Autonomous Lawnmower

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Concept of Operations

REVISION – 3
29 April 2021

Concept of Operations
for
Autonomous Lawnmower

Team 30

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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.

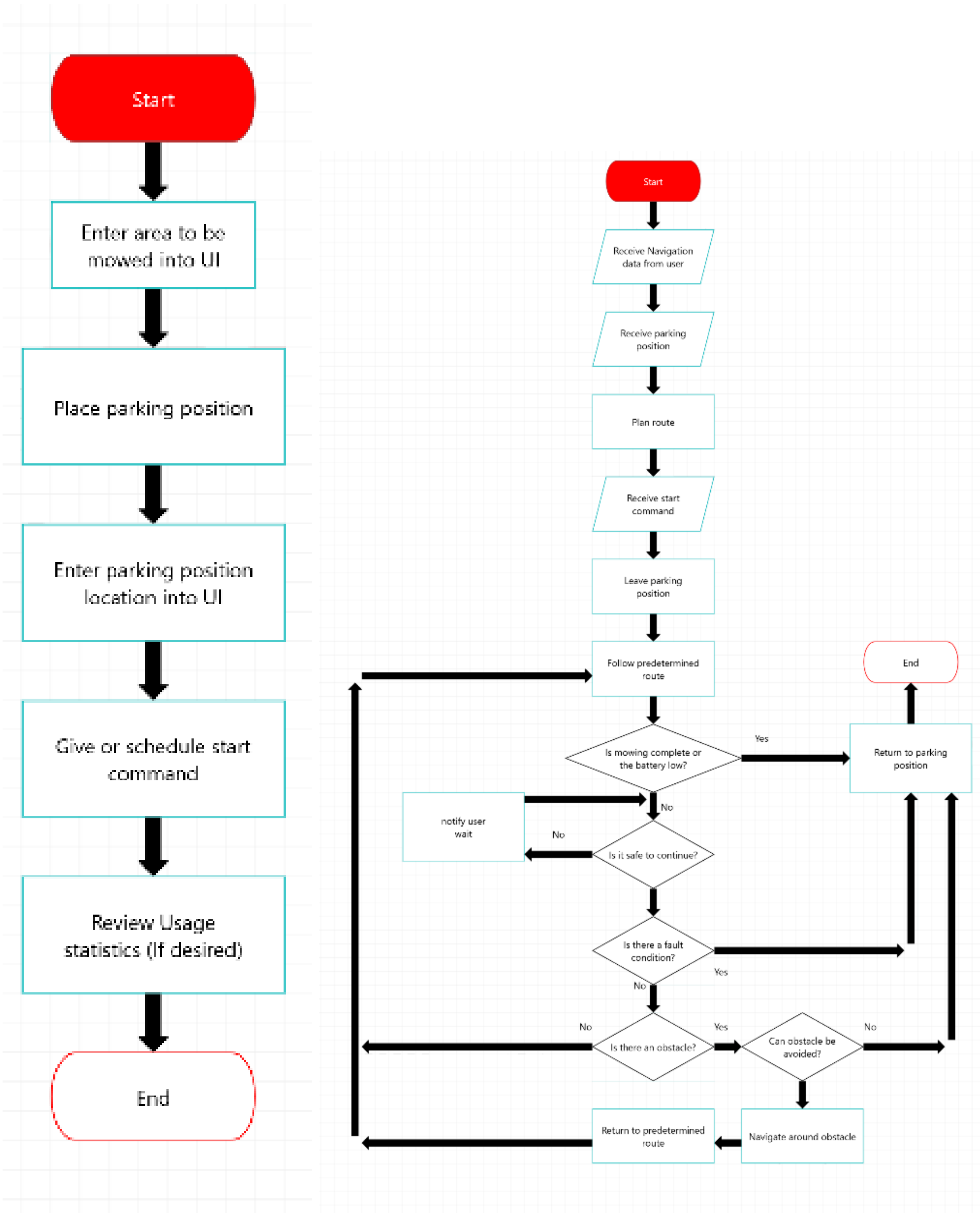

Figure 1: Overview of User and System Actions

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

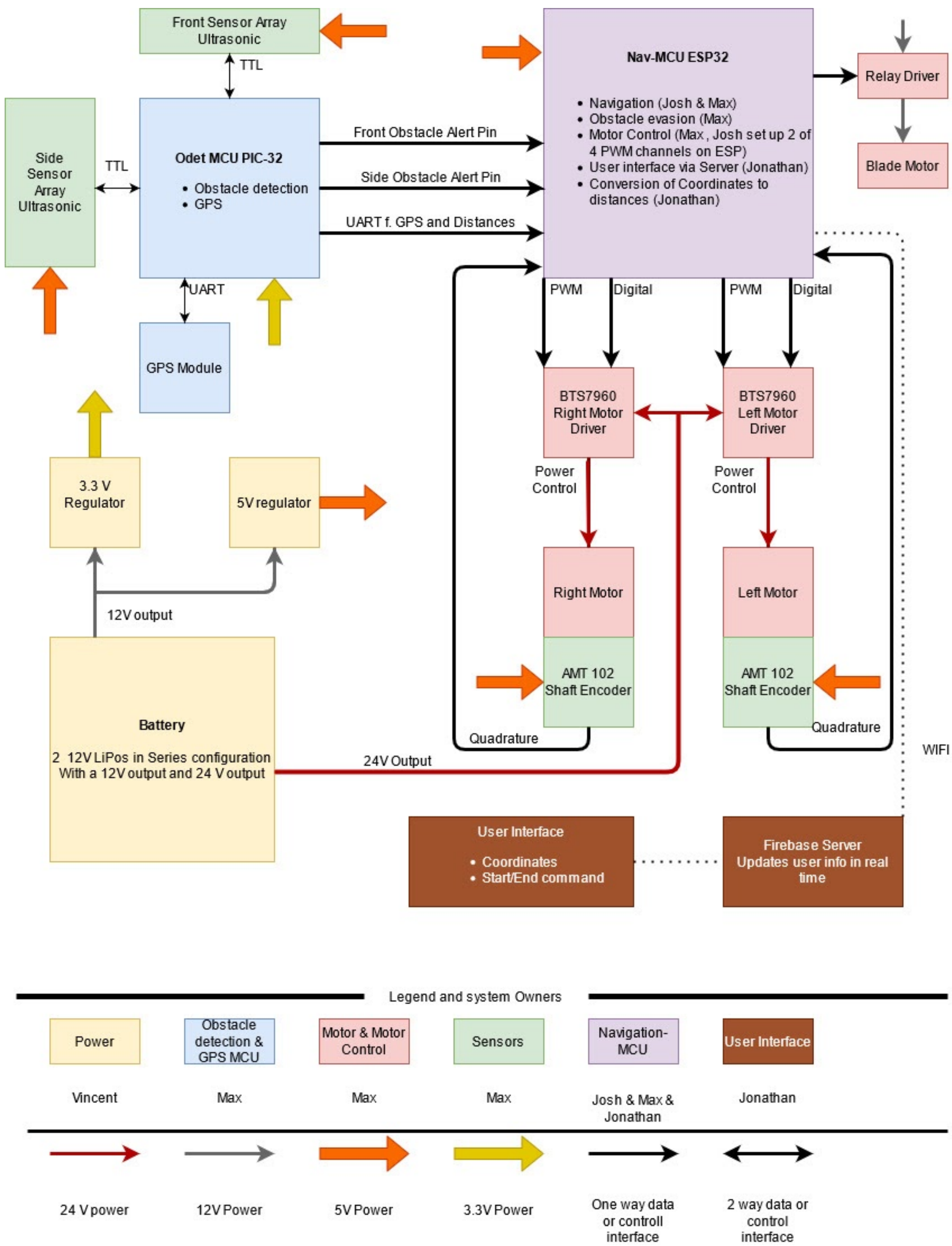

Figure 2: High Level Block Diagram for Signal Flow

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.lThis 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.