale: This is a rough calculation of the overall mass of the lawnmower system, given the different subsystems and their masses. See section 3.2.2.2 rational for mass uncertainty.

3.2.2.2 Volume Envelope

The volume envelope of the Lawnmower shall be less than or equal to 30 inches in height, 25 inches in width, and 40 inches in length.

Rationale: This size requirement is written to account for the size of subsystems and the shell it will be mounted on. Lawn Mowers for residential use typically do not exceed the above size. Since this project is a proof of concept and will use a recycled lawn mower shell as its body the exact dimensions are not currently known. The above is an upper limit that allows flexibility in selecting a shell and mounting external components. The volume envelope is still comparable to residential lawn mowers.

3.2.2.3 Mounting

The mounting information for the Autonomous Lawn Mower components shall be captured in the Autonomous Lawnmower ICD. All Components shall be mounted in a fashion resistant to vibration incidental to lawnmowing.

Rationale: As the system mounts to the Lawnmower platform, the interface between the two includes mechanical, electrical and thermal details. Additionally vibration is incidental to lawnmowing and as such should not negatively impact the system.

3.2.3 Electrical Characteristics

3.2.3.1 Inputs

The lawnmower system shall not be damaged by any possible system generated input. In case inputs outside the specified inputs are received the system shall return to its parking position, or shut down in worst case scenarios. No user input shall cause the system to engage in unsafe or damaging operations. The worst acceptable damage to the system is damage to the blade itself or cosmetic damages to the frame in cases of user negligence. This section excludes grossly negligent damage caused by the user or 3rd parties.

Rationale: The system shall ensure user safety at all times and prevent damage incidental to lawn mowing operations.

3.2.3.1.1 Power Consumption

The power consumption of the lawnmower unit shall not exceed 200 Watts.

Rationale: This requirement is specified based upon the input voltage and current.

Update: The lawnmower currently exceeds this value, as the new motors are rated for 250 W each.

3.2.3.1.2 Input Voltage Level

The input voltage level for the Lawnmower shall be 14.2 VDC to 14.4 VDC.

Rationale: This is the required maximum voltage for the battery to have reached its full charge and for it to be able to function at its full potential.

Update: Because the new motor system requires much more power, the input voltage level will be both 12V and 24 V.

3.2.3.1.3 External Commands

The Lawnmower system shall receive external commands from the User Interface via a WIFI connection. Details will be outlined in the ICD.

Rationale: The ICD will capture all interface details.

3.2.3.2 Outputs

3.2.3.2.1 Data Output

The mowing unit shall inform the user of problems and fault conditions through the UI app via WIFI. Details will be outlined in the ICD

Rationale: Provides the necessary feedback to the user so that the subsystem of the lawnmower can be attended to.

Update: The lawnmower does not inform the user of any issues through the application.

3.2.3.2.2 Diagnostic Output

The MCU shall include a hardware debugging port that may be interfaced to a computer for Diagnostics. Details will be provided in the ICD.

Rationale: Provides the ability to control things for debugging manually.

3.2.3.3 Connectors

Connectors shall be resistant to vibrations and disturbances incidental to Lawn mowing, such as blade vibrations or rough terrain. Connectors shall be reliable for 6 months when operated once weekly before inspection. Specific connectors shall be specified in the ICD

Rationale: to maintain operability under the strains of lawn mowing, within an maintenance interval comparable to traditional lawnmowers

Update: time prevented us from testing the mower for 6 months, observations during testing suggest that this requirement is met.

3.2.3.4 Wiring

The wiring for signal and power interfaces shall be routed clear of any moving internal parts, and clear of all possible outside interference. Wires running on the outside of the unit shall be enclosed in protective conduit. Details will be specified in the ICD.

Rationale: Wires being integral to electrical equipment, and the automated system requiring additional wiring proper protection is critical.

3.2.4 Environmental Requirements

The Lawn mowing system shall operate in all environmental conditions that traditional residential lawn mowers operate and lawn care activities take place.

Rationale: The system is intended to replace traditional lawnmowers operated by homeowners. As such it should be able to perform under the same conditions.

3.2.4.1 Thermal

The Lawnmower shall operate in temperatures ranging from 40°F to 120°F.

Rationale: These temperatures represent the range in which lawn mowing typically takes place.

Update: Unable to test full temperature range, tested range reported in system validation. Tests suggest we can operate over this range.

3.2.4.2 External Contamination

The Lawn mower shall be immune to dust and debris. The Lawn mower systems shall either be protected from, or insensitive to ingress of debriess 1mm or larger, as well as dust, Conforming with Ingress Protection (IP5X) of solids.

Rationale: Dust and debris are incidental in the process of mowing a lawn, and therefore should not hinder the operation of the system.

Update: Not able to fully validate, tests suggest this requirement is met.

3.2.4.3 Rain and extreme weather

The Lawn mower shall not operate in rain. It shall be able to withstand exposure to the elements when parked in the docking station. In extreme weather conditions that may result in strong winds or excessively heavy rainfall the mower may need to be moved to shelter.

Rationale: Lawn mowing in rainy conditions or of wet soil is atypical of residential lawn mowing. Additionally, wet soil introduces issues of traction control and blade operation due to the grass becoming significantly heavier when weighed down. Since the unit is solar charged it however needs to be resistant to rain when not in use. Additionally extreme weather such as hurricanes or strong storms require the mower to be stored in a safe place, as damage from high winds or falling objects is possible. Similar restraints exist for regular lawn mowers.

3.2.4.4 Humidity

The Lawnmower shall function temporarily in conditions of up to 100% humidity. The Mower shall be able to perform its mission in 100% humidity, but requires lower humidity or higher maintenance for long term storage and performance.

Rationale: The humidity in the United States, in particular the southeast, often reaches 100% humidity. As such, the system shall be able to operate in these conditions. However, indefinite periods at this high of a level of humidity is not common in the continental United States, so performance under these conditions is not needed. Therefore, using the device under these conditions for a long period of time is not recommended.

Update: Unable to completely validate due to weather conditions during testing. tested range reported in system validation.

3.2.4.5 Soil Moisture

The Lawn mower shall be able to operate on moist, but not wet solid, on level terrain. For this purpose wet soil is defined as soil that is unable to absorb moisture, thus forming puddles at the surface. The Ability of the system to function on moist soil varies with terrain type. The ability to maneuver on moist grass is reduced, further degrading with uneven or sloped terrain.

Rationale: As outlined in the rain requirement, lawn care typically occurs in dry conditions, as wet grass reduces blade performance and introduces traction control issues.

Update: The autonomous lawnmower system does not possess the necessary torque to turn on grass, therefore soil moisture was never measured so this requirement is void.

3.2.4.6 Distance from Router (WIFI connection distance)

The Lawnmower shall be able to communicate with the network at the operating site from at least 100ft and through at least 1 wall of wood/drywall construction

Rationale: In order to remove the need for an external WiFi antenna on the mower, which would cause additional failure points, the minimum distance has been set. It also is a typical distance for how far someone would have to go from the edge of their house to be able to mow the entirety of their lawn.

3.2.4.7 Sky clearance

The Lawnmower shall be able to operate with light to medium foliage overhead, defined as in all exterior environments where a handheld GPS unit is able to establish a connection to a satellite.

Rationale: The lawnmower requires the ability to connect via GPS to satellites in order to gain the necessary information to mow the lawn. It is also fairly uncommon for lawns to be in highly vegetated areas so this may not be an issue.

3.2.4.8 Vibration

The Lawnmower system shall operate without failure, under vibration incidental to lawn mowing for at least 6 months, when operated once weekly for 1 hour. After this point inspection of electrical and mechanical connections may be required. Additional information in ICD.

Rationale: Heavy vibrations are incidental to lawnmowing and present a risk to mechanical and electrical connections. Traditionally mowing seasons last for about half a year, with normal mowing frequency being weekly or less, after which lawn mowers are typically serviced by the owner. As such our system would require no more maintenance than traditional systems.

Update: Unable to validate due to time frame. Observations during testing suggest that requirement can be met.

3.2.5 Failure Propagation and protocols

3.2.5.1 Blade error

The lawnmower's user interface will notify the user if the blade is stuck on an obstacle. The motor attached to this blade will be connected to a relay, and the mower will power off if the motor can no longer spin. This allows the user to approach the mower and fix the problem.

Rationale: This will preserve the integrity of the blade and its motor.

Update: The application does not currently have the ability to notify the user if the lawnmower blade is stuck on an object. The blade motor does not shut down when blocked.

3.2.5.2 Mower stuck

If the mower becomes stuck in terrain it shall power down, disabling the blade and alert the user.

Rationale: to not expand battery when the mower becomes stuck

Update: The lawnmower does not currently have the ability to detect if it is stuck on something. There is a built in switch to manually turn off all power if problems arise.

3.2.5.3 Lost Wifi connection

In cases where the WIFI connection to the user device is lost the mower will continue on its planned route and return to the rest position. The mower shall not engage in any mowing conditions until connections to the user device is reestablished.

Rationale: occasional WIFI outages are common, and as such should not render the mower inoperable. However to ensure user safety the mower shall not engage in previously scheduled activities without connection to the user.

Update: The lawnmower has no go home function, but will finish its route if wifi connection is lost.

3.2.5.4 Lost GPS connection

If the mower loses GPS connection it shall attempt to follow the planned route to the best ability. If the mower becomes unable to orient based inertial guidance it shall alert the user and stop. Loss of GPS is uncommon and poor GPS signal should be known before purchase and this failure case should be rare.

Rational: GPS loss of signal is rare, and locations with poor GPS signal are not suited for this system. Regardless the system shall try to complete the mission.

Update: The lawnmower does not utilize GPS to help it navigate. It works simply off distances and shaft encoder readings.

3.2.5.5 System Failure

In cases of system failure the mower shall alert the user through the UI, disable the main blade and return to the start position, if possible. If system failure causes the mower to be unable to maneuver it shall remain in place, shutdown all controllable systems and alert the user. If WIFI communication fails the mower shall shutdown all controllable systems.

Rational: Failure of subsystems is undesirable, but never entirely preventable. As such the mower shall act to ensure safety of bystanders first, and user convince second depending on the amount of control it maintains over subsystems. After failure maintenance is required to restore system operability. This is in accordance with failures in traditional lawn mowing equipment

Update: The lawnmower does not currently have the ability to send an alert regarding system failure through the application. The lawnmower also does not have the ability to shut down if it is unable to maneuver. However blade and drive motors will shut down if either connection to the MCU is lost or the MCU itself loses power.

3.2.5.6 Critical System Failure

In Critical Failure cases, that is situations in which the MCU loses all ability to control the mower or it’s subsystems the lawnmower blade will shut off. Protecting the user from possible harm caused by the blade. Details outlined in ICD.

Rational: If the worst case scenario occurs we have to protect anybody around the area.

Update: The blade does not currently shut off if the MCU goes into critical failure mode. but it will stop if the MCU loses power or it becomes disconnected from the MCU.

4 Support Requirements

4.1 Operational support requirements

This section lists external infrastructure requirements needed for regular operations of the system

4.1.1 Android Smartphone

The lawnmower will require the user to have an android phone. This is in order to download the designed application that will let the user specify the area they want mowed.

Rationale: The lawnmower cannot function without the user designed application, as it provides the necessary navigation information.

4.1.2 Wi-fi

The user must have a reliable wi-fi connection, which will allow the lawn mower to receive navigation information and scheduling information as well as relay messages from the mower to the user. .

Rationale: The lawnmower requires information from the user, via WiFi, to operate.

Update: Wifi is only used to send coordinates to the mower.

4.1.3 GPS

In order for the mower to be able to navigate and to receive navigation information form the user, GPS reception at the operating site is required. Both navigational boundaries, and the mower's navigation system rely on GPS to define the area to be mowed and to track the mowers' position.

Rationale: while the mower will make use of inertial guidance to account for position uncertainty of GPS, it still requires GPS to set navigation boundaries and as a means to insure inertial guidance accuracy. Residential lawns typically have little overhead coverage, outside of foliage, and as such GPS reception should not be a problem.

Update: The lawnmower does not currently utilize GPS to determine navigation boundaries or coordinates.

4.1.4 Sunlight

As the battery system will be charged via solar power sunlight is required. The mowers docking station needs to be in a location with ample sunlight. Additionally the mower may not be suited for use in locations or seasons with little sunlight.

Rationale: To ensure enough sunlight to charge the batteries and maintain desired duty cycle appropriate amounts of sunlight are required. As any area that requires a lawn mower can be assumed to be at least reasonably clear of obstructions to sunlight. Additionally even ambient light or short exposure to sunlight can be sufficient to charge the batteries given the expected minimum of 7 days between operation. Finally since lawn mowing is mostly done during the spring, summer and fall, reasonable amounts of sunlight should be available.

Update: Because the docking power station is not currently being utilized with the new motor system, this requirement is void.

4.2 Technical support

This section lists technical support available to the user for installation and in failure cases.

4.2.1 User manual and instructions

The user shall be provided with an instruction manual detailing maintenance the owner is expected to perform, as well as a troubleshooting guide for expected problems and instructions for setup and operation.

Rationale: An explanation of how to operate the system is required for any system, and shall be provided to the user. Additionally ,as with all equipment, some maintenance is required, as such the owner shall be provided with instructions as to how to conduct this maintenance. Traditional lawn mowers provide similar instructions.

4.2.2 User maintenance

As stated above, some periodic maintenance will be required. All maintenance that the user is expected to perform will be listed. These maintenance procedures may be carried out with tools and equipment that the average homeowner can be expected to own or reasonably obtain. Examples may include common screwdrivers, wrenches and pliers. No maintenance expected from the user shall require any knowledge exceeding what is presented in the manual, nor use of any specialized tools not commonly available. Finally the user shall not incur any harm or risk beyond what may be incurred in maintenance of traditional lawnmowers.

Rationale: Some maintenance is required of any equipment, but to allow the use by the broad public the proposed system shall not require any special knowledge or tools that are not commonly possessed or available.

Appendix A: Acronyms and Abbreviations

A	Amp
Ah	Amp hour
DC	Direct Current
FSR	Functional System Requirements
GPS	Global Positioning System
UI	User Interface
I2C	Inter-IC
ICD	Interface Control Document
IP	Ingress protection rating
MCU	Micro controller Unit
lbs	Pound weight
mA	Milliamp
mW	Milliwatt
PCB	Printed Circuit Board
PWM	Pulse width Modulation
SPI	Serial Peripheral interface
TTL	Transistor-Transistor Logic
USB	Universal Serial Bus
V	Volt
VDC	Volts DC
W	Watt
WiFi	Wireless Fidelity

Appendix B: Definition of Terms

The term mower, Lawn mower, or mowing unit refers to the component of the system that engages in lawn mowing. It includes all the subsystems associated and attached with this unit.

The term traditional lawn mower, or lawn mowing equipment is used to describe human operated lawn mowers, such as push type mowers, self propelled mowers or riding lawn mowers. The term makes no distinction between fossil fuel or electric mowers.

The Term User Interface, or UI, refers to the application running on user end devices that allow the user to interface with the mowing unit.

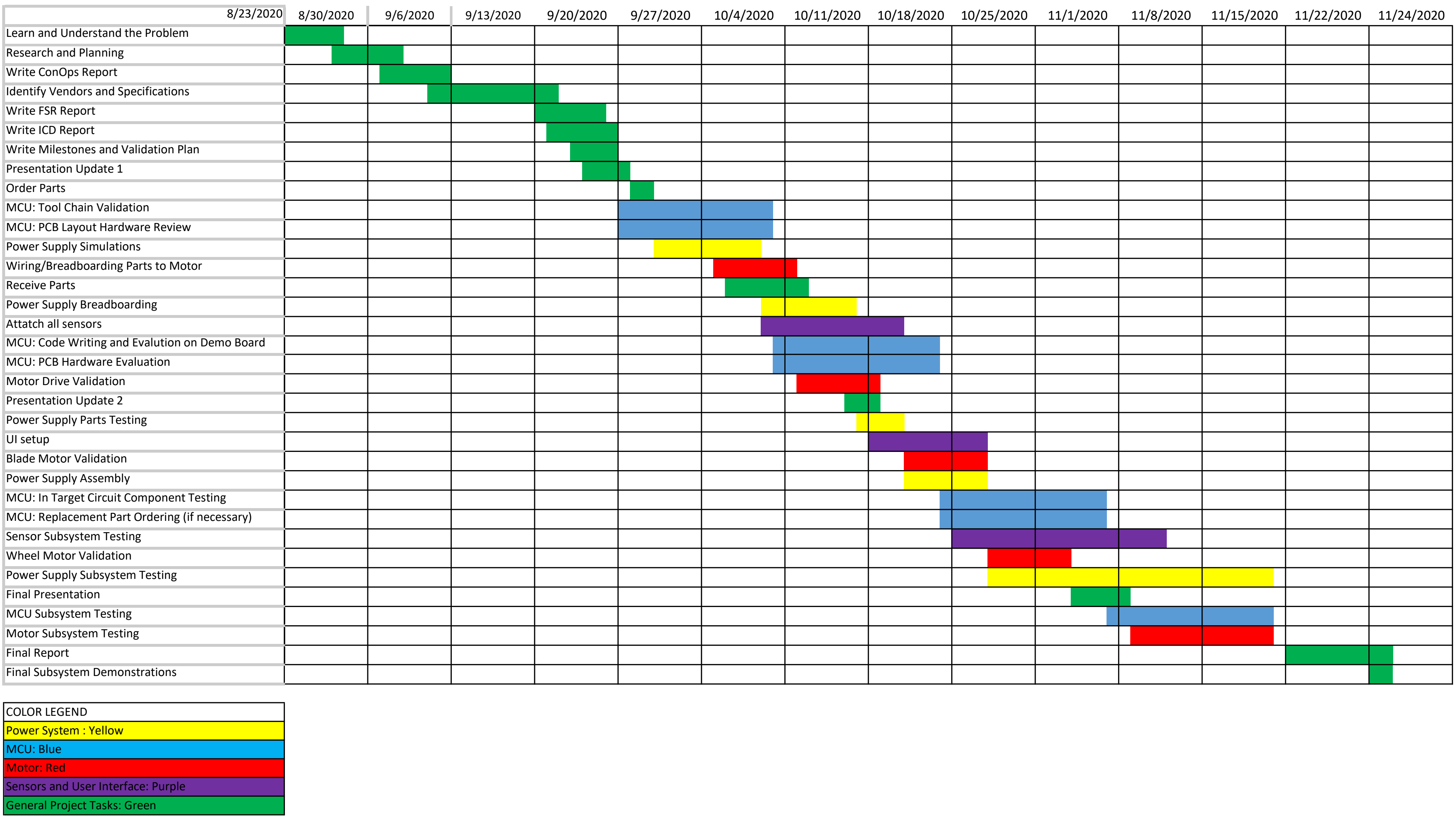
Autonomous Lawnmower

Max Lesser
Vincent McMasters
Jonathan Poulose
Josh Samaniego

SCHEDULE

REVISION – 3
29 April 2021

Execution Plan for Autonomous Lawnmower



Execution Plan for Autonomous Lawnmower

Validation Plan for Automous Lawnmower

Requirement title and heading, as found in the FSR	Abridged text of requirement (see FSR for full text)	Methodology	Status	Responsible team member	Validated By	Comment
3.2.1 Functional/Performance requirements	Performance requirements for the completed system					
3.2.1.1 Operational Stamina	The system shall mow grass continuously for no less than 1 hour in flat, obstacle free terrain	Time operation of system under normal conditions		All	All	
3.2.1.2 Duty cycle	The system shall perform operations at least every 7 days.	Validate Solar/grid charging rate against power consumption in above test		All	M. Lesser	
3.2.1.3 Obstacle Avoidance	The system shall avoid all obstacles that are harmful to the overall system, running over small obstacles that only impact blade sharpness or appearance is acceptable	Individual evaluation of obstacle detection and navigation function under realistic input. Full system validation in Realistic terrain		J. Samaniego M. Lesser	J. Samaniego M. Lesser	
3.2.1.4 Navigation	The system shall use internal sensors to follow a spiral pattern within the boundaries outlined by the user	Simulation of Nav-code, Full system test under realistic conditions		J. Samaniego	All	
3.2.1.5 Obstacle detection Range and Threshold	The system shall be aware of any obstacle in the hypothetical box extending forward from the front of the mower to 2M, as wide as the widest point of the mower	Individual test of Obstacle detection function, in final configuration		M. Lesser	V. McMasters M. Lesser	Sensor array validated to 3M on bench test, after operating on the for 2 weeks we experienced sensor failure on 2, and the maximum distance for any reading was ~ 90 cm
3.2.2 Physical characteristics	Physical Requirements on the completed system					
3.2.2.1 Mass	The mowing unit shall not exceed a maximum weight of 70lbs	Weigh final system		All	V. McMasters J. Samaniego	
3.2.2.2 Volume Envelope	The volume envelope of the Lawnmower shall be less than or equal to 30 inches in height, 25 inches in width, and 40 inches in length.	Measure final system		All	V. McMasters J. Samaniego	
3.2.2.3 Mounting	All components shall be mounted in a fashion to resist vibration incidental to lawnmowing, with service once every 6 months when used weekly	Test connection manually, not able to perform full test, will have to extrapolate results gained from other tests		All	M. Lesser	Given 2 weeks of testing, we expect with the system to operate for 6 months without any major maintenance.
3.2.3 Electrical Characteristics	Definitions of expected external inputs and outputs					
3.2.3.1 Inputs	The system shall not be damaged by any possible inputs or signals produced by the system, No user input shall result in the system engaging in unsafe or damaging operations	Provide mower with all possible input signals and observe performance		All	All	
3.2.3.1.1 Power Consumption	The power consumption of the lawnmower unit shall not exceed 200 Watts.	Measure battery discharge level after use		V. McMasters	V. McMasters	Changes to motors required a larger battery.
3.2.3.1.2 Input Voltage Level	The input voltage level for the Lawnmower shall be 14.2 VDC to 14.4 VDC.	Measure input voltage to battery from charging station		V. McMasters	V. McMasters J. Samaniego	
3.2.3.1.3 External Commands	The Lawnmower system shall receive external commands from the User Interface via a WIFI connection. Details will be outlined in the ICD.	Attempt to transmit Nav/Schedule commands from app and see if mower responds		J. Poulose	J. Poulose	
3.2.3.2.1 Data Output	The mowing unit shall inform the user of problems and fault conditions through the UI app via WIFI.	Generate Fault conditions on mower and see if reports to user		All		ESP sends theoretical battery information to the server and phone application
3.2.3.2.2 Diagnostic Output	The MCU shall include a hardware debugging port that may be interfaced to a computer for Diagnostics.	Physical validation of hardware access ports		M. Lesser	M. Lesser	
3.2.3.3 Connectors	(Electrical) Connectors shall be resistant to vibration incidental in lawnmowing, with service no more than once per 6 months when used weekly	Extrapolate from other physical trials		All	V. McMasters J. Samaniego	Given 2 weeks of testing, we expect electrical connections to last for 6 months.
3.2.3.4 Wiring	The wiring for signal and power interfaces shall be routed clear of any moving internal parts, and clear of all possible outside interference. And protected as appropriate	Visual inspection of completed system		All	V. McMasters J. Samaniego	
3.2.4 Environmental Requirements	The Lawn mowing system shall operate in all environmental conditions that traditional residential lawn mowers operate and lawn care activities take place.	Test in as many environmental conditions as possible and extrapolate				
3.2.4.1 Thermal	The Lawnmower shall operate in temperatures ranging from 40°F to 120°F.	see 3.2.4		All	V. McMasters	Temperature Range Tested: 54°F-66°F and 72°F-82°F
3.2.4.2 External Contamination	The Lawn mower shall be immune to dust and debris. The Lawn mower systems shall either be protected from, or insensitive to ingress of debriess 1mm or larger, as well as dust.	see 3.2.4		All	V. McMasters	Unable to fully test, from operational tests system appears to sufficiently protected
3.2.4.3 Rain and extreme weather	The Lawn mower shall not operate in rain. It shall be able to withstand exposure to the elements when parked in the docking station.	see 3.2.4		All	All	
3.2.4.4 Humidity	The Lawnmower shall function temporarily in conditions of up to 100% humidity, but requires lower humidity or higher maintenance for long term storage and performance.	see 3.2.4		All	V. McMasters	Humidity Range Tested: 41%-44%, 56%-71%
3.2.4.5 Soil Moisture	The Lawn mower shall be able to operate on moist, but not wet solid, on level terrain.	see 3.2.4		All		Unable to test on grass, due to motor/weight problems
3.2.4.6 Distance from Router (WIFI connection distance)	The Lawnmower shall be able to communicate with the network at the operating site from at least 100 ft and through at least 1 wall of wood/drywall construction	see if mower responds when specified distance from WIFI router		J. Poulose	J. Poulose	Was tested from within Max's apartment, which is approximately 100ft
3.2.4.7 Sky clearance	The Lawnmower shall be able to operate with light to medium foliage overhead	test GPS unit in mounting configuration under specified overhead cover		M. Lesser	M. Lesser	Mowing unit can operate without GPS
3.2.4.8 Vibration	The Lawnmower system shall operate without failure, under vibration incidental to lawn mowing for at least 6 months, when operated once weekly for 1 hour.	see 3.2.4		All	V. McMasters M. Lesser	Given 2 weeks of testing, we expect hardware connections to last for 6 months.
3.2.5 Failure Propagation and protocols	No failure shall cause to mower to endanger bystanders					
3.2.5.1 Blade error	The lawnmower user interface will notify the user if the blade is stuck on an obstacle. In this case the blade will shut down automatically	Simulate stuck blade and validate mower sends error message and disabled blade drive		J. Samaniego J. Poulose		
3.2.5.2 Mower stuck	If the mower becomes stuck in terrain it shall power down, disabling the blade and alert the user.	simulate/force mower to become stuck and monitor response		J. Samaniego J. Poulose		
3.2.5.3 Lost Wifi connection	In cases where the WIFI connection to the user device is lost the mower will continue on its planned route and return to the rest position.	disable WIFI router and monitor response		J. Poulose	J. Poulose	Mowing unit can operate without WiFi
3.2.5.4 Lost GPS connection	If the mower loses GPS connection it shall attempt to follow the planned route to the best ability.	disable GPS module and monitor response		M. Lesser J. Samaniego	All	Mowing unit can operate without GPS
3.2.5.5 System Failure	In cases of system failure the mower shall alert the user through the UI, disable the main blade and return to the start position, if possible	Simulate system failure, (i.e. by disconnecting sensors O.S.) and monitor response		All	All	
3.2.5.6 Critical System Failure	In Critical Failure cases, that is situations in which the MCU loses all ability to control the mower or it's subsystems the lawnmower blade will shut off.	Power down MCU during operation and monitor response		All	M. Lesser	Mower shuts off all signals when MCU loses power

Orange: Not Yet Validated
Red: Failed to Validate
Green: Successfully Validated
Blue: Currently in the Process of being validated
Pink: Conditionally Validated

AUTONOMOUS LAWNMOWER

Max Lesser
Vincent McMasters
Jonathan Poulose
Josh Samaniego

VALIDATION PLAN

REVISION – 3
29 April 2021

Table of Contents

List of Tables

List of Figures

1 Validation Plan Introduction

This report will include an explanation as to how we achieved the conditions we outline in the validation plan on the previous page. The requirements in the validation plan are directly taken from the FSR report which can be found in this from the table of contents on page 2 of this report. Our validation consists of the requirement number and description from the FSR, the method by which we would validate the given requirement, the status of the validation of the given requirement, the team member responsible for validating the given requirement, the team member who validated the given requirement, as well as any additional comments necessary. In the status column you can see a multitude of different colors that represent different statuses. Green indicates that the requirement has been completely satisfied. Pink indicates that the requirement was conditionally satisfied or the requirement was changed in the process to more accurately reflect the autonomous lawnmower. Red indicates that the requirement was not satisfied by the autonomous lawnmower.

2 Validation Proof for Various Requirements

This section will include any figures or tables as well as other data that was recorded to validate the various requirements on the validation plan.

2.1 Validation for FSR Section 3.2.1

2.1.1 Validation for FSR section 3.2.1.1

This requirement states that the autonomous lawnmower shall be able to operate continuously for at least 1 hour continuously on flat, obstacle free terrain

This requirement was met by first recording the current used while the autonomous lawnmower was operating. It was found that the autonomous lawnmower operated at 8A while driving straight, and would spike to up to 10.6A while turning, depending upon the force with which the motors had to overcome. Based upon these values, and approximating that the autonomous lawnmower turns approximately 40% of the time. We can find the total current consumption of the autonomous lawnmower for a one hour period.

$$(10.6A * 0.4) + (8A * 0.6) = 9.04A$$

While saying we turn 40% of the time is an overestimate of how much time is spent turning, it proves we can indeed meet this requirement. With a battery capacity of 13Ah the 9.04Ah consumed by the mower clearly allows it to operate continuously for one hour without issue.

2.1.2 Validation for FSR section 3.2.1.2

This requirement states that the autonomous lawnmower shall perform operations at least every 7 days.

This requirement was met by validating the charging rate in conjunction with requirement 3.2.1.1 as specified above. Due to the late changing of the batteries, our new batteries could each be charged in about 30 minutes to full power, meaning that the total charge time would be only 1 hour. This means that the autonomous lawnmower system would be able operate much more often than once every 7 days.

2.1.3 Validation for FSR section 3.2.1.3

This requirement states that the system shall avoid all obstacles that are harmful to the overall system, running over small obstacles that only impact blade sharpness or appearance is acceptable.

This requirement was met by validating our navigation and obstacle detection code. A video showing our obstacle detection and avoidance system within our navigation path was shown during demo time. In that video you can clearly see the autonomous lawnmower going about its navigational path, when it is interrupted by an obstacle, then the blade shuts off and the autonomous lawnmower avoids the obstacle, before resuming the navigational path.

2.1.4 Validation for FSR section 3.2.1.4

This requirement states that the system shall use internal sensors to follow a spiral pattern within the boundaries outlined by the user.

This requirement was met by validating the full run of the navigation code in the completion of a shrinking rectangular pattern that would represent the typical action taken when mowing a lawn. This requirement included the need to implement a turning function, which we implemented using shaft encoder readings to measure distances. We attempted to use GPS for turning, however the GPS only would refresh once per second and only could adjust while the system was in motion, meaning it would take far too long in terms of both time and distance to implement. We also tried to use a gyroscope in order to determine how many degrees the system had turned and correct to 90 when necessary, however the yaw function on the gyroscope was not functioning as intended.

2.1.5 Validation for FSR section 3.2.1.5

This requirement states that the autonomous lawnmower shall be able to be aware of any obstacle in the hypothetical box extending forward from the front of the mower as far as 2W and as wide as the widest point of the mower.

This requirement was conditionally validated by utilizing a plastic shelf that was approximately the same width as the body of the mower and placing it on the ground in front of the mower in order to read the distances that the sensors would output. Below in figures 1 and 2 you can see that the obstacle is placed 60cm in front of the sensors and their corresponding output. In figures 3 and 4you can see that the obstacle is placed 90cm in front of the sensors and their corresponding output. You can see that the sensors worked correctly up to 90cm in front of the autonomous lawnmower. When the sensor array was validated on a testbench, the sensors could read up to 3M in front of them for an object as wide as the autonomous lawnmower. It is our belief that the heavy vibration generated by the motors as well as the process of moving the sensors may have been damaged.

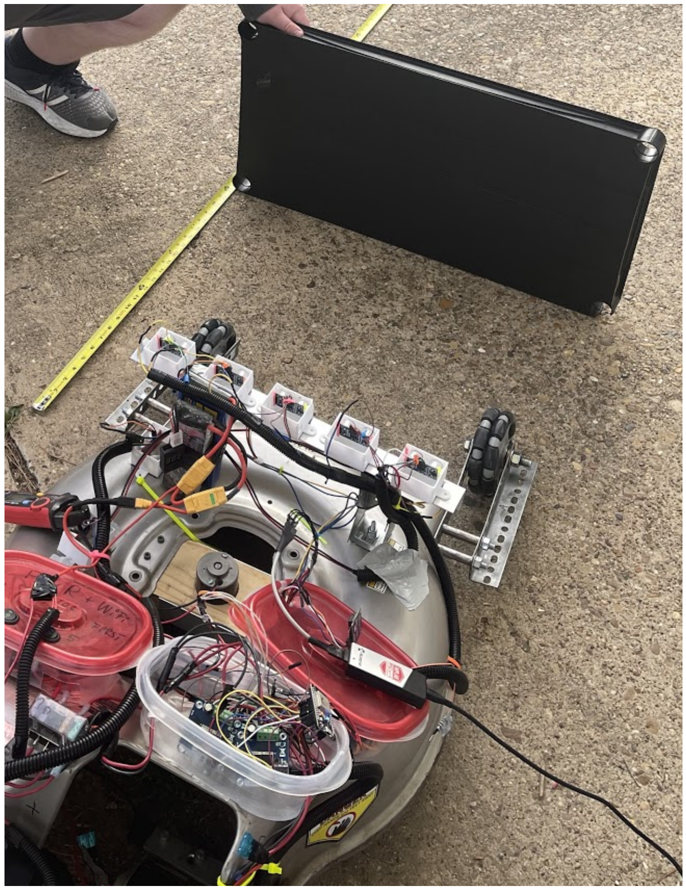


Figure 1: Obstacle Placed 2ft (~60cm) in Front of the Autonomous Lawnmower

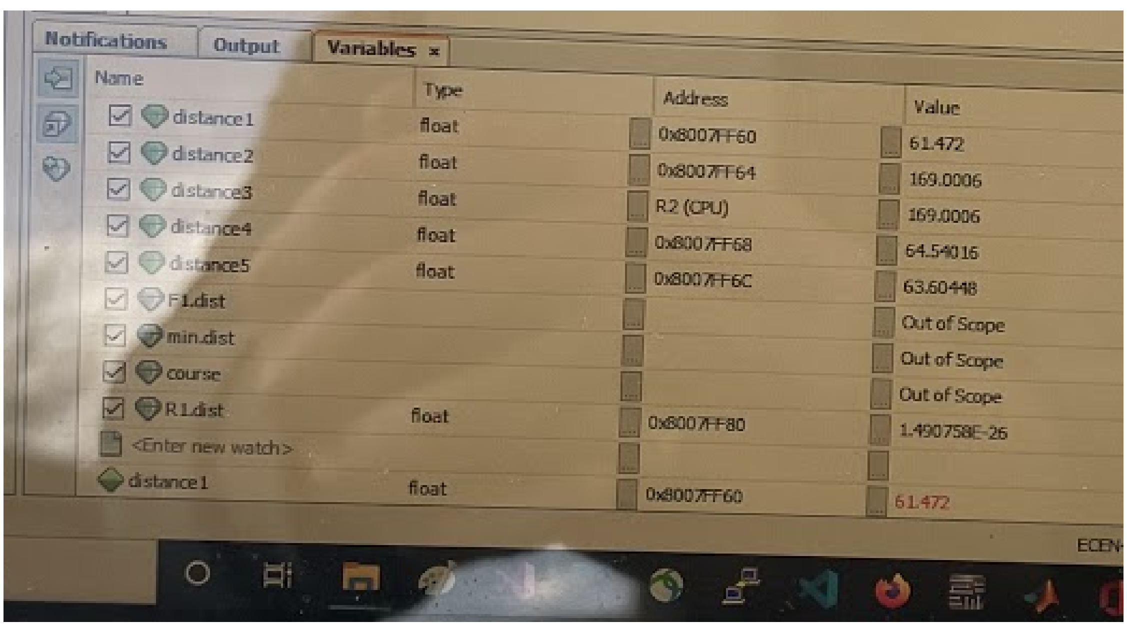


Figure 2: Sensor Readings for an Obstacle Placed 2ft (~60cm) in Front of the Autonomous Lawnmower

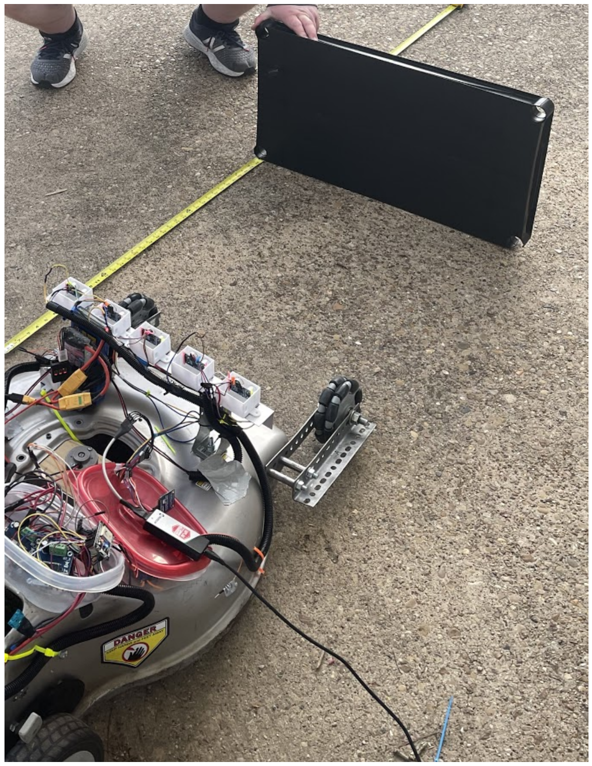


Figure 3: Obstacle Placed 3ft (~90cm) in Front of the Autonomous Lawnmower

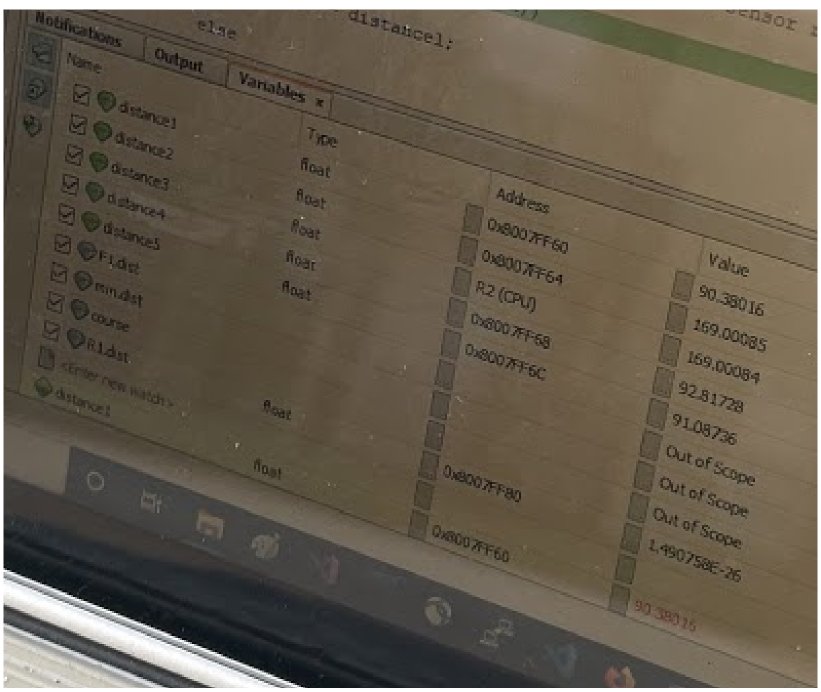


Figure 4: Sensor Readings for an Obstacle Placed 3ft (~90cm) in Front of the Autonomous Lawnmower

2.2 Validation for FSR Section 3.2.2

2.2.1 Validation for FSR Section 3.2.2.1

This requirement states that the autonomous lawnmower shall not exceed a maximum weight of 70lbs.

This requirement was validated by having one of our team members (Josh Samaniego) stand on a scale while holding the autonomous lawnmower unit in order to determine its weight. When measured the weight of the team member and the autonomous lawnmower was 225lbs, with some subtraction we get the following result:

Figure 5: Total Weight of Team Member and Autonomous Lawnmower

Total Measured Weight - Team Member Weight = Autonomous Lawnmower Weight
225lbs - 190lbs = **35lbs**.

Based on this measurement we concluded that the autonomous lawnmower weighed 35lbs, well below the 70lb maximum.

2.2.2 Validation for FSR section 3.2.2.2

This requirement states that the autonomous lawnmower shall be no larger that 30 inches in height, 25 inches in weight, and 40 inches in length

This requirement was validated by measuring the assembled autonomous lawnmower with a tape measure. The measured distances were **15 inches in height, 23 inches in width, and 40 inches in length (15h x 23w x 40l)**.

2.2.3 Validation for FSR section 3.2.2.3

This requirement states that the autonomous lawnmower's components shall be mounted in a fashion to resist vibration that is incidental to lawnmowing, with service once every 6 months when used weekly (one weekly use for one hour for 26 weeks).

This requirement was validated by the fact that our requirement is based upon strenuous testing over a two week period, in which the mower was fully assembled and tested for approximately 8 hours. Given the condition at which the autonomous lawnmower was at after the strenuous testing, we are confident that we can extrapolate to a 26 hour sample and that there would be no noticeable difference.

2.3 Validation for FSR Section 3.2.3

2.3.1 Validation for FSR Section 3.2.3.1

This requirement states that the autonomous lawnmower system shall not be damaged by any possible inputs or signals produced by the system. No user input should result in the autonomous lawnmower system engaging in unsafe or damaging operations. The validation of this requirement is dependent upon the validation of requirements 3.2.3.1.1, 3.2.3.1.2, and 3.2.3.1.3.

2.3.1.1 Validation for FSR Section 3.2.3.1.1

This requirement states that the power consumption of the autonomous lawnmower system shall not exceed 200W.

This requirement was modified, and thus conditionally validated, upon the ordering of new motors and new motor driver boards to be a 250W maximum power consumption. We increased this specification due to the drastic increase in the size of the motors we purchased. The initial motor specifications were for three 30W motors, and at the end we ended up using a 30W motor for the blade and two 230W drive motors. Calculations were performed based upon the component current and voltage while the system was running. As shown below in table 1, the total power consumption was just under the allotted 250W maximum at 243.749W.

<table>
<tr><th>Component</th><th>Voltage</th><th>Current</th><th>Power Consumed</th></tr>
<tr><td>PIC32 MCU</td><td>3.3V</td><td>0.13A</td><td>0.429W</td></tr>
<tr><td>ESP32 MCU</td><td rowspan="3">5V</td><td>0.1A</td><td>0.5W</td></tr>
<tr><td>Ultrasonic Sensors (7)</td><td rowspan="2">0.06A</td><td rowspan="2">0.3W</td></tr>
<tr><td>Shaft Encoders (2)</td></tr>
<tr><td>Blade Motor Relay</td><td rowspan="2">12V</td><td rowspan="2">0.41A</td><td rowspan="2">4.92W</td></tr>
<tr><td>Blade Motor</td></tr>
<tr><td>Motor Driver Boards (2)</td><td rowspan="2">24V</td><td rowspan="2">9.9A</td><td rowspan="2">237.6W</td></tr>
<tr><td>Drive Motors (2)</td></tr>
<tr><td colspan="3">Total Power Consumed</td><td>243.749W</td></tr>
</table>

Table 1: Autonomous Lawnmower Power Specifications

2.3.1.2 Validation for FSR Section 3.2.3.1.2

This requirement states that the input voltage level for the autonomous lawnmower system would be less than 14.4 VDC.

This requirement was validated by measuring the voltage in the two Lithium Polymer batteries on the lawnmower. The battery output voltages are shown below in figures 6 and 7.

Figure 6: Voltage Output of the 5Ah LiPo Battery

Figure 7: Voltage Output of the 8Ah LiPo Battery

2.3.1.3 Validation for FSR Section 3.2.3.1.3

This requirement states that the autonomous lawnmower system shall receive external commands from the user interface via a WiFi connection.

This requirement was validated by testing the start and stop buttons on the android application. The start and stop buttons are mutually exclusive meaning you cannot start the mower while it is already moving, or stop the mower while it is already stopped. Figure 8 below shows the view of the buttons on an android emulator. We had also attempted to implement a go home function, in which the lawnmower would return to its starting position, however due to limited time late in the semester we were unable to implement it in the navigation code.

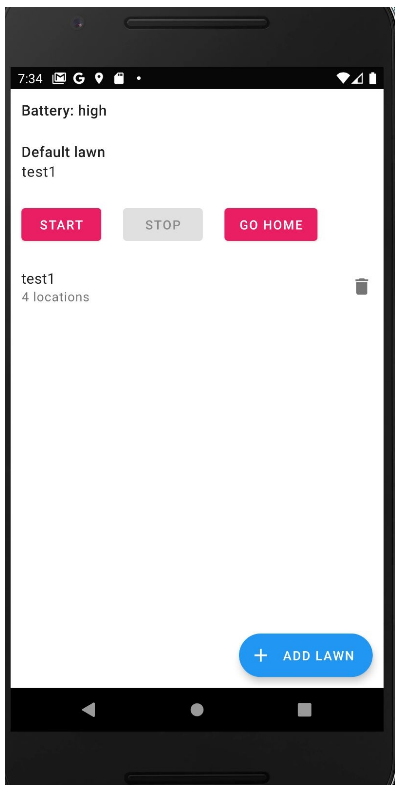


Figure 8: Android application screen showing start and stop buttons

2.3.2 Validation for FSR Section 3.2.3.2

This requirement states that the autonomous lawnmower system shall have two forms of output, data outputs and diagnostic outputs. This requirement was validated based upon the validation of requirements 3.2.3.2.1 and 3.2.3.2.2.

2.3.2.1 Validation for FSR Section 3.2.3.2.1

This requirement states that the autonomous lawnmower shall inform the user of problems and fault conditions through the user interface app via WiFi.

This requirement was not validated as we were unable to connect a circuit that would read the battery level to report to the user. The android application does contain code that would have displayed the battery level if it were to be given a voltage reading from the mower, which can be seen above in figure 8.

2.3.2.2 Validation for FSR Section 3.2.3.2.2

This requirement states that the microcontroller shall include a hardware debugging port that may be interfaced to a computer for diagnostic purposes.

This requirement was validated in the fact that both our microcontroller's contained built in hardware debugging ports. In figure 9 below you can see the hardware debugging port on the PIC32 microcontroller and in figure 10 you can see the hardware debugging port on the ESP32.

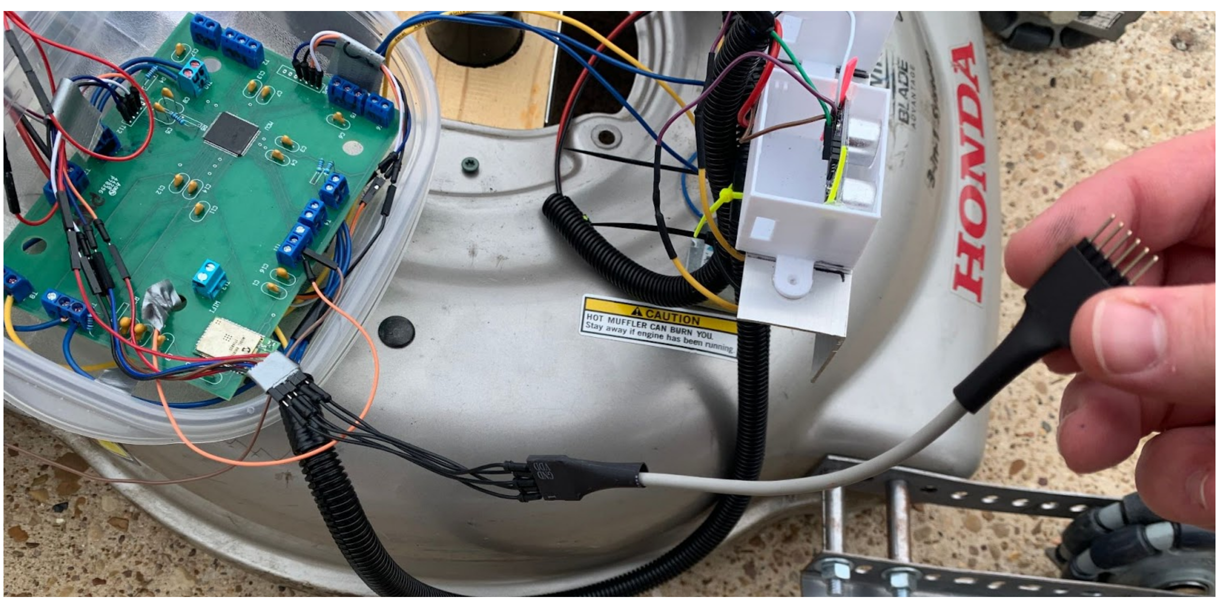


Figure 9: Hardware debugging port on the PIC32 microcontroller

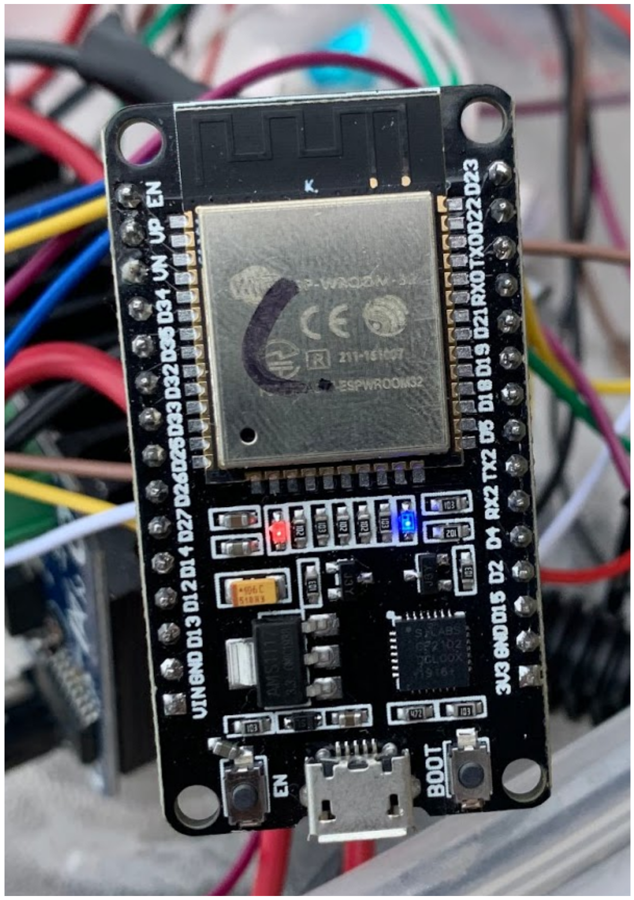


Figure 10: Hardware debugging port on the ESP32 microcontroller (on the bottom)

2.3.3 Validation for FSR Section 3.2.3.3

This requirement states that connectors (electrical or other) shall be resistant to vibration incidental to lawnmowing, with service no more than once per 6 months when used weely.

This requirement was validated by the fact that our requirement is based upon strenuous testing over a two week period, in which the mower was fully assembled and tested for approximately 8 hours. Given the condition at which the autonomous lawnmower was at after the strenuous testing, we are confident that we can extrapolate to a 26 hour sample and that there would be no noticeable difference.

2.3.4 Validation for FSR Section 3.2.3.4

This requirement states that the wiring for signal and power interfaces shall be routed clear of any moving internal parts, clear of all possible outside interference, and protected as appropriate.

This requirement was validated via a visual inspection of the system. The top view and rear view of the system can be seen below in figures 11 and 12 respectively. These images show that the wires are all inside of protective casing, except for where they connect to their respective signal pins or component power supplies.

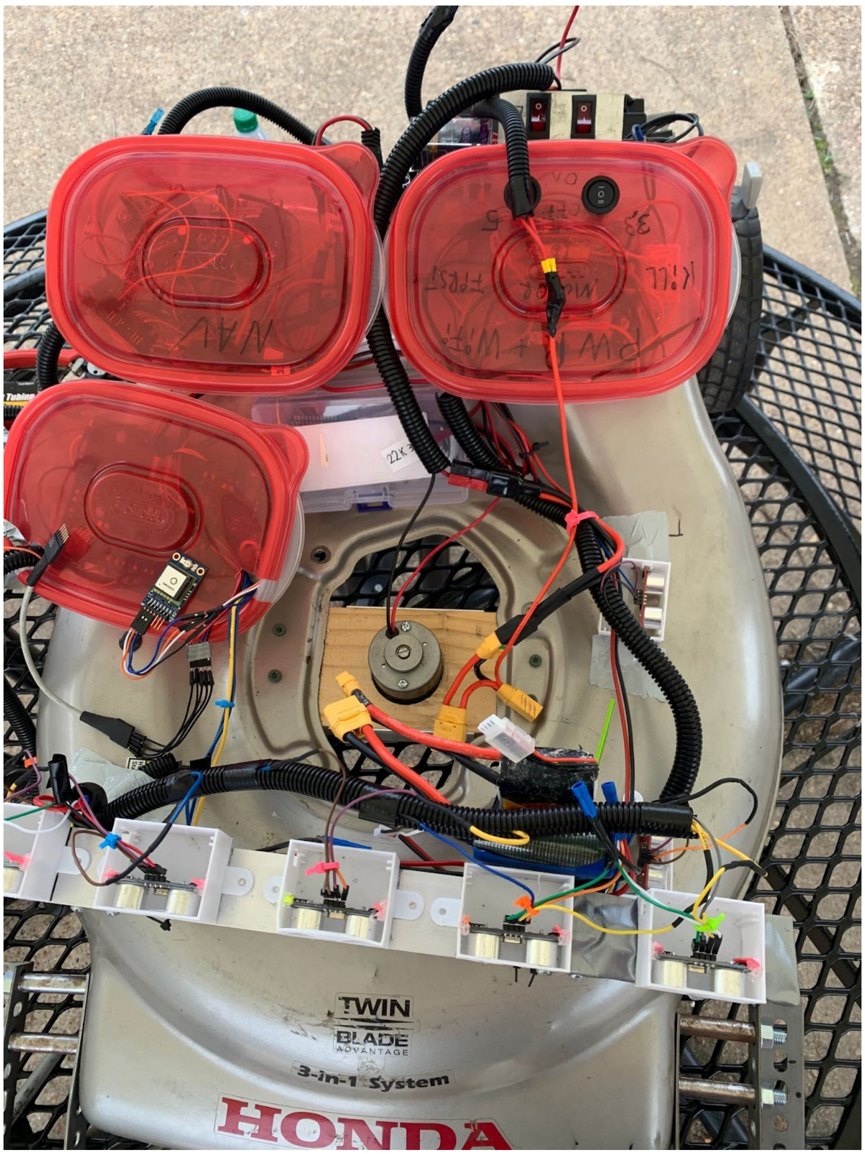


Figure 11: Top View of Assembled Autonomous Lawnmower

Figure 12: Rear View of Assembled Autonomous Lawnmower

2.4 Validation for FSR Section 3.2.4

2.3.1 Validation for FSR Section 3.2.4.1

This requirement states that the autonomous lawnmower system shall operate in temperature ranging from 40°F to 120°F.

This requirement was conditionally validated based upon the temperature data we were able to test at, as it did not reach as high as 120°F or as low as 40°F in march or april in southeast central Texas. We were able to record temperatures varying from 54°F to 66°F and from 72°F to 82°F Our system had no issues with any temperature within the ranges tested.

2.3.2 Validation for FSR Section 3.2.4.2

This requirement states that the autonomous lawnmower system shall be immune to dust and debris. The lawnmower systems shall either be protected from, or insensitive to debris 1mm or larger, as well as dust.

This requirement was conditionally validated based upon the sealed containers the components were placed in to protect them accordingly. Debris under 1mm has no effect on the motors or sensors as both are used to being outdoors in environments similar to the ones we tested in. The components inside of the red tubs as show in figures 11 and 12 on pages 16 and 17 are as follows: in the top right container there is the power bus bar, 12V to 3.3V convertor, and 12V to 5V convertor; in the top left container there is the two motor driver boards and the ESP32 microcontroller; and in the bottom left container is the obstacle detection PCB which includes the PIC32 microcontroller as well as the GPS unit. Through our testing we had no issues with dust or debris.

2.3.3 Validation for FSR Section 3.2.4.3

This requirement states that the autonomous lawnmower system shall not operate in the rain.

This requirement was validated upon the fact that the system was not assembled with waterproof components or wiring, and the components were not placed in water tight containers. The autonomous lawnmower is neither waterproof nor water resistant.

2.3.4 Validation for FSR Section 3.2.4.4

This requirement states that the autonomous lawnmower system shall be able to operate temporarily in conditions up to 100% humidity, but shall operate at lower humidity or will require higher maintenance for long term storage and performance.

This requirement was conditionally validated based upon the humidity data we were able to test at, as it did not vary all the way from 0% to 100% on the days at times that we tested the system. We were able to test at humidities ranging from 41% to 44% and from 56% to 71%. Our system had no issues for the humidity ranges it was tested in.

2.3.5 Validation for FSR Section 3.2.4.5

This requirement states that the autonomous lawnmower system shall be able to operate on moist, but not wet solid, level terrain.

This requirement was not validated, since we were unable to run the autonomous lawnmower system on grass due to an uneven weight distribution. The autonomous lawnmower's rear wheels would slip when trying to turn on grass as they would lift in the air. As a result we cannot say that the autonomous lawnmower can operate on any type of soil.

2.3.6 Validation for FSR Section 3.2.4.6

This requirement states that the autonomous lawnmower system shall be able to communicate with the network at the operating site from at least 100ft away and through at least 1 wall of wood and drywall construction.

This requirement was validated by testing the start and stop functionalities of the android application from within the apartment of one of our team members (Max Lesser) apartments, which was approximately 100ft from the autonomous lawnmower system. The start and stop functionalities both functioned with no issue

2.3.7 Validation for FSR Section 3.2.4.7

This requirement states that the autonomous lawnmower system shall be able to operate with light to medium foliage overhead.

This requirement was made in order to test that the GPS would still be able to maintain readings while operating under cover, however our system operates without the use of a GPS, so it does not matter what amount of cover is overhead, thus this requirement is validated

2.3.8 Validation for FSR Section 3.2.4.8

This requirement states that the autonomous lawnmower system shall operate without failure, under vibration incidental to lawn mowing for at least 6 months, when operated weekly for 1 hours

This requirement was validated by the fact that our requirement is based upon strenuous testing over a two week period, in which the mower was fully assembled and tested for approximately 8 hours. Given the condition at which the autonomous lawnmower was at after the strenuous testing, we are confident that we can extrapolate to a 26 hour sample and that there would be no noticeable difference.

2.5 Validation for FSR Section 3.2.5

2.5.1 Validation for FSR Section 3.2.5.1

This requirement states that the autonomous lawnmower's user interface system shall notify the user if the blade is stuck on an obstacle and at the same time shut the blade down.

This requirement was not validated as the autonomous lawnmower system does not send information to the user via a WiFi connection and the android application. The blade does stop when the mower enters its obstacle detection protocol, but it has no such feature for actually striking an obstacle.

2.5.1 Validation for FSR Section 3.2.5.2

This requirement states that the autonomous lawnmower system shall power down, disabling the blade and alerting the user, if the system becomes stuck.

This requirement was not validated as the autonomous lawnmower system does not send information to the user via a WiFi connection and the android application. In cases where the autonomous lawnmower system becomes stuck, it simply continues to try to move upon its programmed navigational path.

2.5.1 Validation for FSR Section 3.2.5.3

This requirement states that in cases where the autonomous lawnmower system loses a WiFi connection the system shall continue on its programmed path and return to its rest position.

This requirement was validated by turning off the mobile hotspot on one of our team members phones (Jonathon Poulose) in order to monitor the systems response to the loss of WiFi connectivity. The system simply continued on its navigational path upon losing its WiFi connection.

2.5.1 Validation for FSR Section 3.2.5.4

This requirement states that in cases where the autonomous lawnmower system loses a GPS connection it shall attempt to follow the planned navigational route to the best of its ability.

This requirement was validated based upon the fact that we do not use the GPS for navigation, meaning that turning off the GPS has no effect on the navigational path. We tested this by disconnecting the power to the GPS during a test run.

2.5.1 Validation for FSR Section 3.2.5.5

This requirement states that in cases of system failure, the autonomous lawnmower shall alert the user through the user interface, disable the blade and return to the start position if possible

This requirement was validated by disconnecting the sensor array and seeing how the system would respond. When the sensor array was disconnected, the system stopped moving and turned off the blade as a safety precaution.

2.5.1 Validation for FSR Section 3.2.5.6

This requirement states that in cases of critical system failure, or in cases when the microcontrollers lose all ability to control the mower or its subsystems, the autonomous lawnmower system shall power off its blade.

This requirement was validated by turning off the microcontrollers mid test run and monitoring the response. Upon losing power in the microcontrollers the blade motors immediately power off as it no longer is receiving a high signal from the ESP32 microcontroller.

3 Validation Plan Conclusion

In the end, we were able to validate all but four requirements in either a complete or conditional manner. While we would have liked to be able to look at our validation plan at the end and seen nothing but completely validated requirements, we are proud of what we have accomplished. It is apparent now that we were a bit ambitious in the creation of our requirements in our functional systems requirement document back in October. I believe had we had a greater understanding of our project then, we would have been able to generate more accurate requirements for our project description.

AUTONOMOUS LAWNMOWER

Max Lesser
Vincent McMasters
Jonathan Poulose
Josh Samaniego

SUBSYSTEM REPORTS

REVISION – 3
29 April 2021

Table of Contents

Autonomous Lawnmower
Vincent McMasters

POWER SUPPLY SUBSYSTEM REPORT

REVISION – 3
24 April 2021

Table of Contents

List of Tables

List of Figures

1 Subsystem Introduction

This subsystem consists of all the components that are used to power the Autonomous Lawnmower. This includes the PCB, in which there are two paths, one for signal and one for voltage. The signal path takes the input voltages from both the solar panel and the wall power plug and verifies if the solar panel voltage is between 6 and 15 volts using a window comparator. The output from this comparator is a signal that is used as the MOSFET gate, in order to effectively open or close the MOSFET as a switch. The voltage path is the input to the signal path, but are also to be input to the MOSFET source and is passed through in the according path dependent upon the decision made by the signal path. The voltage then flows through the corresponding MOSFET and diode, which is used to prevent backwards voltage flow, and to the PCB output. The PCB output is connected to the input of the solar charge controller, in order to ensure the battery is safely charged. The connection between the PCB and the solar charge controller is disconnectable in order to ensure that the lawnmower can disconnect from the system when it needs to operate freely. On the mower unit itself, is where the solar charge controller, battery, and connections to other systems will be. The charge controller is wired directly into the battery and the loads to the battery are also wired directly to the battery as some of our loads require very high currents, such as our motor driver which will require 7 Amps.

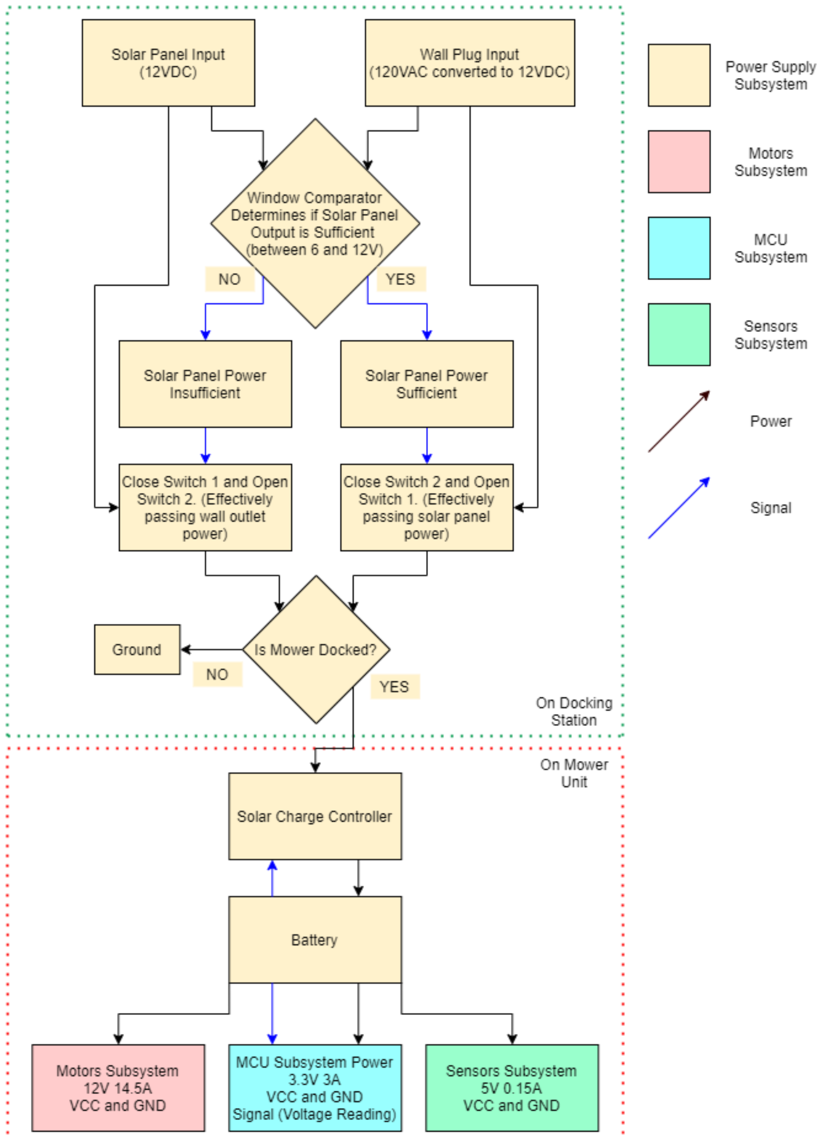


Figure 1: Flow of Signal and Power within Power Supply and to Other Subsystems

The above block diagram represents the major components of the power supply. The top box, represented by green dotted lines, is the portion of the power supply that will reside on the docking station. The bottom box, represented by red dotted lines, is the portion of the power supply that will be on the mower unit. Components on the PCB such as resistors are not included above. In order to simulate the loads I have acquired different wattage landscaping and car lights, which will be replaced by the other subsystems in our application moving forward.

2 Simulation

The first major step in the development of my power supply was the development of my power supply subsystem was simulating the circuit for the determination of which input to take.

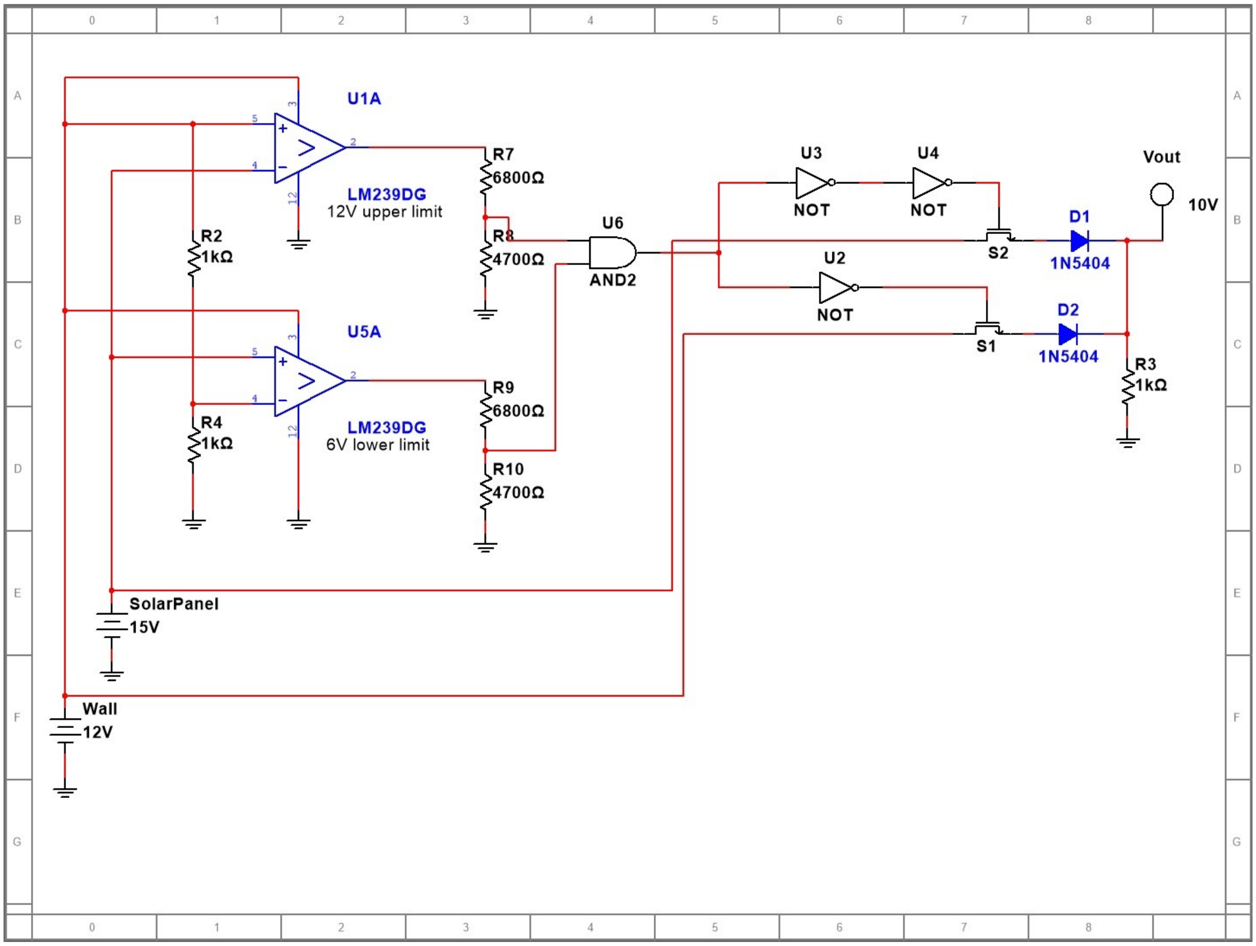


Figure 2: Printed Circuit Board Schematic

In theory, the window comparator should output a high signal for any input voltages in the range of 6V and 12V, exclusive. The comparator can be validated by running a DC sweep, in which the Solar Panel Voltage is varied from 0 to 15V, which is the standard range of a 12V solar panel. Figure 3 below confirms this by showing the solar power path has a high signal for any voltage ranging from 6 to 12V and a low signal for all other voltages. It correspondingly shows in figure 4 that the wall outlet signal is high for any voltage outside the 6 to 12V range and low signal for all other voltages

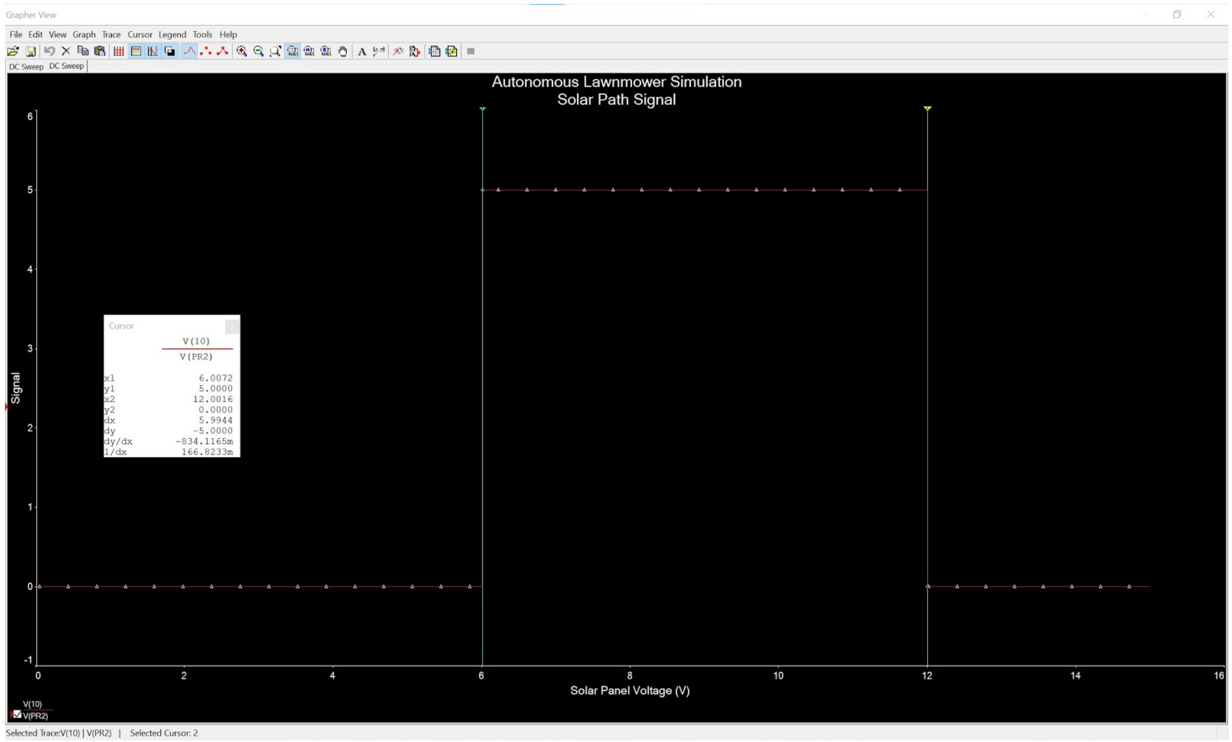


Figure 3: DC Sweep of the Solar Path Signal

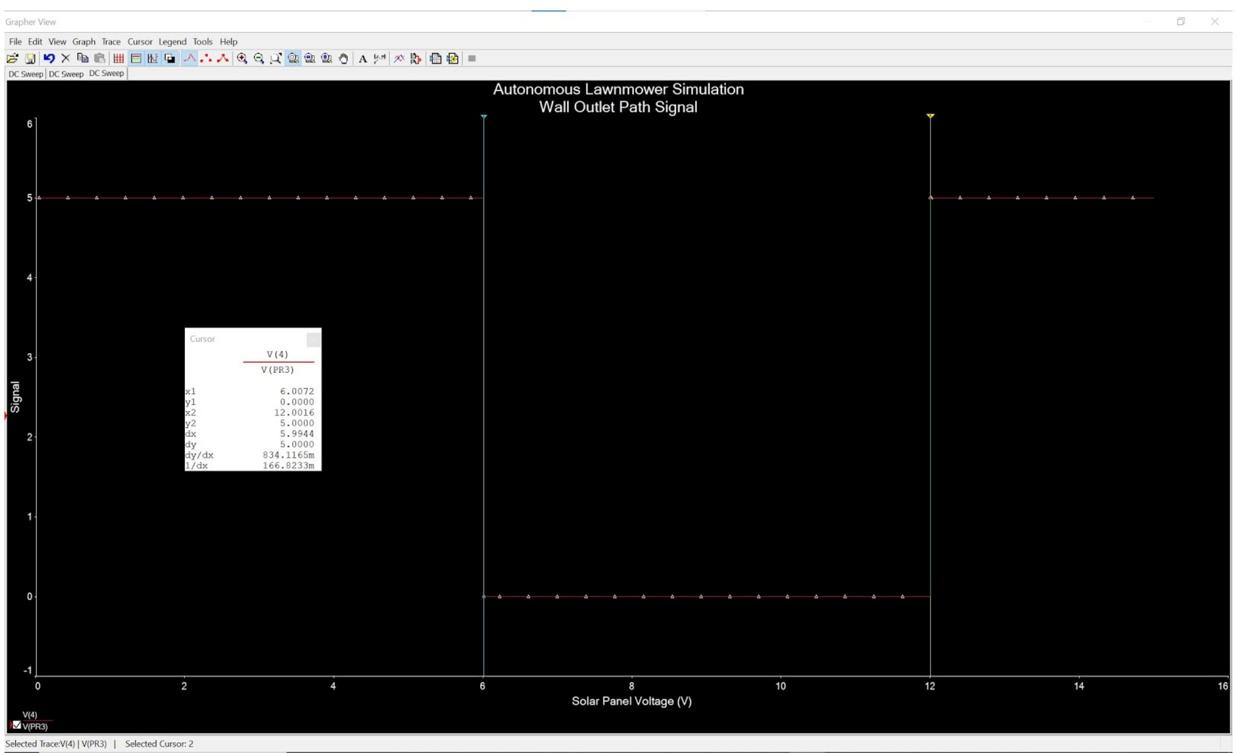


Figure 4: DC Sweep of the Wall Outlet Path Signal

These signals combined tell us which path will be supplying the power to charge the battery for a given voltage of the solar panel. The figure below shows the combination of these two signals, in which we can see the voltage output to the solar charge controller. The

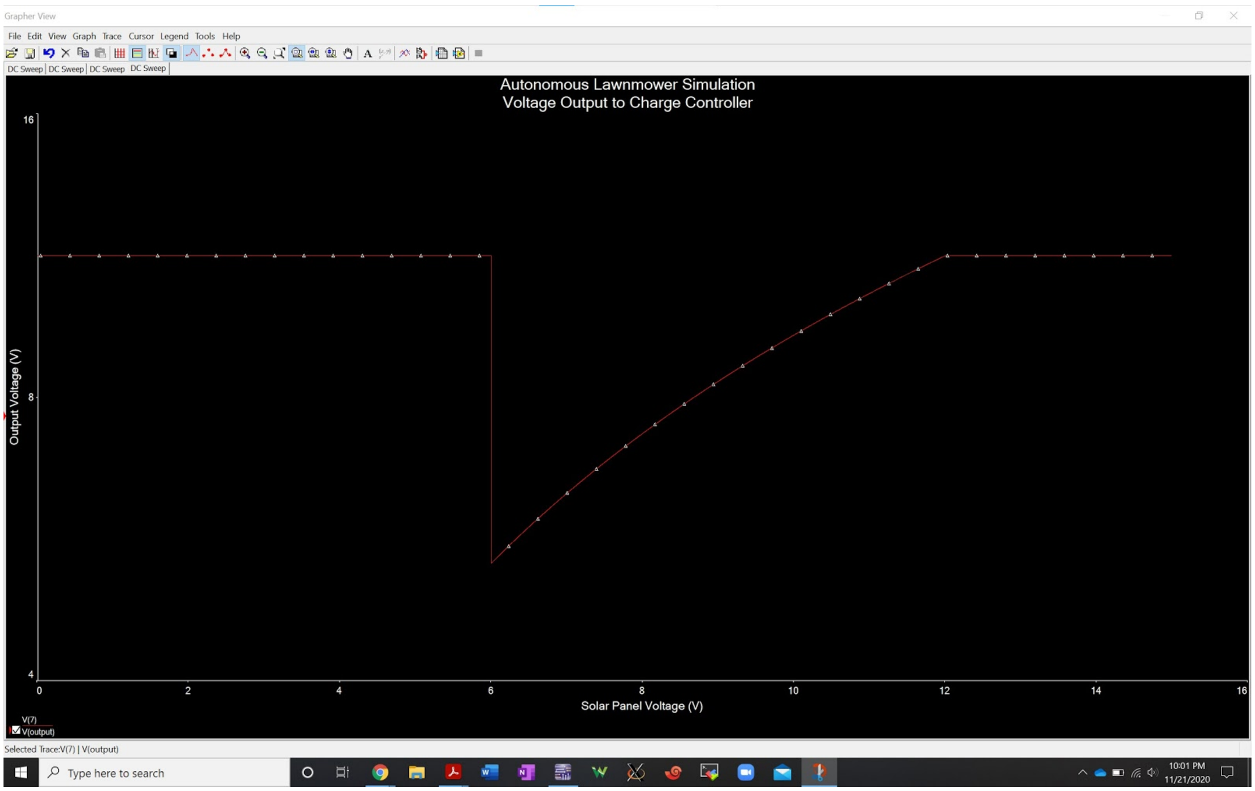


Figure 5: DC Sweep of the Voltage Output that will be sent to the Charge Controller

3 Printed Circuit Board (PCB)

The Power Supply PCB was designed using Altium Designer 20.2.5 as a 2-layer board, in order to reduce overall manufacturing costs. The PCB includes the two comparators that function as a window comparator, screw terminals for input and output ports, resistors, power MOSFETs, diodes, as well as AND and NOT gates used for signal flow. The following two figures show the top and bottom view of the PCB in black and white including the solder pads, traces, through holes, and silkscreen used for part labeling. The original PCB came from Advanced Circuits, but after initial evaluation, it was reordered from JLC PCB as they could produce it for far cheaper.

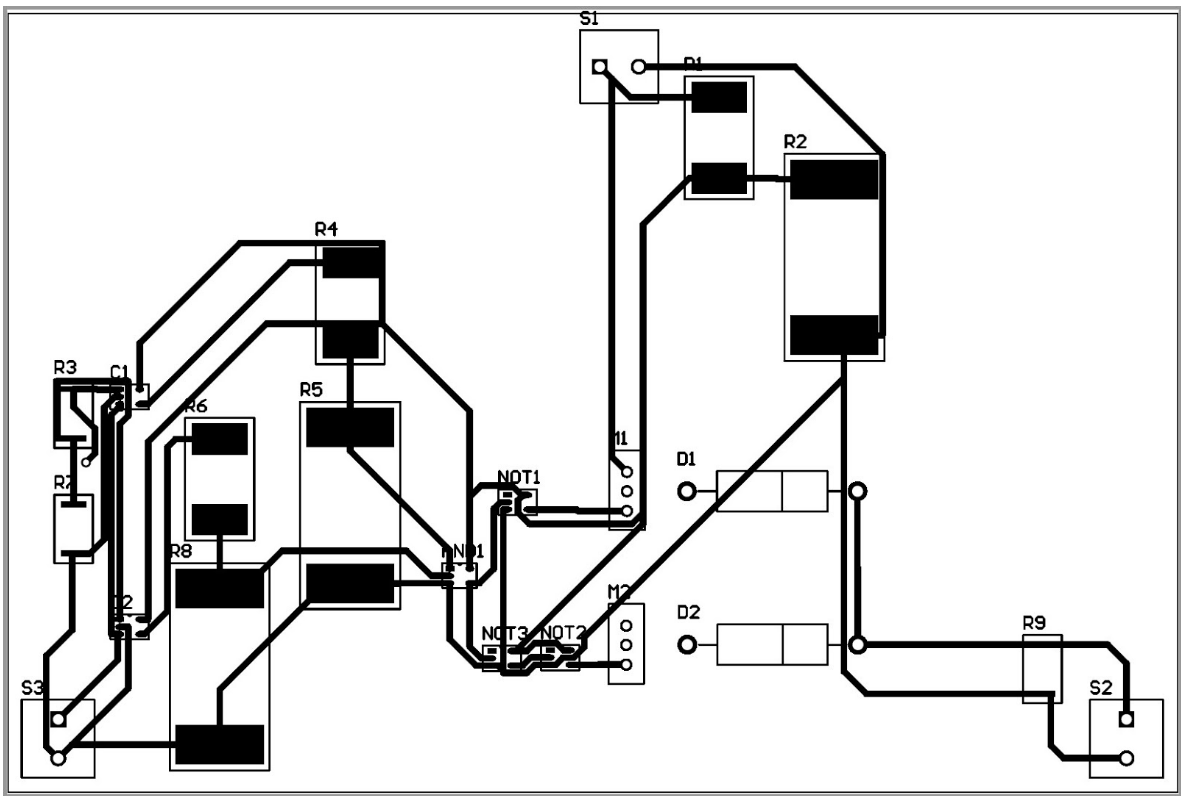


Figure 6: Altium Generated PCB Top View

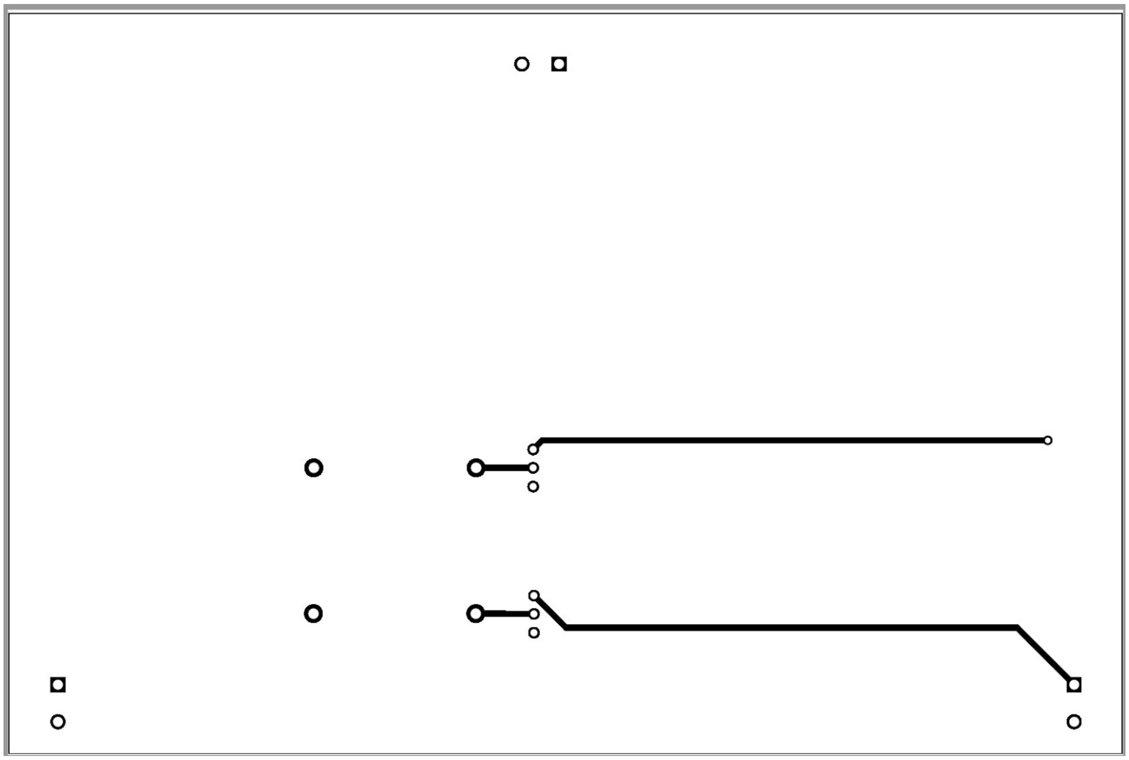


Figure 7: Altium Generated PCB Bottom View

3.1 PCB Evaluation

After receiving the initial PCB and evaluating it some issues became apparent. First, the hole sizes for both the through hole MOSFETs and diodes were too small as I had generated the hole size using the max hole diameter given in the datasheets, but they had been slightly larger than that, within the given percent error. The MOSFET holes also had been corrected to round holes when the pins are rectangular, and in doing so the hole took the diameter from the smaller dimension. Another thing that is worth mentioning but did not create any issues is the fact that some of the traces were right next to each other.

In order to fix these issues I reordered my PCB from a new vendor, JLC PCB, as they could produce the board in about the same time frame, shipping included, but for a much lower cost. They also had a minimum quantity of 5 boards per order, so I was able to have extras if need be as well as to practice soldering on. I enlarged the holes by taking the maximum hole size and adding 3 mil to the diameter for both the MOSFET and diode holes. I also changed my footprints for the MOSFETs to include round holes in which I made sure the diameter of the hole represented that larger dimension, in my case the pin width. Below is the top and bottom view of my final assembled PCB

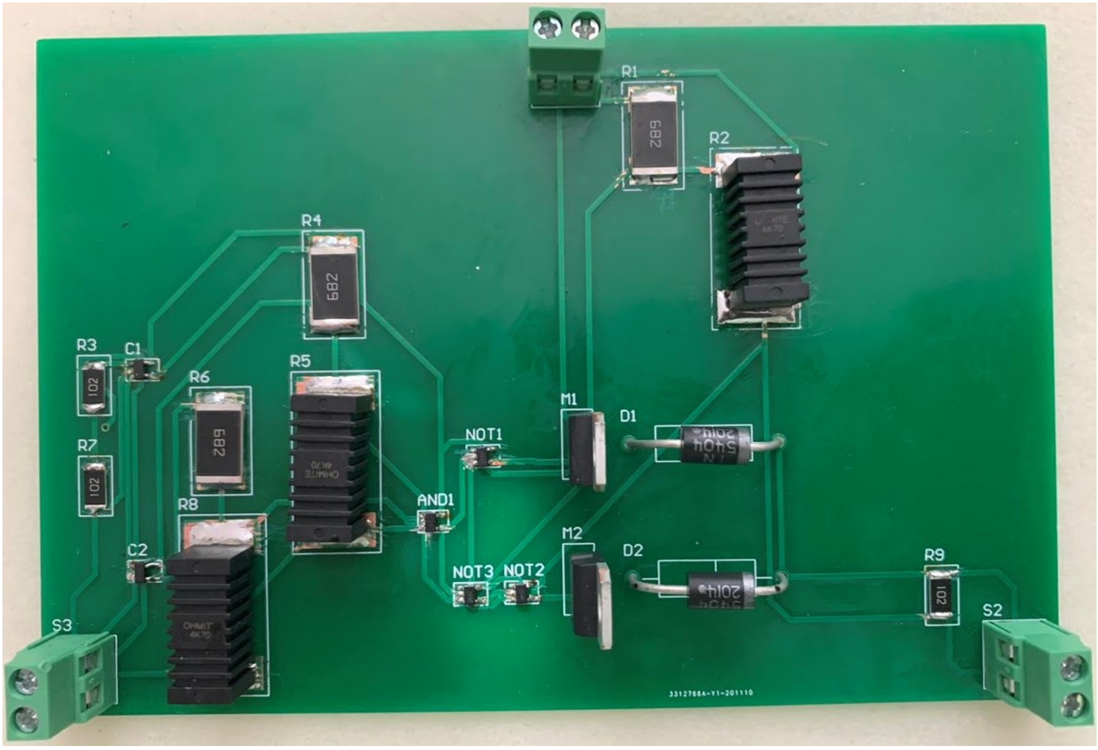


Figure 8: Received PCB Bottom View

Figure 9: Received PCB Bottom View

4 Load Testing

In order to validate my battery size and load values, I had to find a suitable load to test my 3.3V 1A expectation for the Microcontroller Subsystem, my 5V 0.2A expectation for the Sensors, and my 12V 2.42A and 12V 7A expectations for each motor and the motor driver. In order to simulate these loads I used a 12V 100W car headlight to test the highest current level, as this headlight would draw 6A when tested which gives it a power draw of approximately 50W. I used a 12V 10W landscaping bulb in order to test the 5V system, and in this system this bulb draws 0.6A when tested, giving it a power draw is 3W. In order to test the lower voltage, the 3.3V at 1A I used another headlight bulb, this one rated at 12V 5W, it was outputting a power draw of 3.3A. This final bulb tested at 0.21A. The result of using a 12V bulb in both the 3.3V and 5V application is that the bulb does not reach its full luminosity. This can be seen as the lights are very dim, as shown in figures 9 and 10 below.

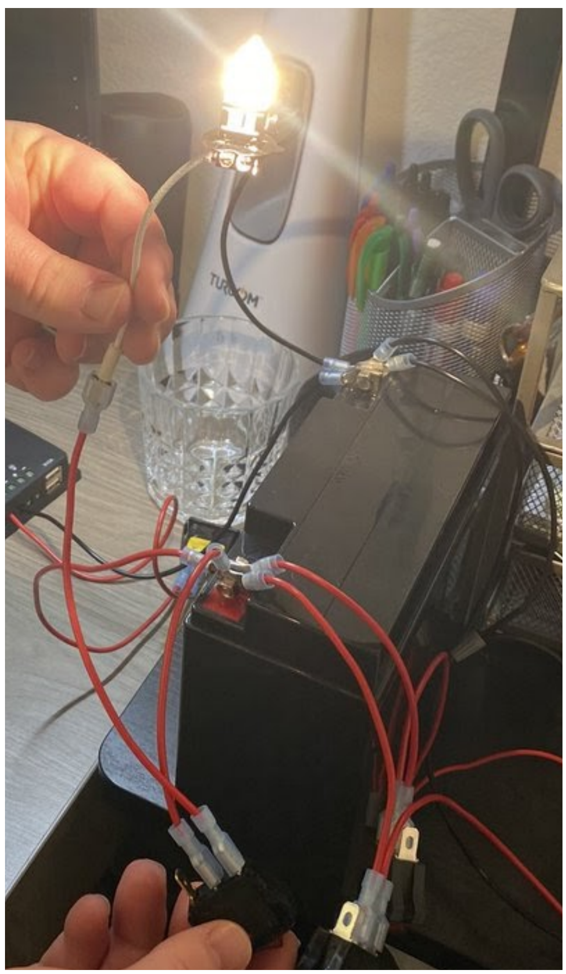


Figure 10: 12V 100W Light Bulb

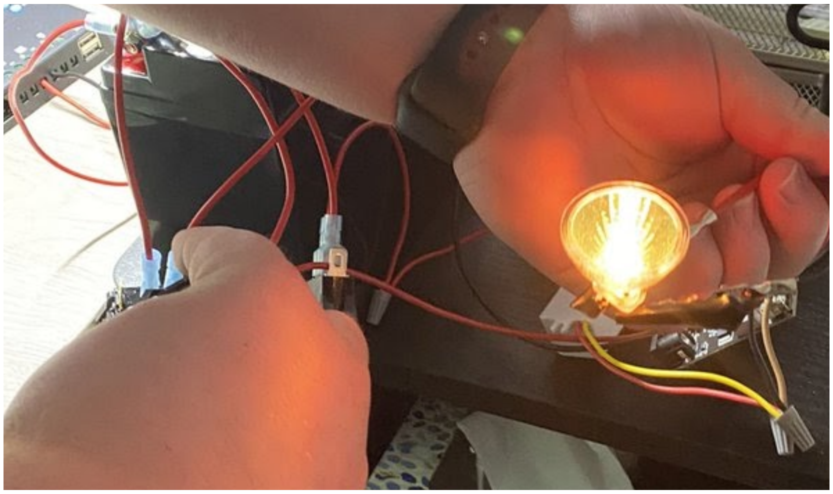


Figure 11: 12V 10W Light Bulb in 5V Circuit

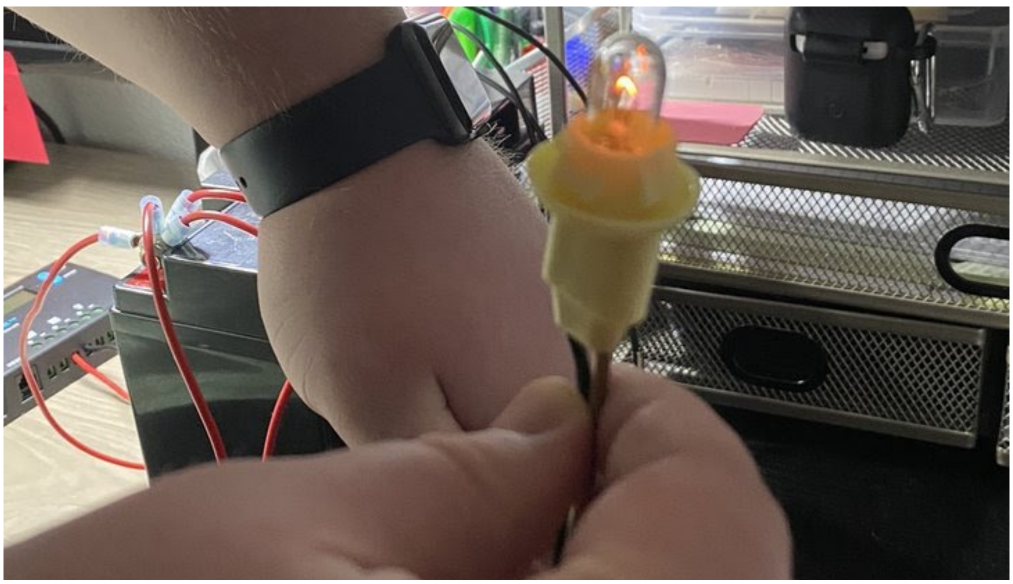


Figure 12: 12V 5W Light Bulb in 3.3V Circuit

5 Final Subsystem at the end of 403

Overall my subsystem consisted of quite a few parts that were obtained both from outside vendors, as well as from the lab room. In this section I will provide the size and weight specifications as well as a look at my assembled subsystem

5.1 Subsystem Weight at the end of 403

Component	Weight
Solar Panel	4.38 lbs
Solar Charge Controller	
Wall Plug	0.7 lbs
Battery	11.4 lbs
12V-5V Convertor	4.8 oz
12V-3.3V Convertor	30 g
12V 100W Light Bulb	0.05 lbs
12V 10W Light Bulb	0.03 lbs
12V 5W Light Bulb	0.02 lbs
Total:	16.946 lbs

Table 1: Autonomous Lawnmower Weight Specifications

5.2 Subsystem Dimensions at the end of 403

Component	Diameter	Length	Width	Height
Solar Panel	N/A	17 in	13.8 in	1.4 in
Solar Charge Controller	N/A	4.25 in	2.125 in	0.8 in
PCB (assembled)	N/A	4 in	6 in	0.7 in
Wall Plug	N/A	2.76 in	2.09 in	2.76 in
Battery	N/A	7.09 in	3.03 in	6.57 in
12V-5V Convertor	N/A	4.8 in	2.1 in	1.4 in
12V-3.3V Convertor	N/A	26 mm	36 mm	21 mm
12V 100W Light Bulb	0.45 in	0.71 in	N/A	N/A
12V 10W Light Bulb	1.375 in	1.625 in	N/A	N/A
12V 5W Light Bulb	N/A	3 in	1 in	4 in

Table 2: Autonomous Lawnmower Dimension Specifications

5.3 Subsystem Image at the end of 403

Below is an image that shows all of the components of my subsystem

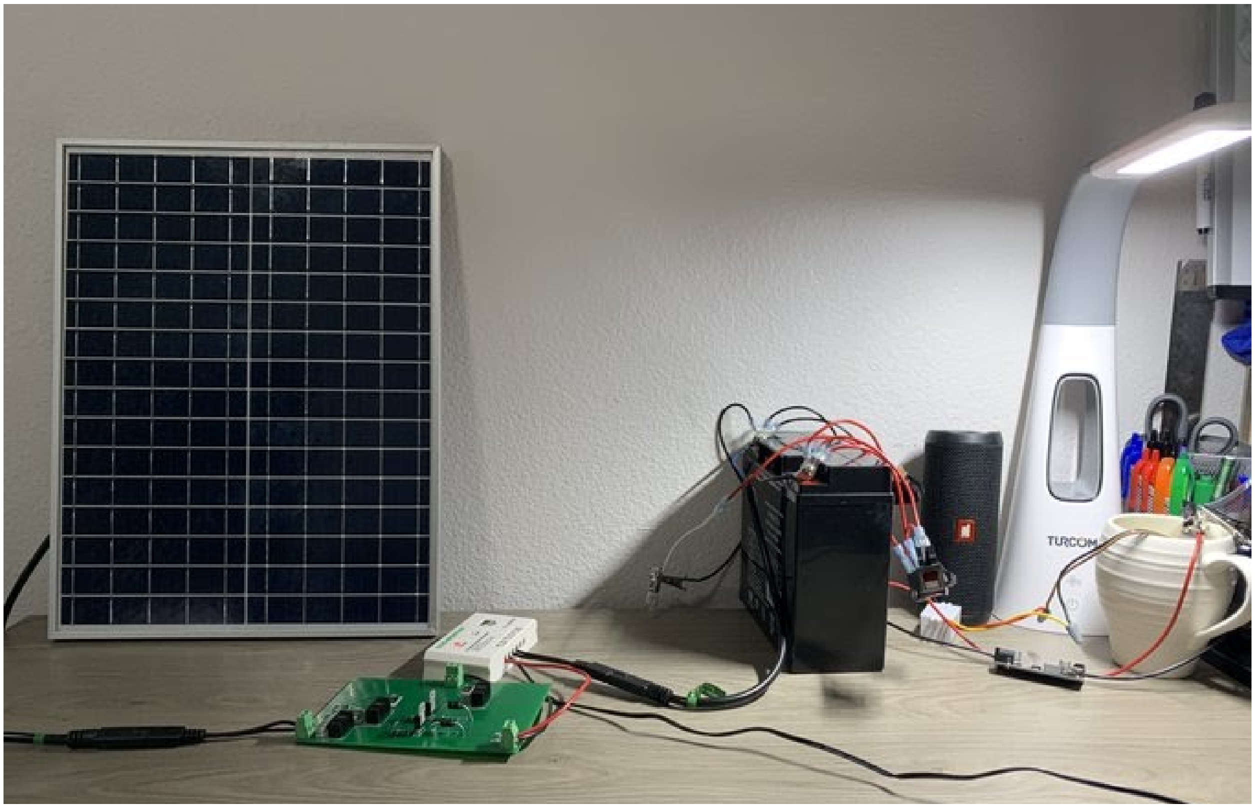


Figure 13: Power Supply Subsystem Overview Image

6 Component Mounting

The previous section outlined where the power supply subsystem stood at the end of 403. In this section, I will discuss the progress made throughout 404.

6.1 Internal Mounting

The first task of 404 in regards to the power supply was to find a solution on how to protect the electrical components from prolonged exposure to elements such as rain, dust, and sunlight. In order to do this I first acquired a plastic box within which the components were mounted. The PCB was mounted onto the inside of the plastic box, as shown in figure 12, using #8-32 1-¼ inch bolts and #8 nuts, a ¼ inch spacer was used in order to provide separation for the backs of the throughhole components. The solar charge controller was also mounted onto the inside of the plastic box, as shown in figure 13, using ½ inch #6-32 bolts and #6 nuts.

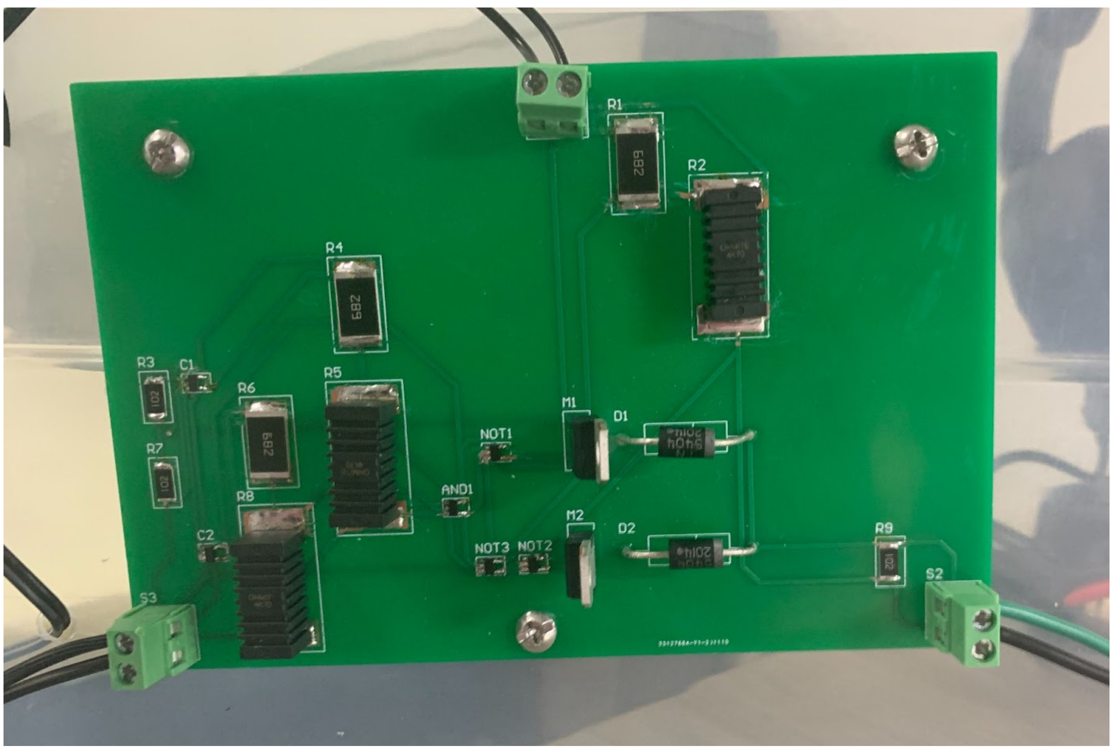


Figure 14: PCB Mounting Image

Figure 15: Solar Charge Controller Mounting Image

6.2 Wiring

In order to be able to power the electrical components mounted within the protective plastic box, wires had to be run through the box. These holes varied in size, with ¼ inch holes for the input of the wall plug and the output to the battery on the mower unit and a ½ inch by 1-¼ inch hole for the input of the solar panel.

6.3 Final Assembled Component Box

The box containing the electrical components mounted as explained in section 3.6.1 and wired as explained in section 3.6.2 can be seen in figures 14 and 15 below.

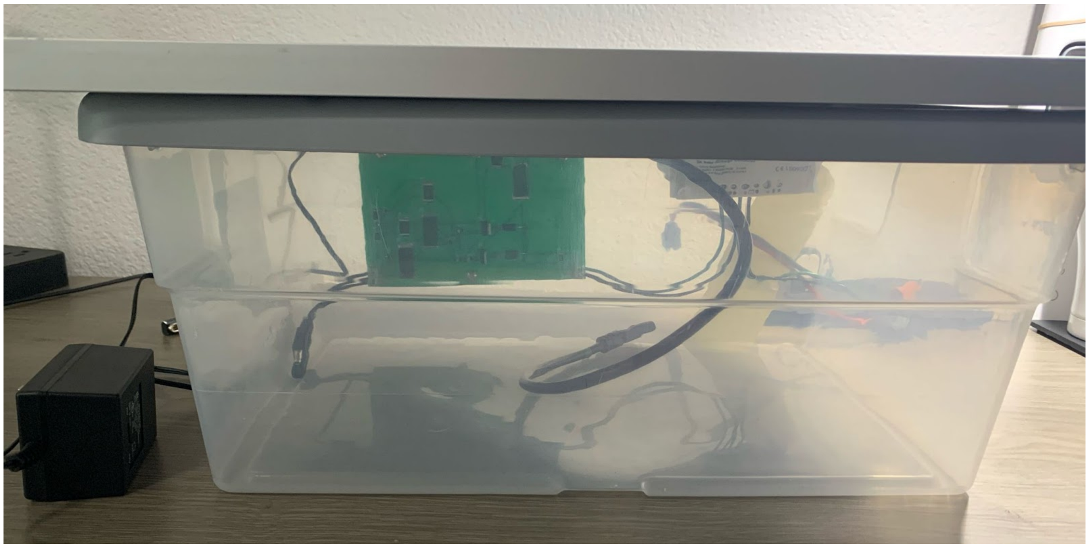


Figure 16: Power Supply Subsystem Overview Image from the side

Figure 17: Power Supply Subsystem Overview Image from the top

7 Unexpected Late Changes

Throughout the semester we encountered numerous issues with our motors subsystem. These changes, which included the installation of more powerful 250W motors and new more powerful 43A motor driver boards, are outlined in greater detail in the motors subsystem report. To compensate for the new motors and now motor driver boards, we needed a more reliable power source than we could get from a sealed lead acid battery. This resulted in the acquisition of two 11.1V Lithium Polymer (LiPo) batteries. These batteries operated at 5Ah and 8Ah, respectively. In order to maximize the power into the new motors, we connected the two batteries such that we would have one 12V output and one 24V output. The 12V output powered the power block which was connected to the PIC32 microcontroller, the ESP32 microcontroller, the GPS, the gyroscope and accelerometer, and the blade motor. The blade motor remained the original 30W motor specified during 403.The 24V output powered only the new 250W motors and the new 43A driver boards. Figure 16 below shows the voltage output of the two LiPo batteries when connected and figure 17 shows the two batteries connected to the system through the 12V and 24V outputs. Also shown in figure 17, in the top is the makeshift bin (heb tupperware), which contains the 12 to 3.3V and 12 to 5V converters, as well as a bus bar to distribute the 3.3V and 5V power levels to multiple devices.

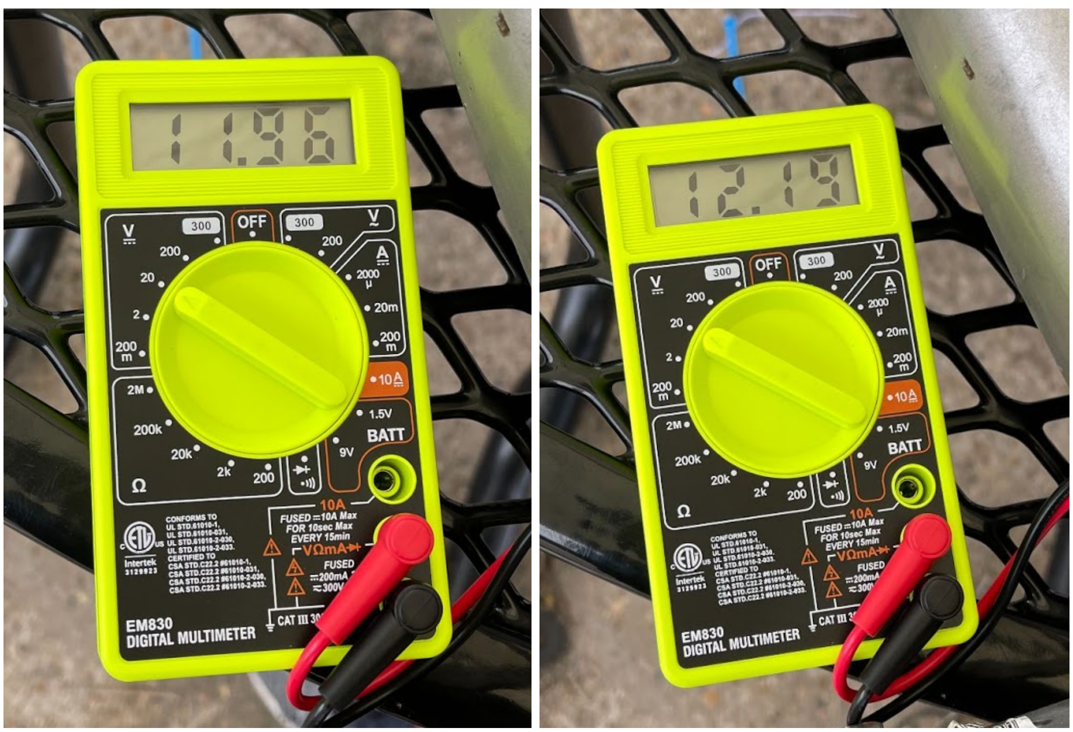


Figure 18: Voltage Output of New LiPo Batteries (5Ah - left, 8Ah - right)

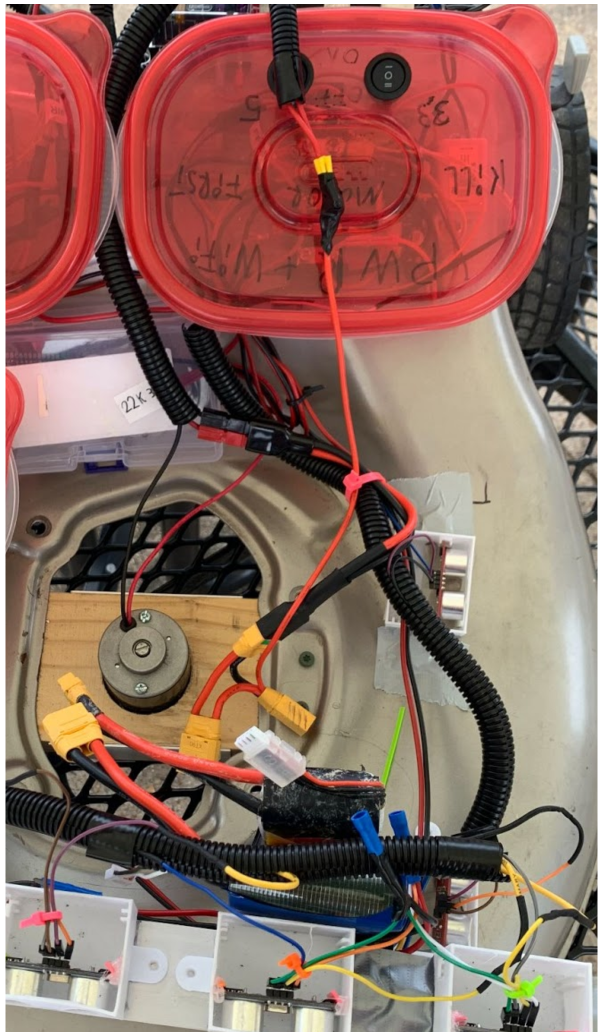


Figure 19: New LiPo Batteries Connected

8 Reflection

Back in August, when it was decided that we would be doing the autonomous lawnmower project, and then subsequently that I would be designing the power supply, I had very little idea about how to implement it. My first approach was to simply utilize a solar charge controller and panel that would have stayed on the mower at all times. After further discussion and research, it was determined that I would take two different power sources and utilizing a PCB determine which voltage source to use. In order to do this I would use a voltage comparator.

8.1 What I Learned

In August, I had never even heard of a PCB, much less Altium Designer. Through guidance from Professor Lusher as well as the resources of the world wide web, I was able to not only discover the endless possibilities presented by printed circuit boards, but I was also able to figure out how to use the software to implement them. Although this course does not use the entirety of the services Altium Designer has to offer, I was still intrigued to learn about things like the bill of materials, which are utilized in practical applications by numerous corporations. Another thing that is an afterthought to most when it comes to a physical project like the autonomous lawnmower is the action of connecting different components. Prior to this project I had never heard of a crimper, or attempted to interconnect electrical components using anything other than breadboard jumper wires. This course allowed me to get hands on experience in wiring and system integration that I would otherwise not have had.

8.2 What I Would Change If I Did It Again

Looking back now at the subsystem I designed, I believe that there are changes that could be made in order to improve the way I approached this problem. First, rather than trying to design the PCB to determine which voltage source to use like I did, I believe it would've been more beneficial to manufacture a single PCB that contained 12V to 3.3V and 12V to 5V convertors. By focusing on a single PCB by which I had two down convertors, I feel like I could've been much more efficient, as the process would have been more or less the same for each, just with different components. I also feel like this would have been a more practical application, as voltage convertors are used in everyday life, whether it be the plug you use to charge your iphone, or components within your iphone.

Autonomous Lawnmower

Max Lesser

MCU Subsystem Report

REVISION – 3
29 April 2021

Table of Contents

List of Tables

List of Figures

1 Subsystem Introduction

The MCU subsystem consists of the Hardware and most of the software to control the Autonomous lawnmower. Due to issues with the PCB manufactured during 403 for the PIC-32, the new MCU subsystem consists of the PIC-32 from 403, and a ESP-32 that was added during 404. The PIC-32, abbreviated to PIC here, performed obstacle detection and GPS reading and Parsing, and relayed this data to the ESP-32. The ESP-32 consists of 2 components, Navigation and Networking. The Navigation component, ESP-N for this report, is responsible for reading information from the PIC-32 and controlling motors for navigation and obstacle avoidance. The Wifi component of the ESP-32, referred to as ESP-W from here on, is responsible for connecting with the User interface and obtaining scheduling and navigation information. This Section of the report will be split into 4 parts. Multi MCU interface, PIC, ESP-N and ESP-W. Beginning with the MCU interface, we will below present how the 2 MCU are interfaced.

2 Multi MCU interface

This project required 2 MCUs as we encountered issues with the PIC hardware, which will be elaborate upon at the end of this section. Reproduced below is the System diagram, which shows the interface between the 2 MCUs, along with their connections. The PIC was connected to the ESP via UART, as well as 2 signals wires used to inform the ESP of obstacles. The final, as built implementation, had an interface line for front obstacle detection and the UART line, but not the side obstacle detection signal wire. While the UART line was connected, it was not ultimately used. Refer to the “As built” section for detailed explanation.

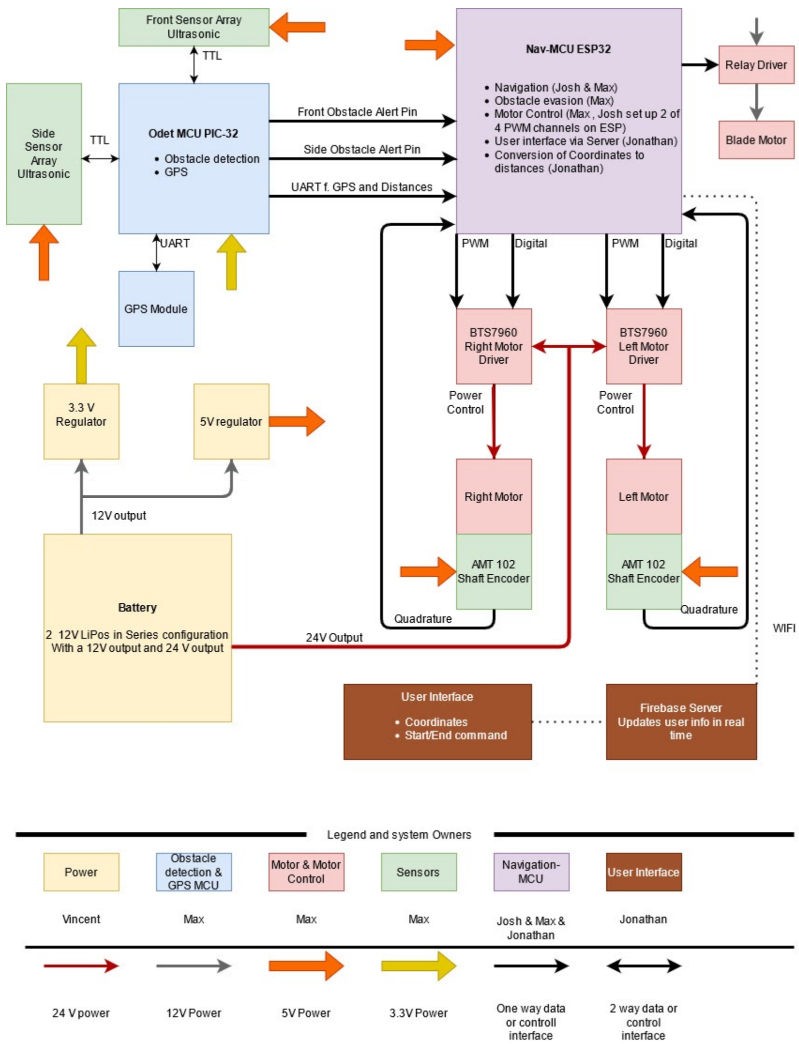


Figure 1: MCU Block diagram

2.1 Interface Descriptions

The 2 MCUs were interfaced with each other on the mower, as well as with other systems on and off the unit. This section will present a brief description of the interfaces used and their purpose

2.1.1 PIC to ESP Interface

The Pic is capable of relating information about obstacles as well as GPS to the ESP. This is achieved using UART for GPS and detailed obstacle information. As well as GPIO connections as an alert signal

2.1.1.1 UART Interface

The UART interface used between the MCU was configured as 9600Baud, 8 data bits, 1 stop bit and no parity. This interface would send text containing detailed information, as listed in the below table

Purpose	Information	Format
GPS	Latitude, Longitude, Course and Speed	[Ddd.ddd, dd.dddd, ccc.cc, s.ss] where the first 2 entries are latitude and longitude, then course and speed in knots
Front Obstacle array	Minimum distance to obstacle, side of Mower obstacle is on	[ddd, S] where ddd is distance in cm, and S corresponds to side of mower the object is on (from mowers perspective)
Side Obstacle array	Minimum distance to obstacle, angle obstacle makes with mower	[ddd, aa] where ddd is distance to obstacle in cm, and aa is angle the obstacle makes with the mower

Table 1: UART Data Transfer Information

This output was set in the PIC using UART print statements, where each data field was delimited by a comma, and entries ended with a carriage return/ Line Feed. Since all information was printed from the PIC, data formats or delimiters could easily be changed as needed.

Physically the interface consisted of the UTX and URX line, even though information only ever flowed from the PIC to the ESP.

2.1.1.2 GPIO Interfaces

In addition to the above UART interface, the PIC and ESP shared 2 wires for a GPIO interface. These wires were intended as an “alert interface” where the PIC would set a pin high if an obstacle was within a certain distance of the mower, and ESP could immediately respond by stopping, without having to wait for a UART message to be received. One wire each was assigned to the front obstacle array, and the side obstacle array. The Pins were read on the ESP via ISR, and by direct sampling of the appropriate pins. Obstacle alert thresholds can be set within the PIC to adjust for conditions.

2.1.2 PIC Interfaces to Other Systems

The PICs primary data interfaces were with the GPS module and the 2 Sensor arrays. The GPS sent information using a UART connection with the same configuration as the PIC-ESP UART connection. The Sensor arrays used GPIO pins.

2.1.2.1 UART interface

The GPS and PIC were connected using 2 wires, for UTX and URX. The Pic would send configuration information to the GPS, and the GPS would echo received NEMA sentences back to the PIC.

2.1.2.2 GPIO interfaces

Ultrasonic sensor operation is described in detail in the appropriate PIC section. The interface between the PIC and these sensors consisted of one trigger signal per array, for a total of 2. And an echo signal for each sensor, for 5 from the front array and 2 from the side

2.1.3 ESP Interfaces to Other Systems

In addition to the pic interface the ESP connected with sensors and motor controllers for the navigation logic, as well as WIFI to facilitate the user interface.

2.1.3.1 Sensor Input

The ESP-N interfaced with 2 Shaft encoder sensors. For each sensor the ESP received 2 signals, one indicating complete wheel rotation, the other indicating partial wheel rotation. Details are outlined in the appropriate ESP-N section. These 4 wires connected the GPIO pins on the ESP, which were configured as interrupts. Allowing us to track asynchronous changes

2.1.3.2 Drive Motor Control

Drive Motors were controlled using 4 wires per motor, of which 2 are PWM signals and the others are digital logic signals. This made for a total of 8 connections to the ESPs GPIO pins to control drive motors

2.1.3.3 Blade Motor Control

The Blade Motor relay was connected to the ESP via Output GPIO pin.

2.1.3.4 User Interface

The ESP-W portion of this MCU connected to the Network and User using the ESPs integrated WIFI capacity, and a local WIFI network, which was created using a mobile hotspot during testing and demo.

2.2 As Built System

Due to Time constraints at the end, some components of the MCU subsystem were not fully implemented, including:

- Side obstacle detection
- GPS based Navigation
- Mower statistics for battery, runtime or distance
- User specified navigation

The underlying systems for the above components function individually, however they were not implemented on the system as demoed, as time needed to include these was used to rebuild the Motor and Navigation subsystem.

Obstacle evasion was implemented using just the front array alert signal elaborate above, and navigation was handled using inertial guidance. Distances for the area to be mowed were hard coded in the code.

3 PIC MCU by Max Lesser

The PIC32 was originally intended as the only MCU, but due to hardware problems it was later used for only GPS and obstacle detection.

3.1 Hardware

3.1.1 Hardware Summary

The primary components of the MCU board are a Microchip PIC-32MZ, a Microchip RN1810 WIFI module and a SIM33EAU GPS module mounted on a Parallax 28504 breakout chip. The board additionally includes capacitors to smooth out power supply ripples, resistors, as well as 2 and 3 pin screw terminals and pin header connectors to allow connection to other subsystems. These components are situated on a PCB, custom designed in Altium and printed by Advanced circuits. During testing the RN1810 WIFI module sustained damage and became inoperable. Additionally and oversight in the PCB design resulted in insufficient PWM pins for motor control. This issue was later exasperated by changed Motor drivers. Due to the Small pitch of the PIC-32 package fixing the board was deemed not possible. As a result we switched to the 2MCU approach, as outlined above.

3.1.2 Hardware Selection

The Pic-32MZ-2048EFH-144 Microprocessor was specifically recommended by prof. Lusher. I followed his recommendation as Pic Microcontrollers have a host of different IO lines, and can operate in a wide range of environmental conditions. Additionally, Pics are small, lightweight and consume little power, making physical and power integration easier in our battery-operated system. Finally, PIC microcontrollers are inexpensive, which is a consideration as we are budget constrained.

The RN1810 WIFI module was selected based on research, as it interfaces easily with PIC processors since it is also a Microchip product. Additionally, it is small and inexpensive, and easy to integrate on the PCB.

The SIM33EAU GPS module on the Parallax breakout board was chosen in part for its breakout board, allowing us to mount it independently of the MCU without need for additional PCBs. Finally, it’s stated performance of 2.5M accuracy and ability to receive signals from several different satellite constellations made it an attractive option.

After using this hardware setup through 404, I still agree with the above, but have come to find that firmware development on the PIC platform is rather advanced and time intensive. Given the host of other issues i needed to address during this project I now believe a simpler, easier to use Embedded platform would have been the wiser choice. While this project could have been realized only with a PIC controller, the workload of PCB design, Firmware development and unrelated integration concerns and issues with other subsystems proved too much to handle. For future iterations I would recommend using either a development board to eliminate PCB design concerns, or possibly an easier to use platform, like the ESP-32 added later during the project.

3.1.3 PCB design

The MCU PCB was designed in Altium as a 2-layer board, to reduce manufacturing cost. The board includes the above-mentioned components, as well as incidental capacitors, resistors, and screw terminals needed for IO. An Additional UART port was included for demo and debug purposes, as well as an access point to the WIFI- MCU UART connection. A Glitch in the Altium software caused us to lose the PCB layout that was ultimately printed. For illustrative purposes we show the last saved layout version, which differs from the printed versions in 2 2-pin terminals for UART output, mounting holes, and slight adjustment of components for clearance.

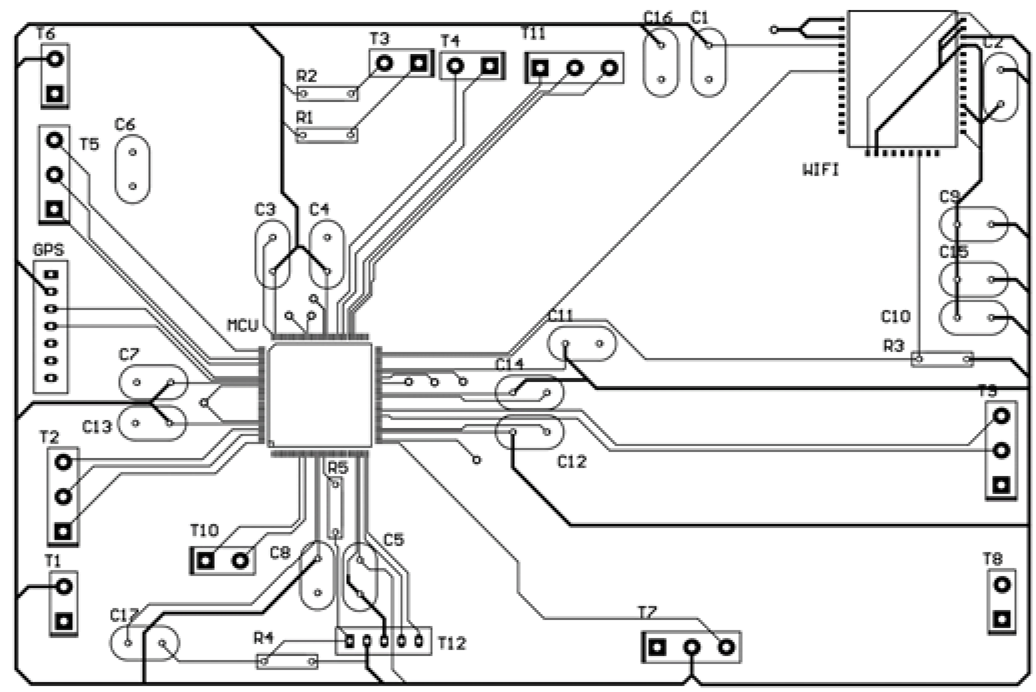


Figure 2: PCB layout

3.1.4 Hardware Faults and Failures

After Evaluating the Received circuit board some issues became apparent. Terminal T-2 in the above schematic was connected to the wrong MCU pin, preventing us from sending PWM through this terminal. Footprints for GPS and Debug interface (T12) were too small to fit the intended header pins. Jumper wires were soldered in place instead and allowed us to connect. Additionally, the MCUs Reset Pin was not connected to the boards debug port properly, the reset interface instead had to be connected to a resistor leg. Finally, pullup resistors to the WIFI modules wakeup pin were missing. This is now irrelevant however as the WIFI module sustained damage from a power supply failure during testing and is not operational.

Improper Debug interface and footprint, along with GPS footprint were overcome at assembly time of the board. Incorrect pin connection to T-2 motor output may be resolved by trading PWM signal with another pin that is PWM capable. WIFI capability is currently being implemented on breadboard, using an ESP-32 module, connected to the MCU via the UART line going to the defect WIFI module. This configuration can be switched from breadboard to Perf-board and implemented permanently next semester if desirable. The sensor subsystem has additionally been made aware of a need for more Ultrasonic sensors, to allow for better obstacle detection. Taking all of this into consideration it may become necessary to print another PCB correcting the mistakes made here and accounting for new insights.

The above issues encountered at the end of 403 were ultimately overcome by using the ESP-32 as primary MCU. The additional Ultrasonic sensors and new motor drivers added more IO than any single MCU at our disposal could provide while also accommodating the rest of the system. Since WIFI was already implemented on the ESP and it had the ability to output PWM without the need for additional jumper wires as the PIC would require, it was decided to use it as the main MCU and use the PIC for Obstacle detection and GPS reading and parsing.

3.2 Software

3.2.1 Software Overview

The Firmware for the PIC-32 MCU was developed in Microchips MP-LabX IDE with Microchip Harmony V3 configurator. Harmony allowed us to graphically configure the MCU for clock rate, Peripheral components and pin mappings. C language code was written in MP-Lab to implement the MCU functions described below. Through the MP lab IDE and PIC-Kit 4 in circuit debugger we were able to test the code piece by piece, in the target device and monitor internal variables and outputs. This proved invaluable in debugging and testing the program.

3.2.2 Configuration of MCU

A detailed overview of what MCU components are used to implement different functions is provided in function sections. The Pic has 9 connections for ultrasonic sensors, 7 for the echo signal and 2 to trigger the arrays. It connects to the GPS via UART, and has 1 UART and 2 GPIO connections for interface with the ESP-32. The Pic also needed an internal timer.

3.2.3 General Program Flow

As the Pic was relegated to Obstacle detection and GPS reading, its program flow is rather simple. It reads the front sensors array and parses the data for an obstacle, then reads the GPS unit and parses the received string for relevant data, and finally reads the side sensor array. This process continues while the PIC is powered on.

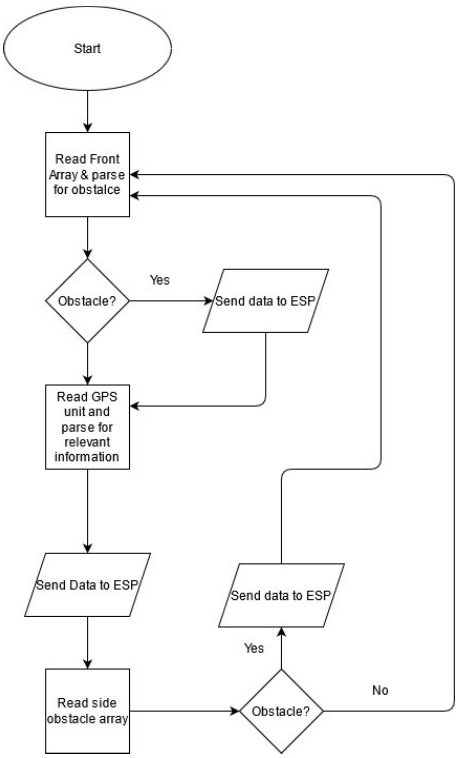


Figure 3: General Program flow

3.2.4 MCU Code Example

The Code written for the PIC-32 is provided in the Github repository under DemoedCode/PIC. The full PIC project, including configuration files is also provided in this directory for completeness.

3.2.5 Sample PIC Output to ESP-N

Presented below is a sample UART Output from the PIC to the ESP-N. The output includes Minimum distance to an object in front of the mower, in (distance, side) format. GPS reading of Latitude, Longitude, speed and course, and side array reading of minimum distance and angle the object makes with the side of the mower. Note that I had to sit in front of the side array for most of this test, hence many of its readings are 0. (as discussed in the Ultrasonic sensor section, readings against fabric do not return accurate results). This text is still formatted for human understanding, but could have easily been formatted in other ways. Unfortunately difficulties with other subsystems prevented us from using most of this information.

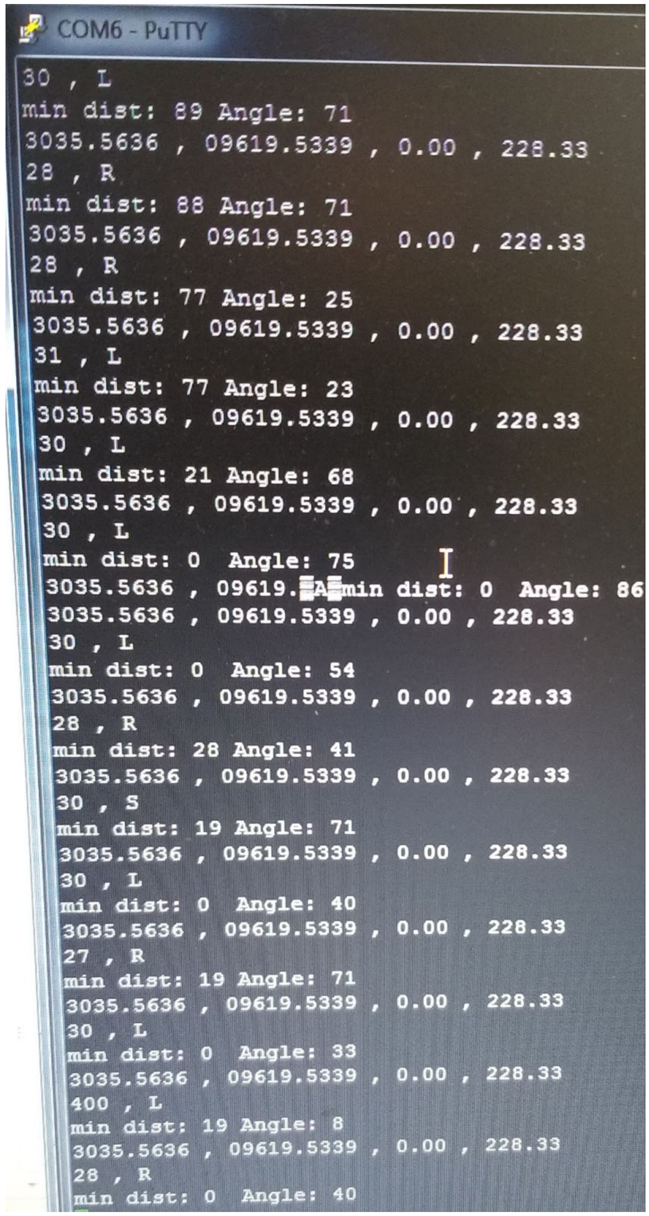


Figure 4: Serial Output from PIC-32 towards ESP-N, with front and side obstacle readings, as well as parsed GPS output

3.2.6 Comments on Program Performance

During the 403 demo the PIC code experienced some tumbles, where it would run through a bunch of statements without executing them. Later during 404 I encountered many exceptions being thrown by the pic for “Instruction Fetch or address load error expectation”. The ultimate cause of these exceptions is not known, however extensive research revealed interrupts on the PIC to be a possible source. After disabling all interrupts the exceptions greatly decreased in frequency. Building and deploying the project in Debug mode further helped. Several stamina tests were conducted during which the code performed without exceptions for 60+ minutes.

3.3 GPS

3.3.1 GPS Summary

The GPS receiver is mounted on a breakout board with male header pins. These connect to a wiring harness leaving the MCU, to allow mounting of the GPS in a location with clear reception. Communication takes place through the MCUs UART3_TX and UART3_RX lines, at 9600 Baud, 8 data bits, 1 stop bit and no parity. The GPS transmits data per NEMA0183 protocol. Upon startup the MCU sends a configuration string to the GPS module, setting it to send only RMC type sentences. The MCU then reads in the received characters and parses them for the needed data, specifically Latitude, Longitude, course and speed over ground. This information can then be accessed by other functions as needed.

3.3.2 GPS Test Results

Two different types of GPS tests were performed. One for consistency, and one for accuracy at different locations. The consistency test was presented in the final update presentation and showed that the GPS module reads identical data within one power cycle, and slightly different data after being power cycled. The second test was conducted at 4 different locations where we took two readings each and compared it with google maps results. This test revealed that accuracy is within the tolerances stated in the data sheet and google maps, however data from both tests combined suggests that the GPS module may be susceptible to noise and interference.

3.3.2.1 Precision Within and Between Power Cycles of GPS Module

For the Final presentation we have demonstrated the GPS modules ability to generate consistent readings within one power cycle. For this purpose, we power cycled the device, waited for the GPS module to acquire a fix, and then read the position 5 times. All 5 readings within one power cycle provided the exact same coordinates, speed and heading. This test was done on the Demo board, but as the accuracy and precision of readings rely on the GPS module only, which is the same module used with the target board, we present this test here. The readings were taken with the GPS module placed inside my apartment, as the system is still heavily reliant on external infrastructure, such as power supplies and multiple laptops. A summary of this test is presented below. The full test data for all 25 readings, to show precision, is presented in Appendix C.

test#	# of readings	Latitude	Longitude	speed	course			Distance to Google Maps point
1	5	3035.5572	9619.538	0	84.71	Pic32	Red	10.75M
2	5	3035.5613	9619.533	0	127.35	Pic32	purple	10.1M
3	5	3035.5583	9619.5307	0	237.76	Pic32	Blue	5.6M
4	5	3035.5612	9619.5342	0	156.33	Pic32	yellow	2.5M
5	5	3035.5629	9619.5344	0	359.03	Pic32	light blue	4.7M
control data								
Control	1	3035.5656	9619.5317			TM-D710GA	Dark Green	
Control	1	3035.5617	9619.5333			Google Maps	Green	

Table 2: GPS precision test results

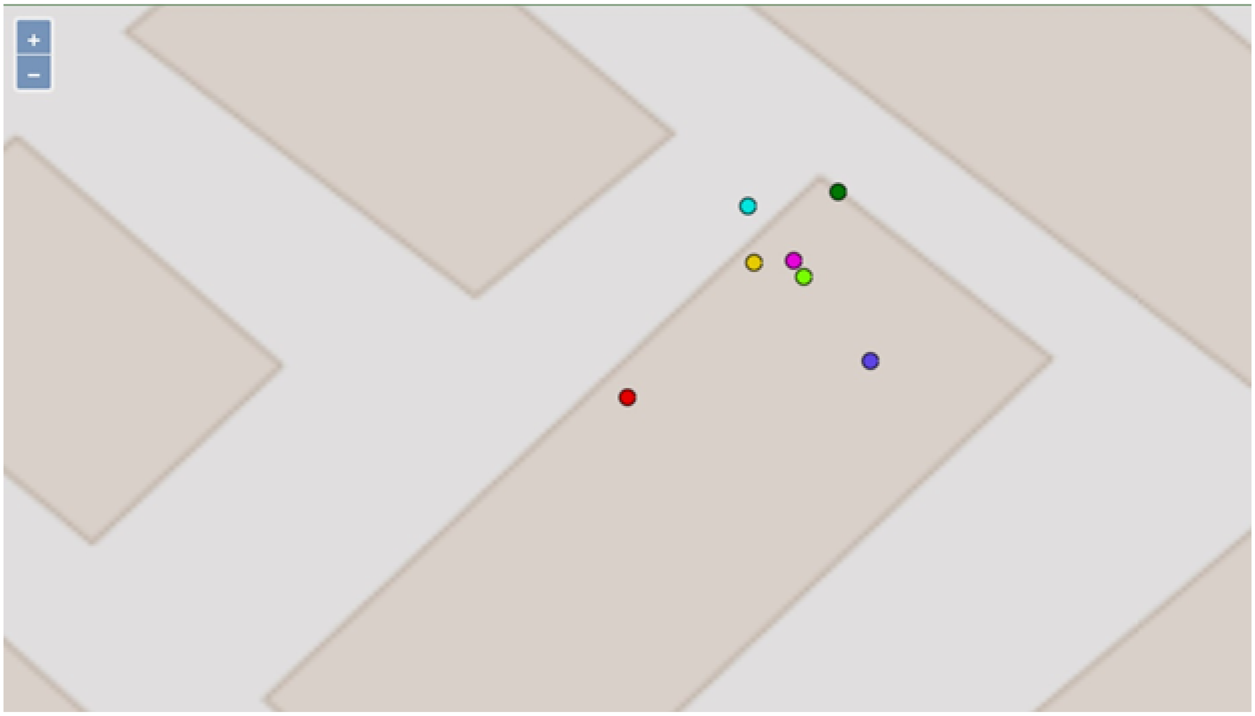


Figure 5: GPS precision test result map

3.3.2.2 Accuracy of GPS Module at Different Locations

To test accuracy on the target board we took 2 readings from the GPS module in 4 different locations and found the distance between the 2 readings and to the google maps determined location. This test was conducted at my apartment complex, with the MCU board and GPS module placed on the hood of my car. The engine was off during the 1st test and running for the last 3. In the figure below, red represents the google maps location, while the 2 readings at each location are shown in blue. Distances to the google maps point and between the measurements are shown in tables below. We point out that according to google support the accuracy of the google maps for GPS positioning is around 20M, while the GPS module used gives accuracy at 2.5M in the datasheet. The tests with running engine exhibit differences between repeated measurements, in excess of the stated accuracy, while the test with engine off does not. Additionally, all points are within 10M of the google maps provide coordinates, staying within the given tolerances.

Figure 6: GPS accuracy test map

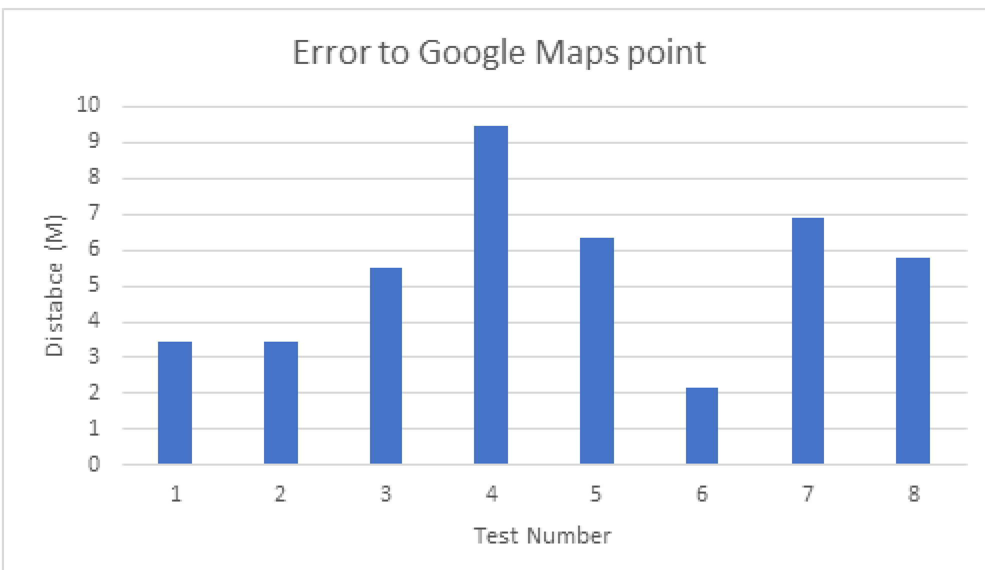


Figure 7: GPS accuracy test error to Google maps graph

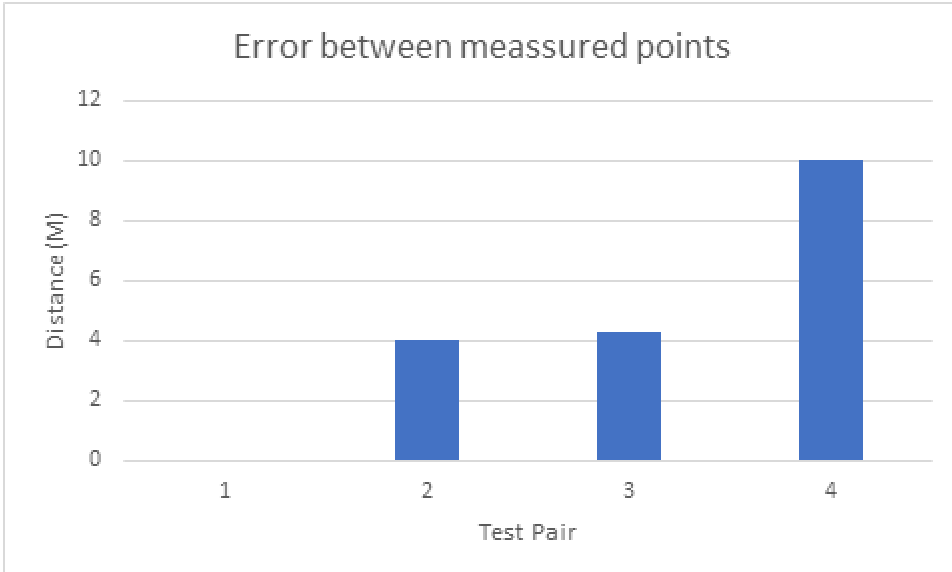


Figure 8: GPS accuracy test Error between measurements graph

3.3.3 GPS Test Summary

The 2nd series of tests exhibits errors of up to 10M for repeat measurements of the same location, the 1st test in this series, with the motor off, exhibits no error for repeat measurements. Additionally, 5 sets of 5 repeated measurements have been taken in section 1.2.4.2.1, none of which exhibit error within one power cycle. The 1st series of tests was done indoors, while the 2nd was done outdoors. It is possible that temperature changes from moving air caused errors. However, the 1st test in the 2nd series, done with the car engine off, did not produce an error. This suggests that interference from the cars electrical system, such as spark ignition, may have contributed to the error. As the development progresses it will be important to test the GPS both with the mower systems motors on and off and see if we have an error for repeat measurements at the same location. Outside of this, the accuracy from GPS measured coordinates to Google maps measured coordinates lies within the tolerances for the 2 systems. We conclude that the GPS system needs to be further investigated for effects of electronic noise but is generally operational.

3.4 Ultrasonic Sensors

3.4.1 Ultrasonic Sensor Summary

The HC-SR04 Ultrasonic sensors used require a trigger pulse as input and return an Echo pulse as output. The distance from the US to the object it is detecting is proportional to the time the echo pulse is high. To operate the sensors the MCU sends a 10µs trigger pulse and waits for the echo pulse to go high. Once an echo pulse is detected the MCU starts a timer, and the appropriate pins are sampled continuously, once the echo pin resets to low, the duration of the pulse can be calculated. This is the 2-way travel time of a sound wave from the sensor to the object. Multiplying by the velocity of sound in air and dividing by 2 gives distance to the object. The Speed of sound is variable with temperature, to account for this while keeping complexity down the speed of sound is set corresponding to a temperature of 29˚C, which is within expected operating range but gives better results at higher temperatures, when the system is more likely to be used.

Speed of sound over our operating range of 0˚C to 50˚C ranges from 331.4m/s to 360.3 m/s. For a maximum detection distance of 4M, resulting in 8M total signal travel, this gives a 0.0222s travel time at 50˚C and 0.02414s at 0˚C. For 29˚C, as used in code, the speed of sound is 349.3m/s. plugging this and the 2 times found above into the equation used in the code. Gives results of 3.87M and 4.21M at the 2 extreme temperatures for a 4M distance at 29˚C. If this error is determined to be excessive in later testing, provisions to adjust for temperature exist.

In the Final implementation we used 5 front facing sensors and 2 side facing sensors, labeled the front and side array. Each Array has its own trigger input, and each sensor its own echo return wire. By seeing which sensor reports the lowest distance to the object we can determine what side the object is on, for the front, or if we are moving towards or away from it for the side array. During system testing 2 of the 5 front sensors unfortunately failed, while the other sensors encountered an error limiting their range. Test results from 403 for a single sensor are provided below, while Sensor array results taken in the scope of system testing are provided in the validation section.

3.4.2 Test Results

Tests were conducted by placing the test target Infront of the Ultrasonic sensor, for incidence angle within 15˚ of Normal. Target distance was recorded, and 5 samples at each distance were read, next the target was moved back, and the process repeated. All distances were converted to cm. The US was mounted 6in above a desk, facing into the room. The 3 tests below represent 150 total data samples and show that we can detect large objects, such as a 4x4ft whiteboard very accurately up to 3+M, the maximum distance we were able to test. A 3.5x5.5 in object was successfully detected up to 2M from the sensor. We were not able to detect a person accurately at any distance.

3.4.2.1 Test of 4ftx4ft Whiteboard

The first Series of Tests was conducted by measuring distance to a 4x4 section of white board. Results are very accurate and consistent, becoming slightly less accurate at longer ranges. The Errors Graphed below show that we have a maximum error of around 3%. The relatively high error for 16cm may be due to the fact that target distance was recorded by hand, and any slight imprecision in hand measuring would be much more significant at this short distance.

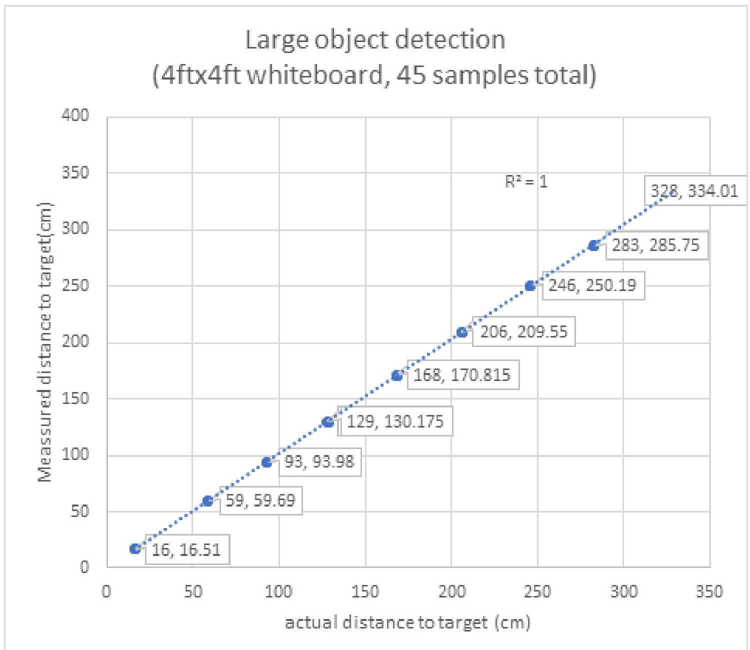


Figure 9: Ultrasonic sensor detection of large object test result graph

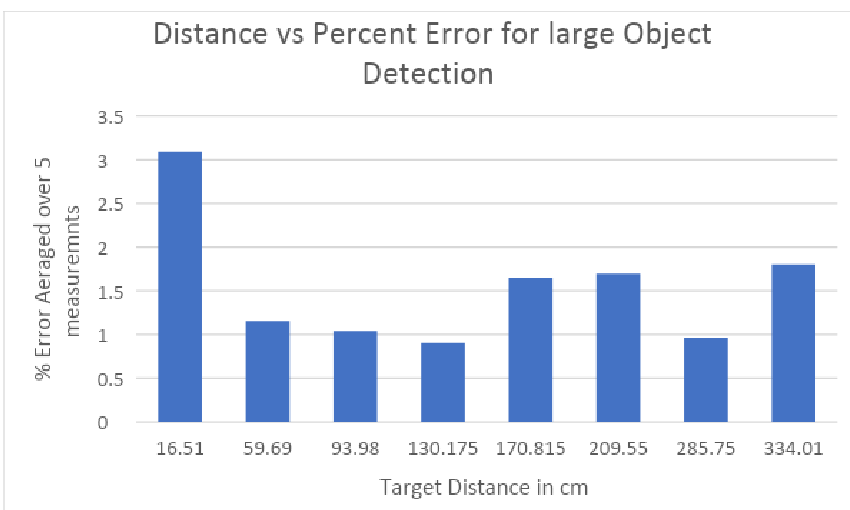


Figure 10: Percent Error for Large Object Detection

3.4.2.2 Test of 3.5inx5.5in Camera

Here we tested our ability to detect a small object. The target for this test was a DSLR camera, mounted on a tripod, with the back side facing the sensor. The area presented was approximately 3.5x5.5 inches and relatively smooth. Measurements were accurate up to about 2M. At that point the sensor was picking up the background rather than the camera. We did have 2 outlying points at ~14M. This is believed to be due to an error inside the sensor and will be elaborated upon at the end of the test section. Measured vs actual distance is shown in the first graph below, the second graph shows Percent Error vs distance, averaged over 5 measurements at each distance. The Yellow columns on the second graph show those cases where the US picked up the background instead of the object we were trying to detect. Additionally, the Red bar shows our highest error case over the valid range. As the measurements to the target were done by hand with a tape measure, it is possible that the target distance was measured incorrectly for this point, as it lies far outside of any other value. Finally, as mentioned above, we have 2 points at 14M, likely due to a sensor error that will be explained below. This data was omitted from the error graph as its high value rendered the graph useless for all other data. Instead it is presented with the other errors in a table below and marked in yellow.

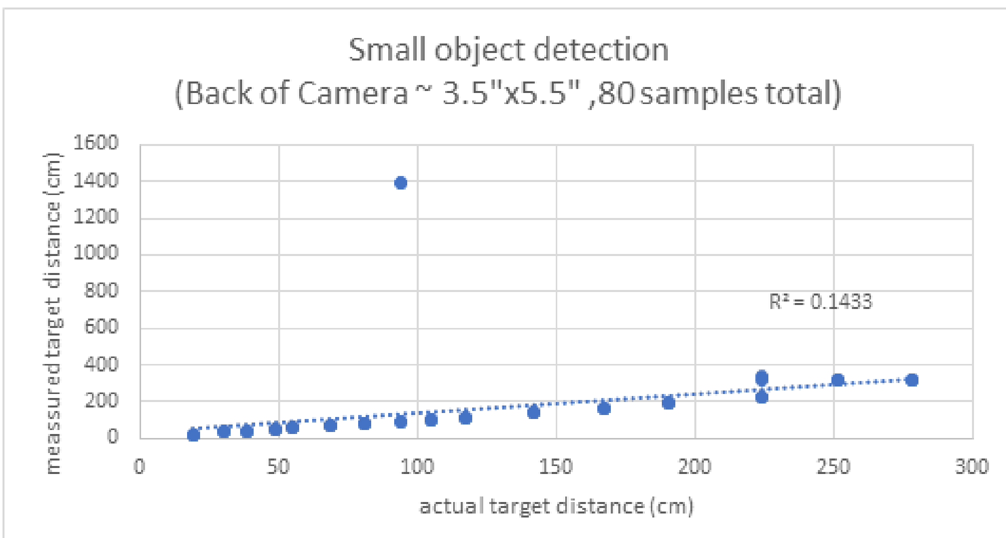


Figure 11: Ultrasonic sensor detection of small object test result graph

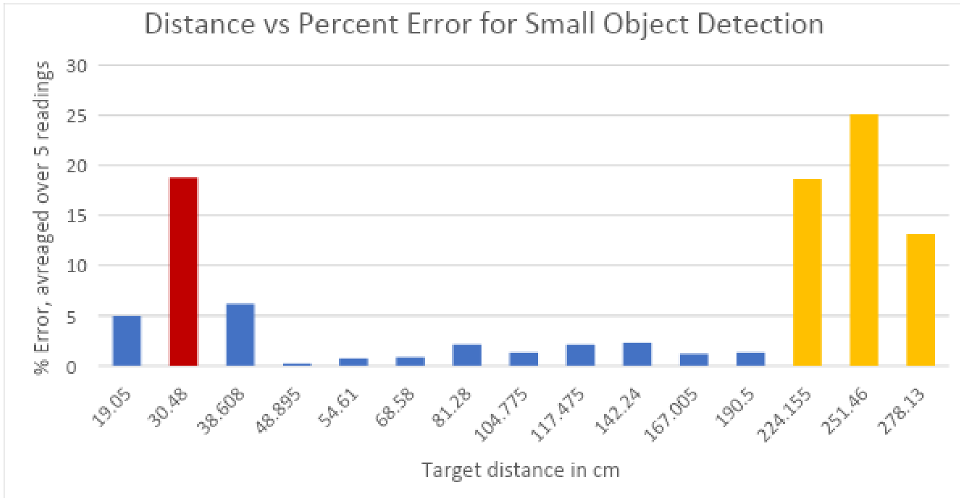


Figure 12: Percent Error for small object detection

Small Object Detection Error	
Target distance in cm	% Error to target
19.05	4.98687664
30.48	18.7664042
38.608	6.195607128
48.895	0.214745884
54.61	0.714154917
68.58	0.845727617
81.28	2.116141732
93.98	552.4792509
104.775	1.312335958
117.475	2.106831241
142.24	2.27784027
167.005	1.200562857
190.5	1.312335958
224.155	18.66788606
251.46	25.10936133
278.13	13.18448208

Table 3: Distance and Error Percentage for small object detection

3.4.2.3 Test of Person

These tests were done with the help of an assistant, wearing sweatpants and a sweatshirt who stood in front of the sensor at the indicated distance. It is clear that the obtained results are very poor, with only 3 out of 25 samples being within 20cm, while the others were off by 50+cm and often multiple meters. We see 14M repeated often, as in the above test of the small object, which we will elaborate upon next. We currently believe the reason we can't pick up people is due to their clothes. The fabric likely absorbs the Ultrasonic sound, and never reflects a return echo the US can pick up. The second table shown below gives percent error vs distance, averaged over 5 samples. It appears as though the accuracy gets better as the distance increases, but this is only because the sensor started picking up the background.

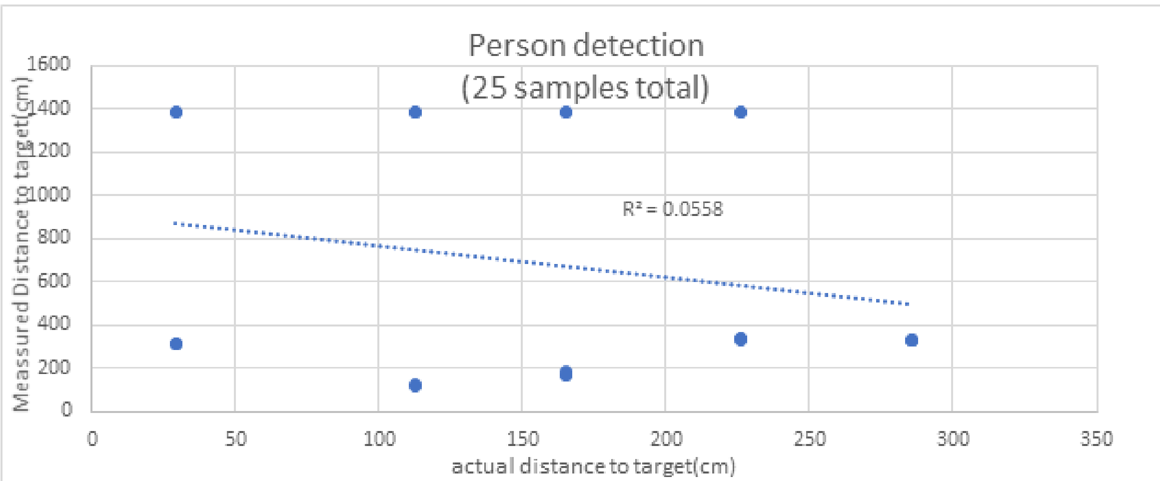


Figure 13: Ultrasonic sensor detection of person test result graph

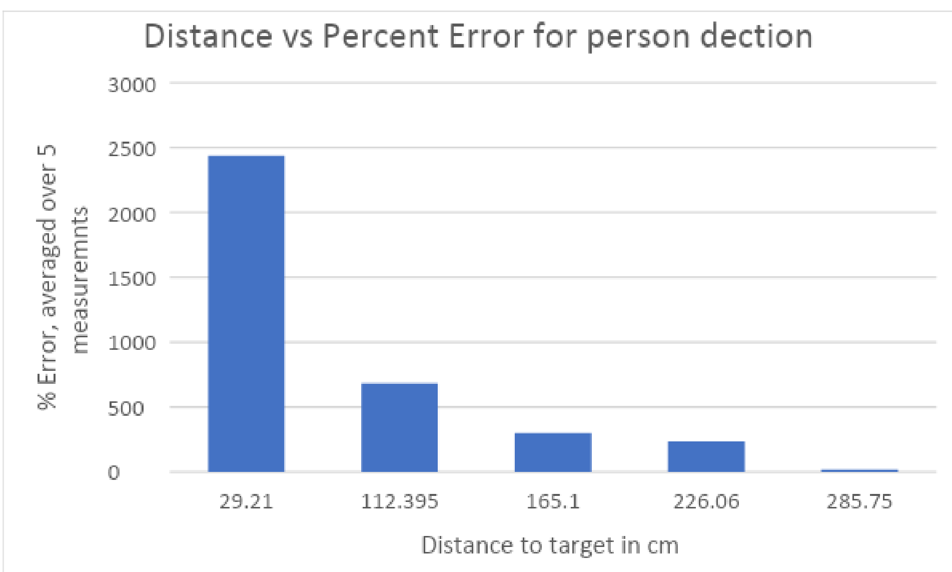


Figure 14: Percent Error for Person detection

3.4.3 Ultrasonic Sensor Test Summary

As seen above we have problems detecting small objects at distances over 2M and detecting people at any distance. Many sensor readings show 14M, which is greater than the maximum distance possible at the test site. This distance likely corresponds to the maximum time the echo output stays high if no return pulse is received. Since we can not distinguish between cases where the distance is too great to receive an echo, and cases where the incident Ultrasonic pulse was absorbed, for example by fabric, this signal is of no use to us. For 404 a front array of 5 sensors and a side array of 2 sensors was implemented to gain a better understanding of our environment. This allowed us to obtain angular information about objects. The issue of revolving obstacles covered in fabric was not solved.

3.5 WIFI-Module

3.5.1 WIFI Summary

As the WIFI module on the PIC failed, we used an ESP-32 to implement WIFI capacities. This is part of the ESP-W component of the MCU subsystem and was implemented by Jonathan, who will provide a report in the appropriate section.

3.6 Drive Motor Control

3.6.1 Motor Control Summary

As described above Hardware issues prevented us from using the PIC-32 for motor control. It was instead implemented in the ESP-N portion by Max. I will elaborate upon it in the appropriate section.

3.7 Blade Motor Control

3.7.1 Blade Motor Control Summary

Blade Motor Control was also implemented from the ESP-N. It could have been controlled by the PIC, but from a control logic perspective, using the ESP-N was the better idea. The hardware and software solution to this will be presented by Max in the appropriate ESP-N and Motor section .

3.8 Accelerometer and Gyroscope Unit control

We did attempt to implement a Gyroscope and accelerometer with the ESP-32, however this proved unsuccessful. See ESP-N section for details.

3.9 Battery Status Interface

3.9.1 Battery Status Interface Summary

Due to time constraints the Battery status interface was not addressed further than at the end of 403, whose extent is listed below. Additionally a changed battery requirement would have rendered any previously designed Battery status interface useless.

The Battery status interface intended to read battery level, has not been fully implemented. We are awaiting exact specifications from the power subsystem as to what voltages set the threshold for a charged and discharged battery. The proposed solution is to use a comparator with Zenner diode reference, and a voltage divider to bring the battery voltage into a range where the charged battery voltage would be above the Zenner Voltage and low charge voltage below. This would provide us with a 0V and 3.3V at the comparator output, for a charged and discharged state respectively. We can choose which we want to correspond to charged and discharged by which pins of the Comparator we connect to which signal. The voltage level at which the battery is considered discharged can be set by the resistor divider and the Zenner diode. Since we do not have this information available it is impractical to construct the circuit at this time. However, to demonstrate the design, we have Multisim simulations, using realistic components, that verify the design.

3.9.2 Battery Status Interface Simulation Results

The circuit simulated here assumes 12.0V and above for a charged battery, and 11.9V and below for a discharged battery. In operation this threshold will need to be adjusted such that the Mower system has enough time to return to the docking station once the low voltage alert has been tripped. The threshold can easily be varied by changing resistor R1. Additionally, this circuit outputs logic low when the battery voltage is sufficient, and logic high when it is low. This behavior is chosen such that during normal operation the MCUs GPIO pin takes as little current as possible, to keep MCU power dissipation, and hence heat, to a minimum. The output from the comparator can be read using a configured GPIO pin on the MCU, which can be used to provide a Boolean variable driving a “Return to base” logic.

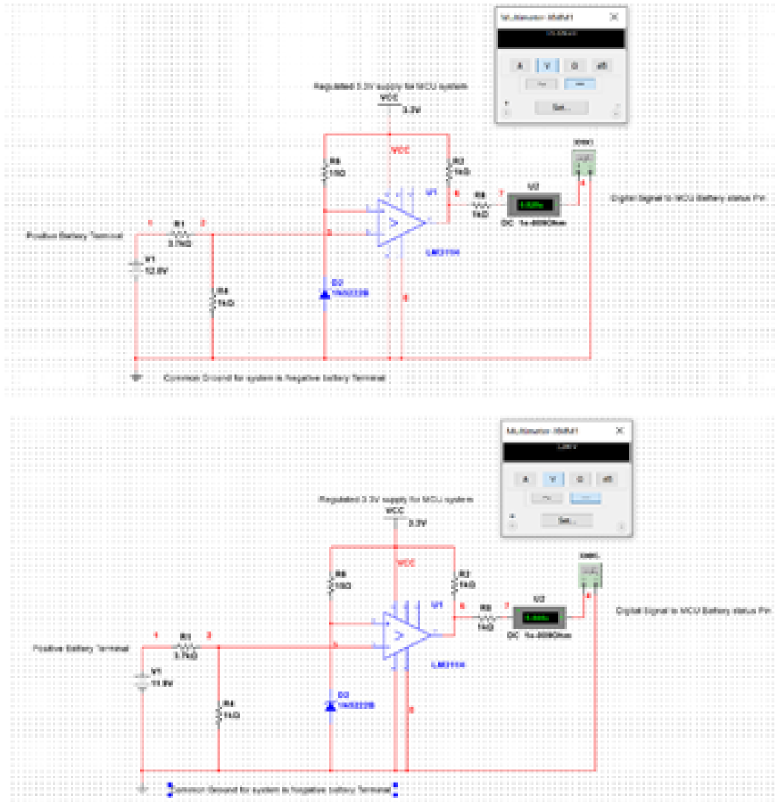


Figure 15: Battery read circuit simulation for "Battery Charged" (top) and "Discharged" (bottom)

3.10 MCU Functions Relegated to and Dependencies on Other Subsystems

The Following is a list interface issues that need to be addressed and reconciled with other subsystems. This List is by no means extensive, but it lists some of the interface issues that need to be addressed immediately next semester, and those that have limited us in development of the MCU subsystem. Additionally, we list any functions that have been turned over to other subsystems.

3.10.1 Functions Turned over to and Dependencies on Motor Subsystem

The motor subsystem was rebuilt by Max after the initial Motor subsystem failed. Its control was implemented on the ESP-32, also by Max. See motor subsystem for Hardware details, and ESP-N subsystem for control details.

3.10.2 Power System Dependencies

Due to time constraints and component changes any dependence on the power subsystem, outside of power delivery, was removed.

3.10.3 Sensor System Dependencies

The Sensor subsystem was taken over by Max, additional sensors for angular resolution were added, however the issues surrounding detection of fabric covered obstacles was not solved.

3.10.4 User Interface Dependencies

The Connection to the user interface took palace on the ESP-W, and was handled by Jonathan.

3.11 PIC-32 MCU Subsystem Conclusion

The PIC-32 was intended as the sole MCU for the system. Due to failures of the WIFI module and a misprint of the PCB an ESP-32 was added. Aside from solving the WIFI issue, this also provided enough IO lines to include additional Ultrasonic sensors, as well as accommodate new motors drivers, elaborated upon in the Motor SUbsystem section. The PIC-32 performed well in obstacle detection and reading of GPS.

In hindsight the PIC firmware and hardware development was a very large task, and a better approach may have been to use a development board to save time on hardware development. Nonetheless learning embedded system design on the pic proved very educational, and has certainly made me a better programmer, and set me up to be a better engineer.

4 ESP-N Subsystem by Max Lesser

4.1 Introduction

As elaborated above, the MCU subsystem is splint into the PIC component, ESP-N for navigation and ESP-W for user interface, where both ESP components are on the same Microcontroller, but since they perform distinctly different functions and were executed by different team members they have separate sections.

Here I will elaborate upon the Navigation and motor control component of the ESP-32. Jonathan will explain the User interface component in the next section.

The ESP-N is tasked with controlling the drive and blade motors, following a rectangular path and avoiding obstacles as needed. It also reads Shaft encoder data, and has provisions for reading IMU data.

I will note here that the navigation component was originally in the scope of Josh's subsystem. I began developing an alternative towards the end of the semester when it appeared the original navigation subsystem would fail. The solution implemented here was very much an emergency effort on my part, parallel to me rebuilding the motor subsystem and working on general integration. This subsystem is hence not as sophisticated as it should have been, given more time and not as extensively tested as it could have been.

4.2 Navigation

Navigation is implemented using inertial guidance from shaft encoders. By measuring the number of wheel rotations we can conclude where we are relative to a starting position. Turning is implemented in the same way, by breaking one wheel and rotation the other one until a 90 degree turn is complete. The issue with this scheme is that error accumulates. I attempted to address this issue using a Gyroscope, as well as Accelerometer and Magnetometer. This approach proved unsuccessful due to a faulty sensor. A second approach was made using the PICs GPS unit, this however failed due to the GPSs slow update rate of 1Hz. With more time one or both of the above schemes could have been successful. As a result the mower drifts of course the longer it runs, as can be seen in submitted videos. Details about the sensors will be addressed further below.

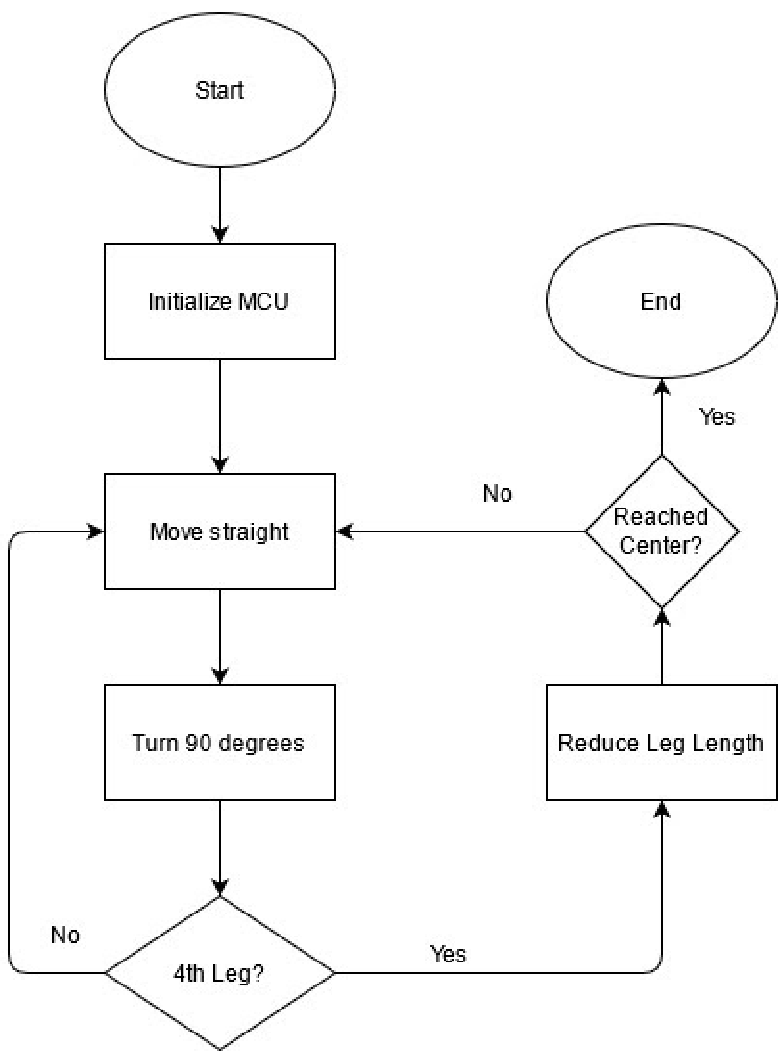


Figure 16: General Navigation flow without obstacle evasion

4.3 Obstacle Evasion

Information about Obstacles was obtained from the Pic, as explained above. Once the PIC located an obstacle within 40 cm of the unit, it would set a GPIO pin high, which the ESP polled during maneuvering. This function was originally implemented using an ISR on the ESP, but stray voltages on the alert pin would cause unexpected triggers of the ISR. The GPIO pin approach proved more robust.

Once the ESP was altered to an obstacle, it was to immediately break and disable the blade motor. It was then to turn away from the object until the front array no longer reported anything. Then it was to move straight to clear the object. Once cleared the side array would be checked. If the side was clear the mower was to return to the original path, resulting in a triangle pattern. If the side was not clear, the mower was to move parallel to it until the side became clear, and then return, following a trapezoidal pattern. This is outlined in the Flowchart below. Unfortunately we encountered a failure of the Left Shaft encoder. Which rendered the above approach impossible. The work around to this problem was time based obstacle evasion, where the mower would turn for a set time, then move straight, turn for twice the original time, move straight again, and finally turn back onto the original path, resulting in a triangle shaped evasion path. This approach did allow us to clear obstacles, but with limited fidelity.

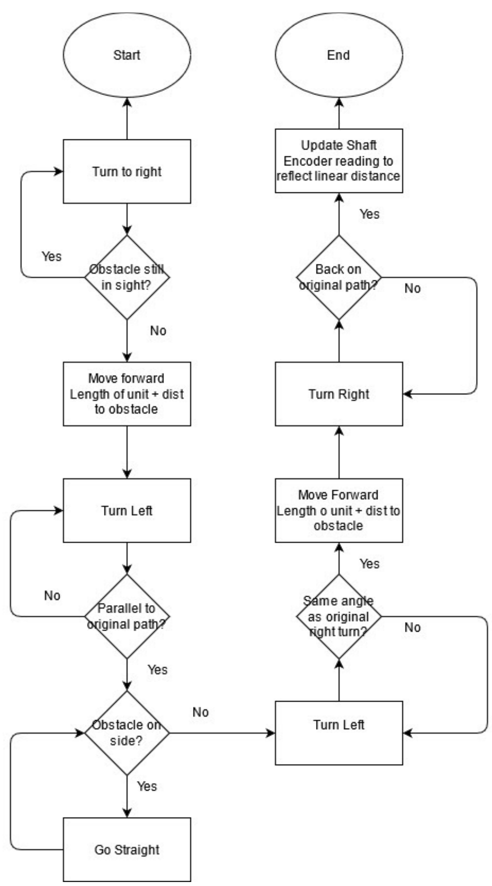


Figure 17: Obstacle Detection Flow Chart

4.4 Shaft Encoders

For Inertial Navigation the system uses 2 AMT102-V shaft encoders on the rear wheels. These allow us to measure shaft rotations with an accuracy of 48 counts per revolution. Translating Shaft Rotations to Wheel rotations, taking into account the existing gearing used to attach to the drive wheels then gives us distance traveled. This measure would let us accurately turn up to a 48th of a rotation, as well as travel in a straight line and use the above described obstacle evasion scheme. Unfortunately the Left wheel shaft encoder failed during late stage testing, rendering impossible obstacle evasion as described above. This also forced us to turn towards the left, instead of the right as intended. Which meant our side detection array was useless as it would now point away from any obstacle, towards the inside of the yard.

Discounting the issue above, both shaft encoders are powered by 5V, and send an indicator pulse for full wheel rotation, as well as a quadrature pulse train signal with 48CPR, where the lead or lag of the pulses determine forward or backwards rotation. As we can control the rotational direction of the motor, only one of the 2 quadrature signals was connected for each sensor, in an attempt to reduce complexity. For mounting details see Motor subsystem section

4.5 Accelerometer Gyroscope and Magnetometer

In an attempt to improve inertial navigation, and overcome the issues presented by the failed shaft encoder I added a miniIMU 9-v5 to the system. This sensor includes a Gyroscope, Accelerometer and Magnetometer. The Accelerometer and Magnetometer can be combined to obtain a compass heading, compensated for Pitch and Roll of the unit. In Bench tests of this setup the heading varied by over 60 degrees when the sensor was stationary. A second approach was to integrate the Gyroscope reading to obtain angle turned. This approach was successful in indicating 90 degree turns. It was however highly unreliable as the Gyroscope output would sometimes read all 0s or NaN. This combined with the issues with heading lead to the conclusion that the sensor is defective. It was too late to obtain a replacement at this time. See additional code/MAX section in the github repo for software implementation details.

4.6 Motor Control

The original motor subsystem proved underpowered for our unit, new motors and driver boards were required. The hardware details are outlined in the New Motor Subsystem section. The New drivers required 2 PWM signals per motor, for forward and reverse. As well as 2 digital logic pins each to set functionality. The ESP-N attached to these new drivers with the above signals. Setting the logic pins high permanently at the beginning, and then giving PWM to either the forward or reverse input of each driver, and setting the other one low allowed for straight line or turning motion. The PWM sent was at 5 KHz, with a maximum duty cycle in turn of 62%, 27% for straight motion, 2.7% reverse for breaking.

4.7 Blade Motor Control

The Blade motor was controlled by the ESP-N via relay driver. The hardware details are outlined in the New Motor subsystem section. The software side of this implementation is rather simple, as the mower simply sets a GPIO pin high to activate the blade, and low to stop it. This control scheme results in the balde being shut off when the MCU loses power. For safety the balde was deactivated during obstacle evasin

4.8 Summary and Conclusion

As my attempt to find a solution to navigation and obstacle avoidance was very last minute, it clearly lacks sophistication a semester long subsystem might have. Additionally we were plagued by failures of shaft encoders and IMU sensors, not to mention the physical rebuild of an entire subsystem. Given this the ESP-N subsystem performs reasonably well, and is close to being a successful subsystem. A means to successfully read heading would have solved our navigational challenges. Additionally with more time a true SLAM algorithm could have been implemented using the PICs GPS output. Unfortunately time constraints and other issues prevented this. Given perhaps 2 more weeks many of these functions could have been implemented. Nonetheless, considering the short time and other issues the Navigation and control subsystem presented above was reasonably successful in achieving the mission.

5 ESP-W Subsystem

To learn more about the ESP-W system refer to Section 4 of the User Interface Subsystem Report

Autonomous Lawnmower

Max Lesser

MOTORS SUBSYSTEM REPORT

REVISION – 3
29 April 2021

Table of Contents

List of Tables

List of Figures

1 Introduction and Purpose

During testing it became apparent that the previous Motor subsystem was not powerful enough to allow for navigation. Hence a new motor Subsystem was needed. This section details the new motor subsystem, developed and implemented at the very end of 404. As it was developed in the last 2 weeks of the semester, it was rather rushed, leaving this section somewhat empty of testing detail as could have been achieved by a semester long development.

This subsystem consists of two 230W 24V motors, and an off the shelf H-bridge for each, shaft encoders for the drive motors, as well as the 12V blade motor from the original motor subsystem, and its relay driver. In addition, this system includes mechanical components, such as front wheels and drive shaft assembly needed in the rear, along with mounts and incidental hardware to attach the motors. The H-bridges and relay driver are connected to the ESP-N subsystem which controls the motors. Shaft encoders are mounted to the motors, and over the motor shafts to measure wheel rotations, outputting data to the ESP-N. Driving of the wheels is achieved via the grearing and cogs that existed on the original mower. However, custom parts had to be manufactured to attach to the Cogs and Motor shafts. Mecanum wheels are used in the front to allow for 0 radius turns.

2 Part Selection

Due to delayed testing the need for new motors did not become apparent until the end of the semester. Hence the prime criteria for new motors was power, followed closely by delivery time, and cost. The Motors meeting all of these requirements were YaeTek 24V Brushed DC motors. As these new motors were substantially more powerful than the old ones, new drivers were also required, with again the same urgency as the motors. The BTS-7960 driver boards meet our needs and were available in a short time frame. The downside to these new parts was that the motors required new mounts due to their larger size, and the driver boards required a different control logic from the ESP-N. As well as a need to run the Motors on 24V. This was not ideal, but seeing as this motor and driver combination was the only one that could get here in time while being strong enough and affordable, the choice was made.

3 Mounting and Attachment

The new motors were mounted using L-brackets bolted to the side of the mower. With holes drilled to match the pattern on the motors. Due to the heavy motors, not flat mower sides, and limited manufacturing capacities, the motor shaft did not perfectly align with the hole through which it needed to fit. Fortunately some inherent play in the gearing absorbed the difference.

The gears themselves were attached to the old motors by means of custom manufactured M-8 nuts. As the original mower was self driving, allowing for either powered or pushed operation, the gears interior surface was roughly triangular, to allow a slotted key to either grab or slip. For attachment to the old motors triangular nuts were manufactured to grab into this pattern and allow the wheels to spin forward and backwards. These Nuts were attached to M-8 threaded shafts which were then bolted to the old motor shafts. These were reused for the new motors, after a way to mount the shafts was found.

A larger issue was presented by the Motor shaft itself, which was a left-hand metric thread. This was not apparent from the vendors website, and instead had to be addressed after receiving the motors. As a Left hand to right hand metric coupler was locally unavailable, manufacturing one using a regular M-8 coupler with the threads drilled out to slip over the left handed thread was the next solution. Drilling perpendicular through the New motor shaft and this coupler allowed the insertion of a cotter pin. This solution was not ideal as the cotter pin broke repeatedly during testing. With more time a proper adapter could have been obtained, but this was not an option for us.

A final issue was presented by the shaft to wheel attachment. While the actual drive used cogs, the mowers original drive mechanism was a single shaft enclosed in an axel bolted to the frame in multiple places. Since we did not have the luxury of an axle, nor the space or manufacturing ability to add shaft bearings we had to improvise. By forcing backwards a rubber bushing in the hole the shaft would pass through, roughly 1/8th inch recess was created.Using an M-8 inside diameter washer with outside diameter greater than the hole, I was able to grind down the outside using a drill and angle grinder. Once small enough to fit into the hole but not the bushing, we had our own shaft bushing. Pinned with 2 nuts from the outside, the shaft was held in place. This configuration allows us to drive the wheels with our new motors, without excessive play. Credit for this saving idea goes to Vincent McMasters.

In order to allow 0-degree turns yet maintain stability, mecanum wheels were used in the front. To mount these custom brackets were made to extend the wheels forward enough. This mounting solution provided for relatively stable forward motion, while allowing us to turn from a stand still. Pictures detailing these components are presented below.

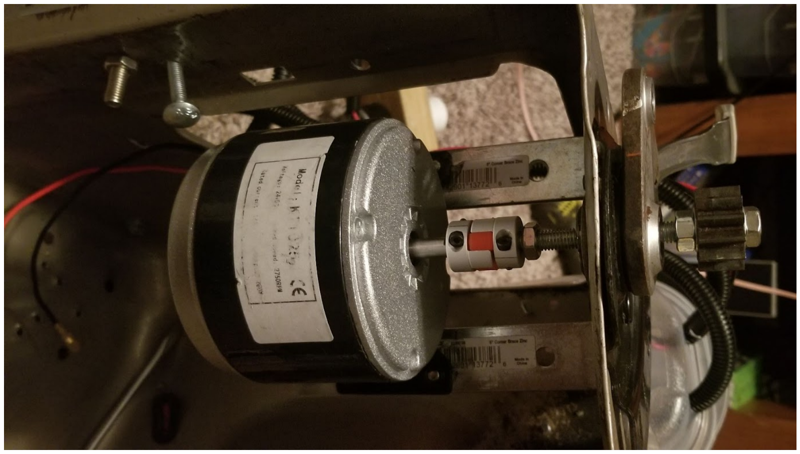


Figure 1: New 240W Motor with gears attached, with first shaft coupler attempt attached

Figure 2: Original Lawnmower's gears and the manufactured nuts to mount to the shaft

Figure 3: Gear Configuration of both the gear on the motor shaft and the wheel

Figure 4: Mounted Shaft Encoder on Motor

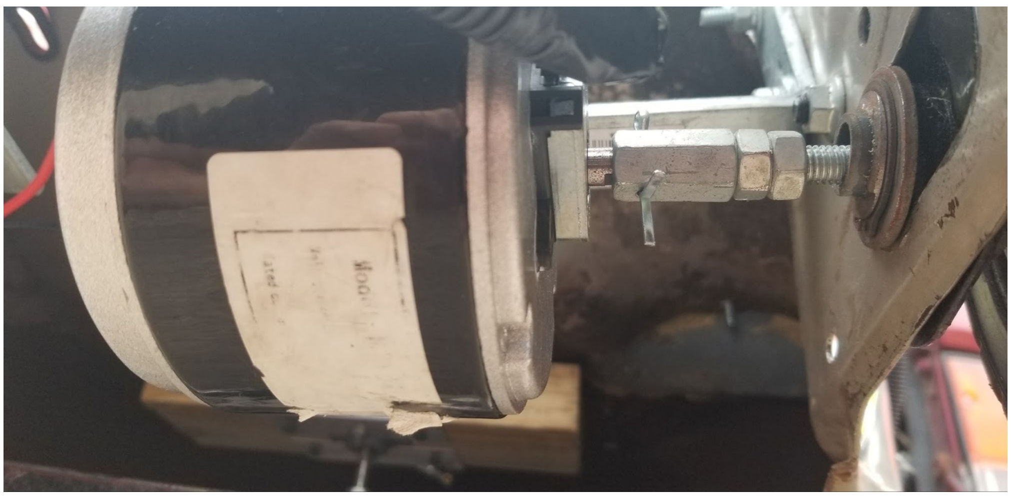


Figure 5: Shaft Adapter Assembly and Shaft Encoder

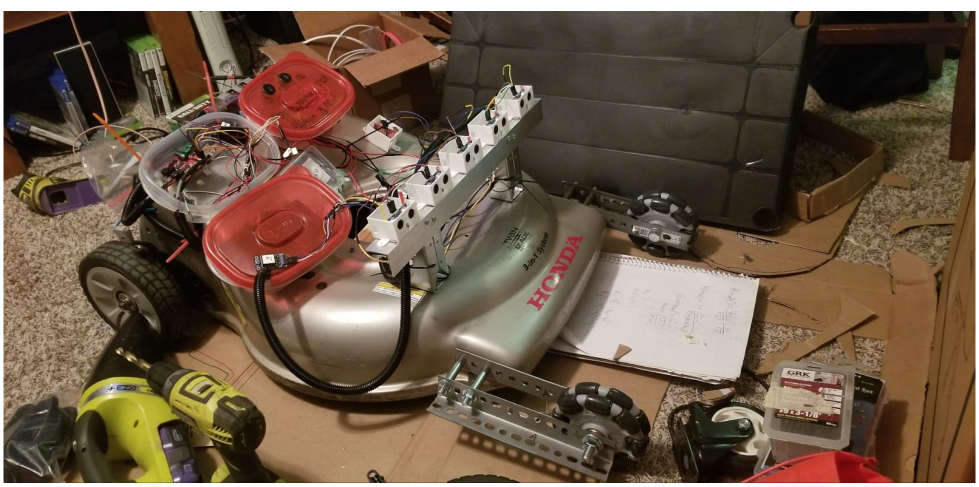


Figure 6: Mower Assembly Showing Mecanum Wheels in the Front

4 Motors

The New motors used were straight forward once the shafts were attached (see section 4.3). A 24V power supply was needed to provide sufficient power, which unfortunately eliminated our ability to use the docking station and charging system. See Section 4.7 for details.

5 H-bridge

An initial attempt was made to reuse the previous H-bridge from the old motor subsystem, as described in section 4.7 this attempt was abandoned due to overheating problems. The replacement H-bridges, ordered along with the motors, were BTS-7960, capable of handling up to 43A per motor. This did change the control inputs from the previous motor driver to that listed in the table below. Pin 3&4 had to be set to enable operation, with pin 2 low and PWM input into Pin 1 the mower would move forward, Pin 1 low and PWM into Pin 2 resulted in reverse. One such H-bridge was needed per motor.

Pin Number	Function
1	Forward PWM signal
2	Reverse PWM signal
3	Forward enable
4	Reverse enable

Table 1: Control Signal Table for New Motor Drivers'

The following PWM settings were used to perform the different navigation actions.

Function	Left Motor	Right Motor
Go straight	Forward 27.3 %	Forward 27.3%
Turn	Reverse 23.4%	Forward 39 %
Stop	Reverse 2.7%	Reverse 2.7%

Table 2: Control Signals for Different Actions as a Percentage of Maximum

6 Blade Motor

The blade motor was the original 12V blade motor, interfaced with the ESP-N via darlington pair relay driver controlling a G5LE relay. This Allows the ESP-N to control the blade motor without drawing too much current. And shuts down the balde in case the MCU loses power.

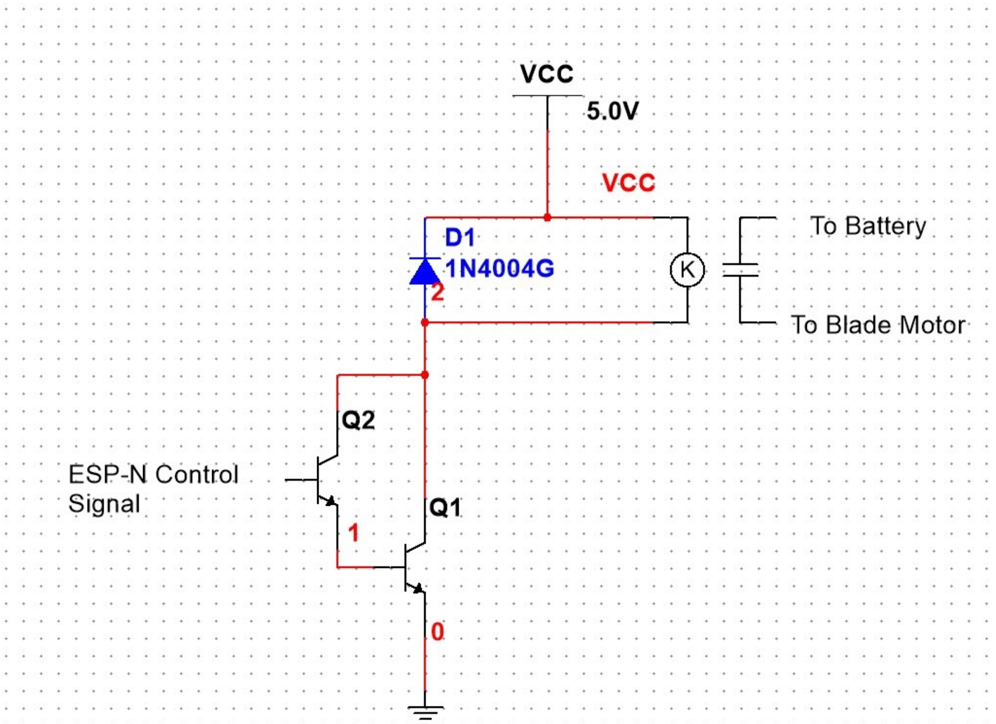


Figure 7: Relay Driver Circuit Diagram

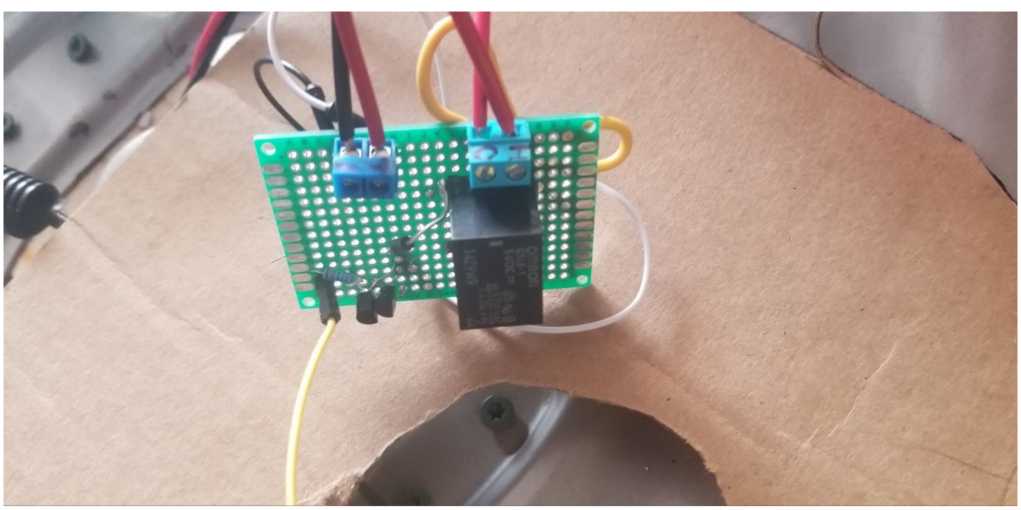


Figure 8: Assembled Relay Driver

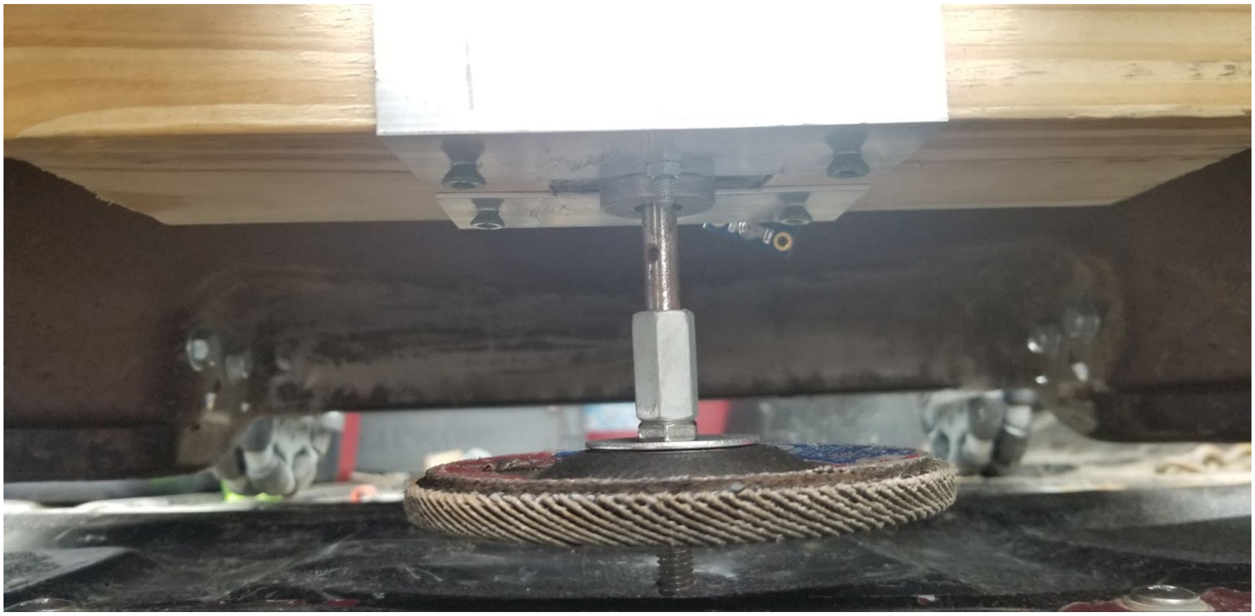


Figure 9: Bottom view of blade Mounted to Blade Motor. Flap disk used in testing for safety

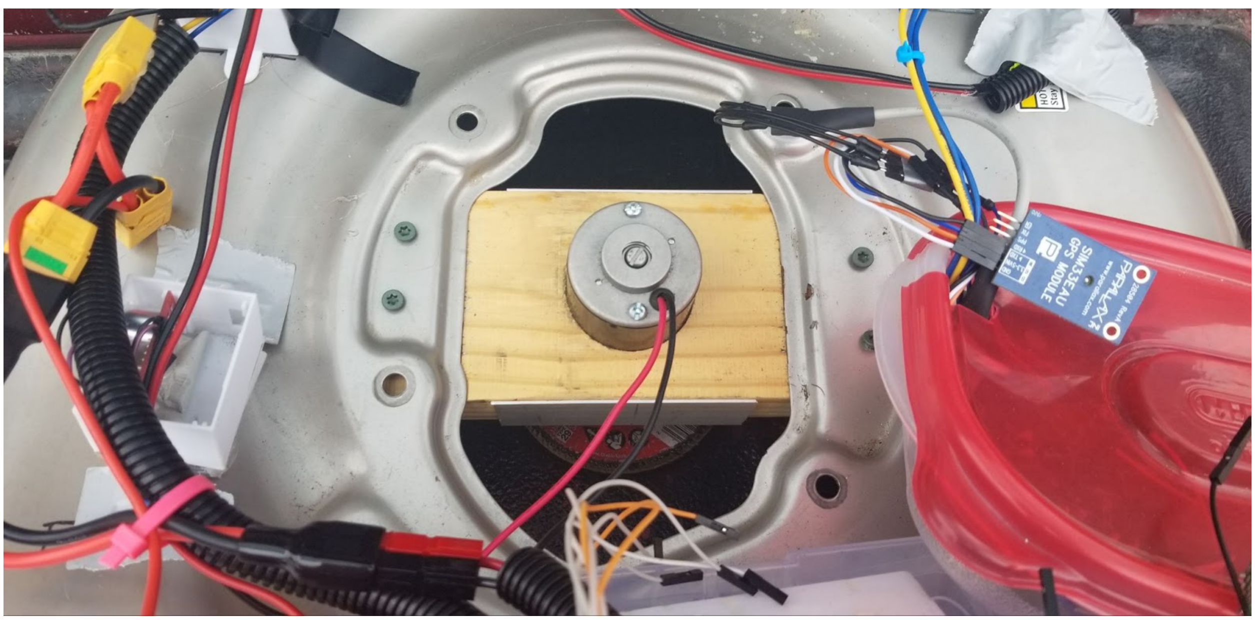


Figure 10: Top view of blade motor, Cover not shown but can be added

7 Transition from Old Motor System to New Motor System

After the new motors were acquired, an attempt was made to reuse the previous power and motor control subsystem with the new motors.In initial bench tests of the new motors, an constant input of 12V at 5A seemed to provide sufficient power, so it seemed as though we could reuse previous power and control components. In system tests however, a loss of power with increasing runtime was observed. After less than 60 seconds the power output decreased to the point the mower was no longer able to move. An initial consultation with Prof Kalafatis suggested the motors may be overheating. To overcome this fans were added, however this had no observable effect. Further investigation suggested that the Lead Acid battery may not be providing sufficiently consistent power. Through a gracious loan by a friend I was able to abstain LiPo batteries for RC planes. The capacity of these batteries was limited, and since LiPos removed the charging ability developed by the docking station regardless of configuration, it was decided to assemble them in series, powering the motors from 24V to compensate for lower capacity, and tapping 12V from one of the batteries for the remaining mower systems. This approach did improve power output. The torque however still declined with increasing runtime, just more slowly now. After temperature measurements we found the old H-bridge to reach excessive temperatures. Replacing it with the new components described in section 5 resolved the issue entirely. While this rebuild was very hectic, and not ideal, it did allow us to achieve our core mission of lawn mowing. As such it was in our opinion the best option considering all alternatives.

8 Conclusion

This Subsystem was very much scraped together at the end of the semester after the initial motor subsystem did not function. While the part selection was not ideal, and gave many mechanical problems, as outlined in section 3, there ultimately was no alternative. The mechanical and control challenges presented were overcome, but this time cost time that couple have been applied to the implementation of other subsystems such as the ESP-N. Nonetheless, given the short notice I had to develop this component I am satisfied with my solution. In hindsight I believe we as a team should have been more demanding of validation and test results from team members, such that this shortcoming could have been detected sooner, if not entirely prevented.

Autonomous Lawnmower

Jonathan Poulose

USER INTERFACE SUBSYSTEM REPORT

REVISION – 3
29 April 2021

Table of Contents

List of Figures

1 Subsystem Introduction

The User Interface subsystem consists of the Java and XML code that was used to construct the android application used to control the autonomous lawnmower. The software used to write and test the code is Android Studio. The android application will write directly to the Firebase Server Database and upload information and commands in realtime. The main function of the application will be to set the specific coordinates of the corners of the user's lawn to draw the path of the lawnmower. To create this application API Keys and OAuth 2.0 Client IDs will be needed for Google Maps, Google Account login, and Firebase integration. Another part of my subsystem was the WiFi component of the ESP32.

2 Android Studio IDE

The entirety of the application will be coded and tested on the integrated development environment, Android Studio version 4.0.1. This software also allows me to test the application on any virtual android device. I have been emulating the apk file on the Pixel 2 and 3a as well as the Nexus 5 & 6 with android 9.0 and 10.0 to test. Android Studio made the integration with google maps very easy especially because there were many built in functions made specifically for google maps.

2.0 Features Added This Semester

- Stop Function
- Scheduling ability
    - Days of the week/time
- Default lawn
- Battery status

2.1 Main Activity Screen

Allows user to login with any google account

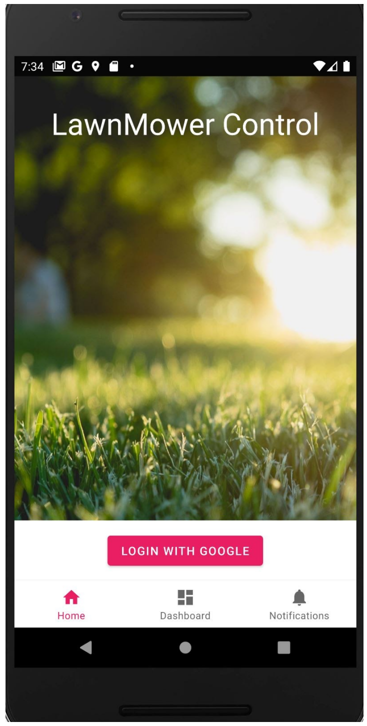


Figure 1: Home Screen Prior to Login

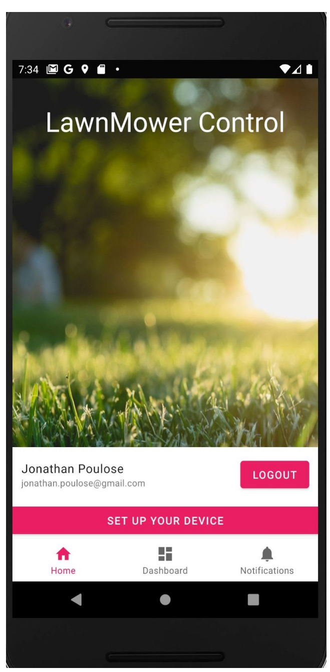


Figure 2: Home Screen When Logged in

2.2 Setup Activity

Allows user to add multiple lawns and shows lawnmower information

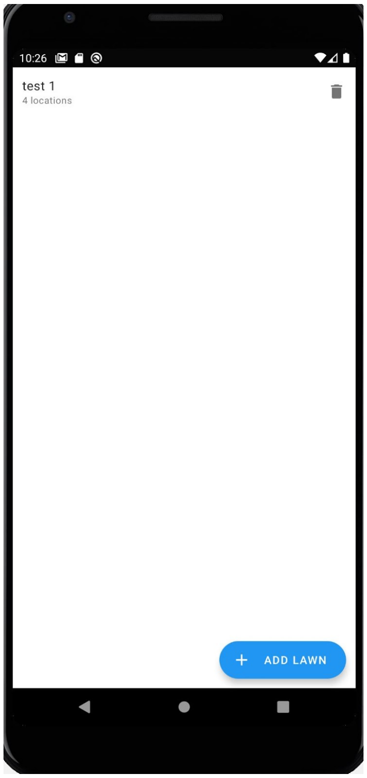


Figure 3: Add Multiple Lawns

2.2.1 Default Lawn

Allows users to select default lawn (lawn that will be cutting in real time). This part of the application was crucial because this allowed the ESP32 to get only the coordinates from the selected lawn. The ESP32 code could only get the coordinates from a certain path in firebase so I had to create a “default lawn” section that would change once it was selected in the application.

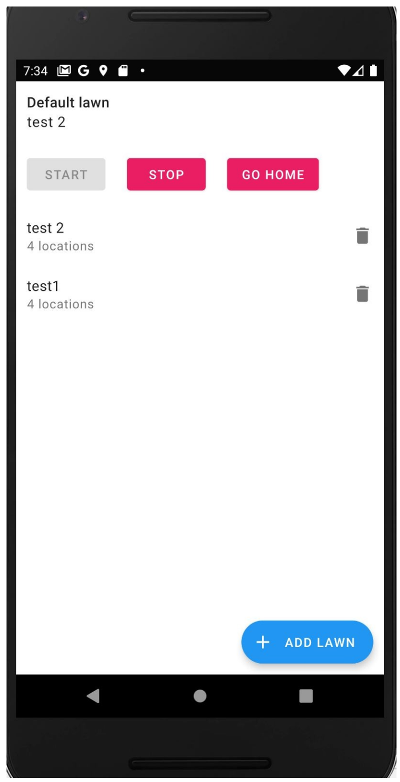


Figure 4: Default Lawn

2.2.2 Start/Stop Changing

Start and Stop gets Greyed out when one of the buttons is clicked

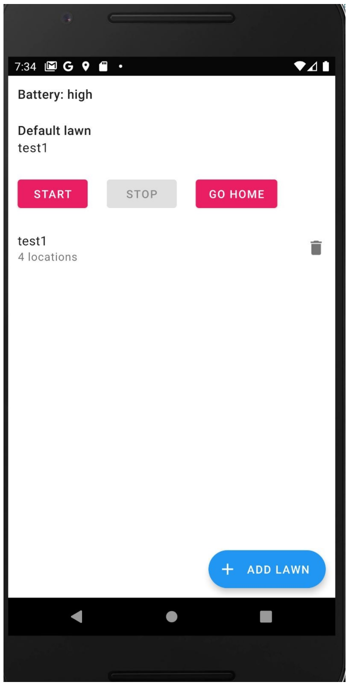


Figure 5: Start/Stop

2.2.3 Battery Level

Battery Level is shown as high or low

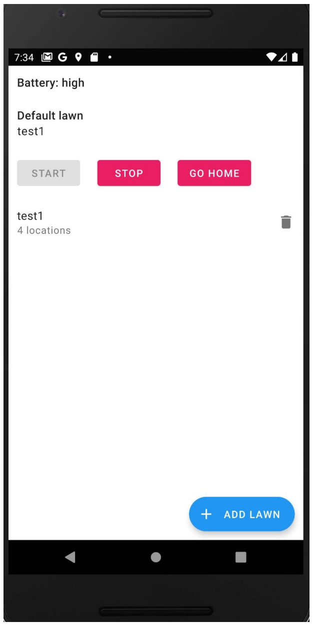


Figure 6: Battery level

2.3 LawnActivity

Allows users to use current location, set the path of the lawn, and name the lawn. Each marker placed starts from 1 to desired amount. Can add unlimited coordinates

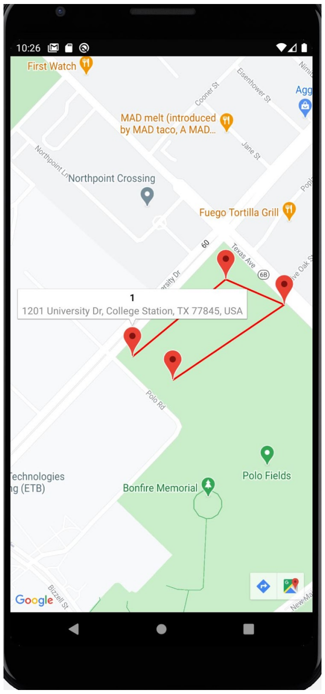


Figure 7: 4 coordinates

2.3.1 Lawn Name

Allows user to add lawn name and unlimited number of coordinates

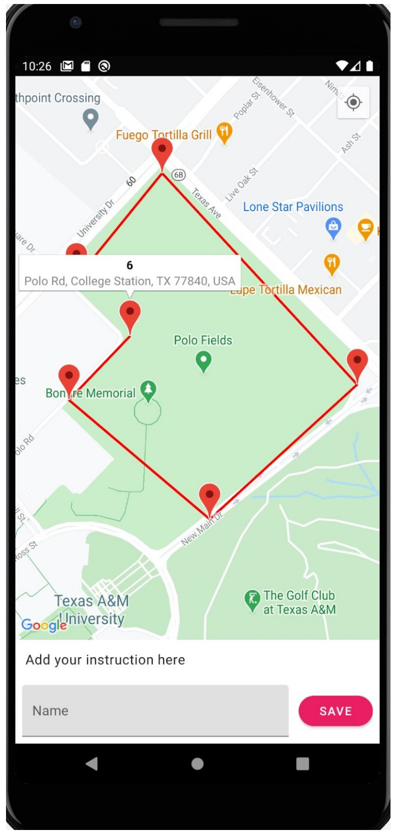


Figure 8: 6 coordinates

2.3.2 Scheduling

Allows user to schedule the lawn mower to go at a certain time and day of the week

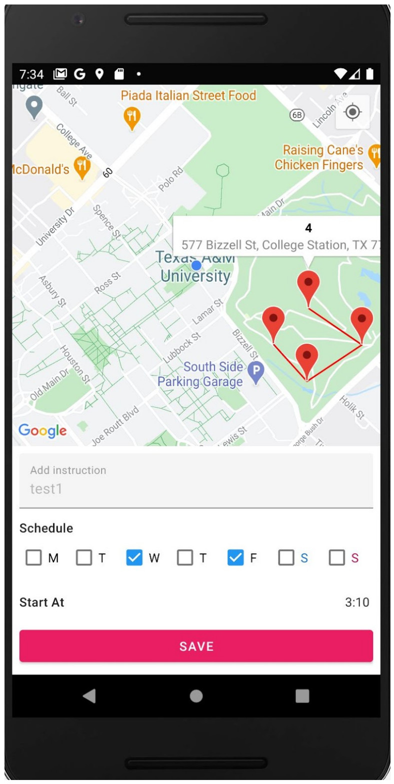


Figure 9: Days of the week

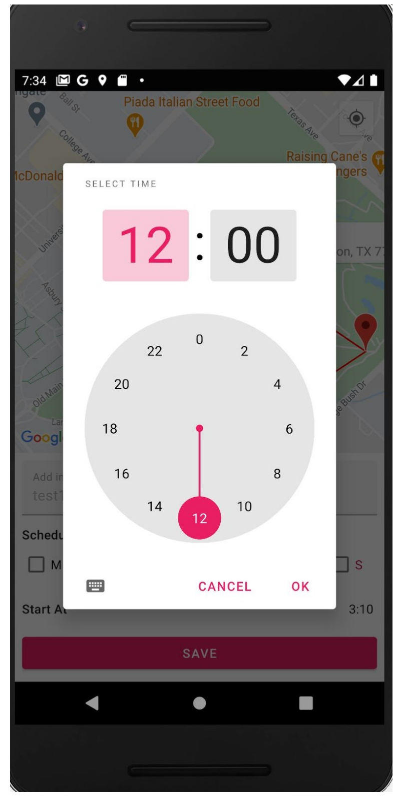


Figure 10: Time

3 Firebase

Using the Realtime Database in Google Firebase platform, the latitude and longitude coordinates are constantly updated as soon as a user signs in and saves a “lawn”. The child hierarchy goes in order from Application Name>user ID>lawn name>marker number>latitude and longitude. When connecting the server to the WiFi module, the coordinates have to be in the same format as whatever the MCU can read it in. Once the application is complete all information such as usage statistics and navigational data will be transferred through the wifi module attached to the MCU and the Google Firebase Database.

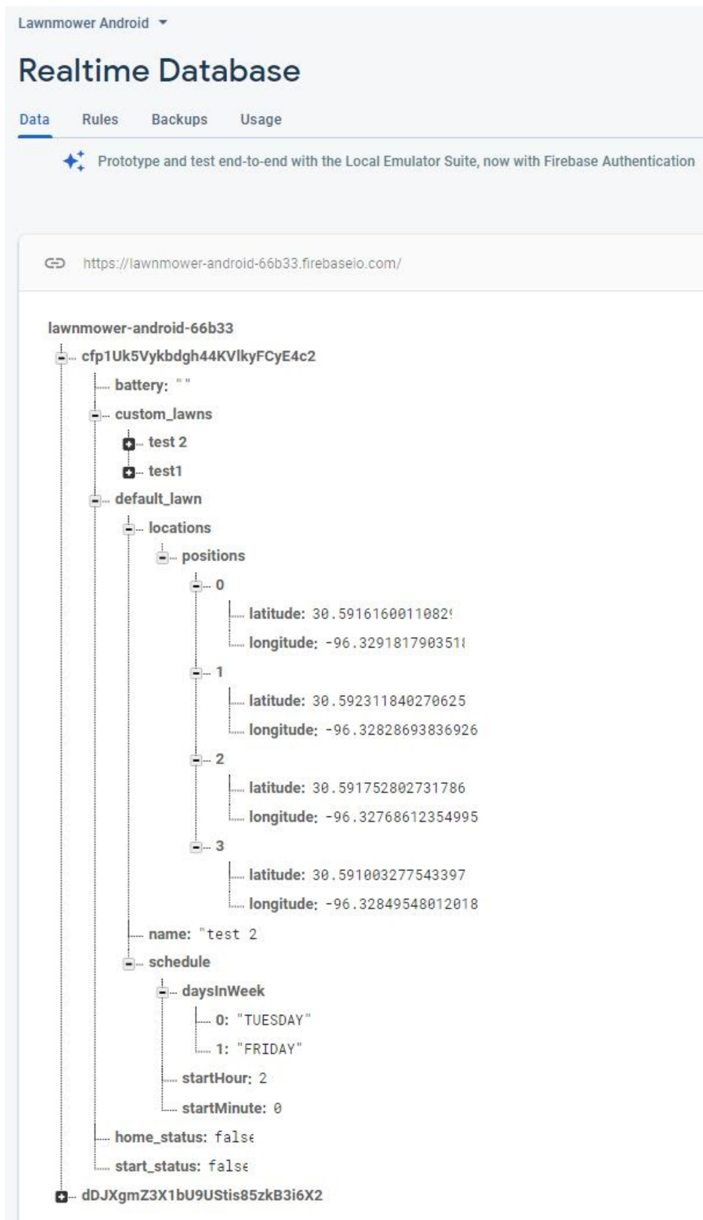


Figure 11: Full Firebase Server for 1 user

3.1 Google Cloud Platform

The Application credentials types that will be used are API keys & OAuth 2.0 client credentials. The only API key used in the code is the Google Map SDK API key to allow users to use google maps. All the other credentials were autocreated. Google Firebase auto created an android and browser key to allow the information to get updated in the realtime database. Google Services auto created an android client and web client to allow users to sign in to the app using a google account.

API Keys

Name	Creation date ↓	Restrictions	Key
Google Map SDK	Nov 21, 2020	None	AIzaSyBsW1...cNXQLJsSV8
Android key (auto created by Firebase)	Nov 21, 2020	None	AIzaSyAHc5...HtLqJpq91c
Browser key (auto created by Firebase)	Nov 21, 2020	None	AIzaSyAnLF...QMmaLOfTTE

OAuth 2.0 Client IDs

Name	Creation date ↓	Type	Client ID
Web client 2	Nov 21, 2020	Web application	287950388755-ap9s...
Android client for lawnmower.app (auto created by Google Service)	Nov 21, 2020	Android	287950388755-ts34...
Web client (auto created by Google Service)	Nov 21, 2020	Web application	287950388755-p41k...

Figure 12: Screenshot of API credentials created

4 ESP32

My first versions of the code were for two seperate ESP32s, WiFi and Navigation. In the beginning of the semester, we decided that I would work on the WiFi ESP32 and Josh would work on the Navigation ESP32. I ended up writing code for both so that they could communicate with each other and send variables back and forth.

I tested both of the old files/ESPs without the navigation code to see if they would execute all functions and communicate effectively and there seemed to be no issue. You can see that coordinates successfully are being sent from one ESP to the other in the figure below

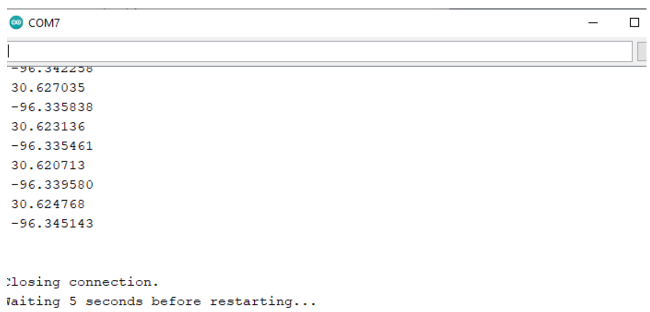


Figure 13: Successful communication between the two ESP32s (Serial Monitor from Nav ESP)

4.1 WiFi ESP32

For the WiFi ESP, the functions were:

-Connect to Wifi for Firebase Server & Connects to Nav ESP
-Receive coordinates & start_status from Firebase Server
-Recieve battery information/statistics from Nav ESP
-Send battery information/statistics to firebase server
-Send coordinates & start_status to NAV ESP

In the figure below you can see the variables being sent and received as well as connecting to my routers network as well as the the other ESPs network

WiFi_MCU

```
//#ifdef ESP32
#include <WiFi.h>
#include <HTTPClient.h>
#include <FirebaseESP32.h>
//#include <FirebaseJson.h>

//Txt files
#include <SPIFFS.h>
#include "FS.h"

#include <Arduino.h>

// Set web server port number to 80 - SoftAP
WiFiServer server(80);

// ESP32 wifi network connection data
#define ssidEspServer "ESP32Server"
#define PassEspServer "87654321"

// Connection data to the user's local wifi network
#define ssidWiFiLocalSet "Poulose"
#define passwordSenhaWiFiLocal "2147707702"

//Data for connection to the "Firebase" database
#define FIREBASE_HOST "https://lawnmower-android-66b33.firebaseio.com"
#define FIREBASE_AUTH "4YOEWZHxqEOpZokJi5bhdcMpuIy15Qwgh45MKTO2"


//Define FirebaseESP8266 data object for data sending and receiving
FirebaseData fbdo;

//Variables
String receiveCar; // Car Received Data
String sendReceive; // Selection of active Tasks
String firebaseReceive; // Data Received from Firebase
String strJsonFirebase; // Data Json Received from Firebase
String strJsonClient = "{\"battery\":\" \",\"start_status\":\" \",\"latitude\":\" \",\"longitude\":\" \",}"; // Data Json Received from client

```

Figure 14: Snippet of WiFi MCU Code

4.2 Navigation ESP32

For the Nav_MCU, the functions were:
-Create WiFi Network so WiFi MCU can connect to it
-Send battery information/statistics to WiFi ESP
-Recieve coordinates & start_status from WiFi ESP

Below you can see the variables being sent and received to the Navigation ESP32

NavMCUwithoutNav

```
#include <WiFi.h>
#include <WiFiMulti.h>

//Txt files
#include <SPIFFS.h>
#include "FS.h"

WiFiMulti WiFiMulti;
String receiveData;
String battery ; // Percentage value of battery
String start_status; // Car status
String latitude; // Current car latitude
String longitude; // Current car longitude
String _0_latitude; // Orientation coordinates
String _0_longitude; // Orientation coordinates
String _1_latitude; // Orientation coordinates
String _1_longitude; // Orientation coordinates
String _2_latitude; // Orientation coordinates
String _2_longitude; // Orientation coordinates
String _3_latitude; // Orientation coordinates
String _3_longitude; // Orientation coordinates

SemaphoreHandle_t myMutex; // Semaphore to allow access to variable by different tasks at different times

// Method that allows to use "Serial.print ()" in different tasks
String str_global = "";
void printGlobal(String str) {
  xSemaphoreTake(myMutex, portMAX_DELAY);
  str_global = str;
  Serial.println(str_global);
  xSemaphoreGive(myMutex);
}

// -------------------------------------------- //-----------------------------------------//

// Method of creating and reading files;
// Start: Create filess
void createFiles(String _file, String content) {
  //
  bool createFile = SPIFFS.exists("/" + _file + ".txt");
  if (createFile) {
    File file = SPIFFS.open("/" + _file + ".txt", "r");
    if (!file) {
      exit(0);
    }
    int s = file.size();
```

Figure 15: Snippet of Nav MCU Code

4.3 Problems

Once I added Josh's old navigation code, the variables would send to each other but the navigation was not working. There were many errors and bugs that led to a rebooting issue with the Navigation ESP.

```
receiveData :[{"start_status":"   ","_0_latitude":" 30.621404 ","_0_longitude":" -96.334650 ","_1_latitude":" 30.622638 ","_1_longitude":" -96.335838 ","_
receiveData :[{"start_status":"   ","_0_latitude":" 30.621404 ","_0_longitude":" -96.334650 ","_1_latitude":" 30.622638 ","_1_longitude":" -96.335838 ","_


Waiting for WiFi...
WiFi connected
IP address:
192.168.4.2
30.6214
 30.621404
 -96.334650
/home/runner/work/esp32-arduino-lib-builder/esp32-arduino-lib-builder/esp-idf/components/freertos/queue.c:1442 (xQueueGenericReceive)- assert failed!
abort() was called at PC 0x40088869 on core 0

Backtrace: 0x4008c434:0x3ffcfa30 0x4008c665:0x3ffcfa50 0x40088869:0x3ffcfa70 0x400d6023:0x3ffcfab0 0x400d1a32:0x3ffcfad0 0x40088b7d:0x3ffcfb60

Rebooting...
ets Jun  8 2016 00:22:57

rst:0xc (SW_CPU_RESET),boot:0x13 (SPI_FAST_FLASH_BOOT)
configsip: 0, SPIWP:0xee
clk_drv:0x00,q_drv:0x00,d_drv:0x00,cs0_drv:0x00,hd_drv:0x00,wp_drv:0x00
mode:DIO, clock div:1
load:0x3fff0018,len:4
load:0x3fff001c,len:1044
load:0x40078000,len:8896
load:0x40080400,len:5816
entry 0x400806ac
receiveData :[{"start_status":"   ","_0_latitude":" 30.621404 ","_0_longitude":" -96.334650 ","_1_latitude":" 30.622638 ","_1_longitude":" -96.335838 ","_
receiveData :[{"start_status":"   ","_0_latitude":" 30.621404 ","_0_longitude":" -96.334650 ","_1_latitude":" 30.622638 ","_1_longitude":" -96.335838 ","_


Waiting for WiFi...
WiFi connected
IP address:
192.168.4.2
30.6214
 30.621404
 -96.334650
/home/runner/work/esp32-arduino-lib-builder/esp32-arduino-lib-builder/esp-idf/components/freertos/queue.c:1442 (xQueueGenericReceive)- assert failed!
abort() was called at PC 0x40088869 on core 0

Backtrace: 0x4008c434:0x3ffcf160 0x4008c665:0x3ffcf180 0x40088869:0x3ffcf1a0 0x400d6023:0x3ffcf1e0 0x400d1a32:0x3ffcf200 0x40088b7d:0x3ffcf290

Rebooting...
ets Jun  8 2016 00:22:57
```

Figure 16: Rebooting Issue with Josh’s code

4.4 Fixes/Improvements

To fix this problem, Max ended up rewriting the Navigation Code and I decided to combine all the code into one ESP to have one less step of the line of communication with the variables. This fixed the problem.

The functions for the final code:
-Connects to Wifi for Firebase Server
-Receives coordinates,start_status from Firebase Server in realtime
-Sends battery information/statistics to Firebase Server in realtime
-Navigates the Mower (explained in detail above in navigation section)

****Added to new combined code****
-Converts 4 coordinates into Distances which you can see in the figure below

```
Set string data success
Local-Control
start_status:
0
_0_latitude:
30.591616
_0_longitude:
-96.329182
Local-Control
_1_latitude:
30.592312
_1_longitude:
-96.328287
_2_latitude:
30.591753
_2_longitude:
-96.327686
Local-Control
_3_latitude:
30.591003
_3_longitude:
-96.328495
{"battery":" ","start_status":"0","_0_latitude":"30.591616","_0_longitude":"-96.329182","_1_latitude":"30.592312","_1_longitude":"-96.328287","_2_l
Local-Control

Distance to destination(M): 0.000115


Distance to destination(M): 0.000085


Distance to destination(M): 0.000114


Distance to destination(M): 0.000095
```

Figure 17: Shown Distances Calculated from the 4 coordinates (Serial Monitor)

4.5 Summary for ESP32 Code

The ESP32 was set up in STA Mode to connect to the WiFi network. In the final code/demo, we ended up using my iphone as a hotspot to connect to. In the code you can see the network
name as "iPhone" and the password as "jonathan". By connecting to WiFi, I were able to to receive the start_status (Start & Stop) boolean and the longitude and latitude
from the coordinates selected in the App in realtime as well as send battery status/statistics to the server in realtime. The ESP checked the the server for these variables every
110 ms. The hardest part was finding the correct format from the Firebase Server & JSN file to display all of these variables correctly which is a lot of my code.

I added a while loop to the navigation code so that when start_status is 0, the mower will stop and when it is not, it will start.

I also added code to convert the coordinates (8 total variables) longitude and latitude into distances for the outside legs of the navigation using the haversine formula.

The WiFi part of the code worked fine without any issues.

5 Conclusion for User Interface/Server/WiFi

I am very satisfied with all the work I have put into this project. I think I did all I could and to the best of my ability. Although the lawnmower did not have hardware to check for battery level, I still added code to both ESP32s and UI that would allow this information to be passed through to the server and to the mobile application. I successfully created the user interface which had all of the following functions:

- Allows user to login through Google Account
  - as many google accounts as you want
  - saves information for each account
- Allows user to add multiple lawns using Google Maps API
  - Select Default Lawn
  - Select current location
  - Unlimited markers/corners for each lawn
  - records coordinates for each marker and sends to server
  - Numbered each corner from one to desired amount
  - Add lawn name
- Scheduling
  - Add time
  - Days of the week
- Control of Lawnmower
  - Start
  - Stop
  - Go Home
- Lawnmower status
  - Battery level
  - Other statistics
- Uploads all information to Firebase Server

6 Moving on

I was honestly scared to code my first mobile application because I had no idea how. After doing this project, I know that I will be coding more applications in the future which I am very excited about. I am glad I went through this so it will be easier for me in the future. Thanks and Gig’em.