Autonomous Lawnmower

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FUNCTIONAL SYSTEM REQUIREMENTS

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Functional System Requirements
FOR
Autonomous Lawnmower

Team 30

Approved by:

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Team Member Date

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Prof. S. Kalafatis Date

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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

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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.

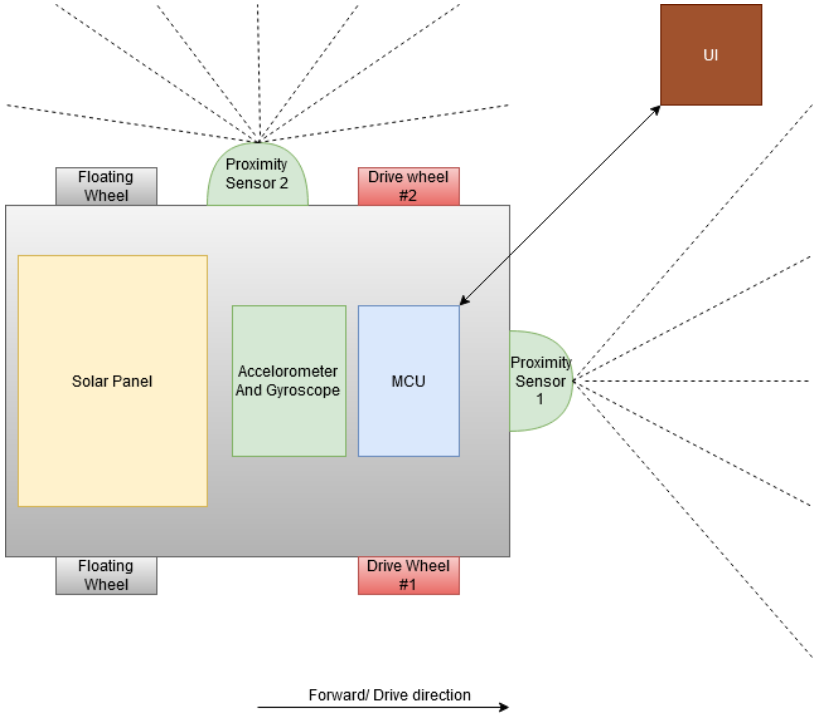

Figure 1: Autonomous Lawnmower Layout, Top View, case omitted for clarity.

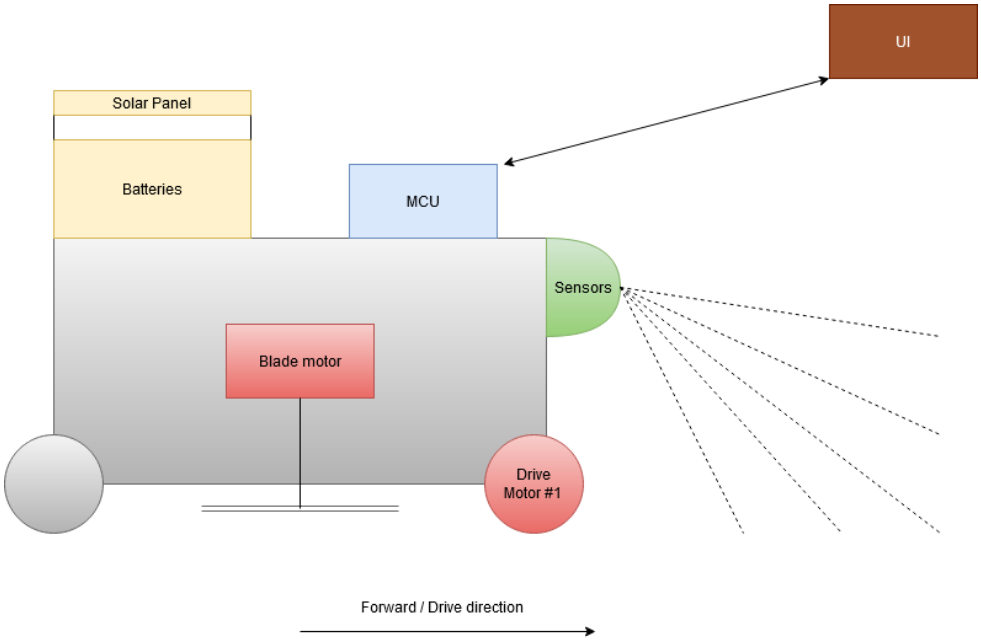

Figure 2: Autonomous Lawnmower Layout, Side View, case omitted for clarity. Final design iterations may place the solar panel elsewhere.

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.

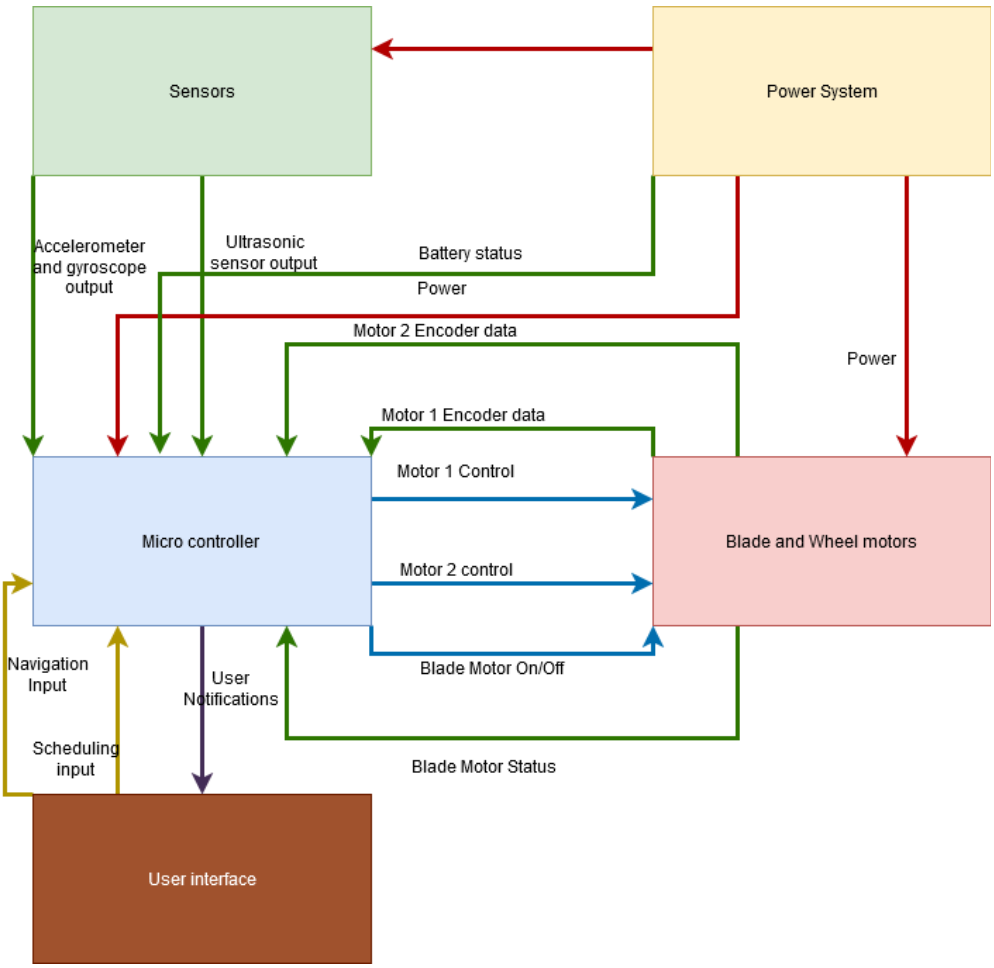

Figure 3: Autonomous Lawnmower Block Diagram

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.