Maple Robotics

February 21, 2021

Dr. Craig Scratchley
Dr. Shervin Jannesar
School of Engineering Science
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Burnaby, British Columbia
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Re: ENSC 405W/440 Requirements Specification for Lawnsweeper Mark I

Dear Dr. Scratchley and Dr. Jannesar,

The attached document comprises the Requirements Specification document for Maple Robotics' Lawnsweeper Mark I. The Lawnsweeper Mark I is an autonomous, robot-based collection system designed for fallen leaf collection in residential yards. By combining an efficient collection system, various sensor feedback, and an intelligent path-finding algorithm, our objective is to efficiently collect fallen leaves from a residential yard to ease the laborious task of raking leaves.

The purpose of the attached Requirements Specification document is to highlight the various product stages required to bring the Lawnsweeper Mark I to fruition. Specifically, a system overview, various requirements, engineering, safety and sustainability standards for the respective product stages are discussed in detail.

The Maple Robotics team is composed of an interdisciplinary team of computer engineers Daimon Gill, Haoming (Mark) Jing, Zi Zhou (John) Qu, Johnny Tsai, and Bin Xiong and Systems Engineer Ziniu Chen. Our team provides diversified experience in the following fields: process automation and controls, electromechanical and electronics engineering, 3D printing, web and mobile application development, and real-time systems programming.

If any questions regarding the Lawnsweeper Mark I arise, please contact Chief Communications Officer, Daimon Gill, at daimong@sfu.ca. On behalf of the Maple Robotics team, we thank you for reviewing our Requirements Specification document.

Gratefully,

D Gill

Daimon Gill
Chief Communication Officer
Maple Robotics

Maple Robotics

Requirements Specification

Lawnsweeper Mark I

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Abstract

Lawnsweeper Mark I is an autonomous leaf collection system which automates the normally tedious and time-consuming task of raking and collecting leaves for yard waste disposal. By navigating a residential yard in an efficient manner, avoiding obstacles, and collecting organic matter, Lawnsweeper Mark I aims to decrease time spent on the laborious, manual task of collecting fallen leaves. Lawnsweeper Mark I is a robotic system that is composed of the following subsystems: the robotics and leaf collection systems, various proximity and location sensors, and a software system to implement intelligent pathfinding algorithms.

From this document, the reader will be able to obtain a full understanding of the higher-level system design, system components and their functional and non-functional requirements of the Lawnsweeper Mark I. Additionally, aspects of engineering standards, responsibilities, safety, and sustainability of this project are outlined to provide an overview for practices to be followed by the engineers of Maple Robotics. This document will conclude by discussing the planned deliverables for the proof of concept, alpha, beta and final stages which are going to be showcased throughout ENSC 405W and ENSC 440.

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Glossary

ABS	Acrylonitrile Butadiene Styrene
CSA	Canadian Standards Association
GPS	Global Positioning System
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
PLA	Polylactic Acid, a common renewable material used for 3D printing
RF	Radio Frequency
UWB	Ultra Wide Band
VOC	Volatile Organic Compound

1. Introduction

1.1. Background

The lawn has been an essential feature of North American suburbia for more than a century. A well-kept lawn reflects favourably upon the socio-economic status of the homeowner, and can impact property resale values. Many activities go into the maintenance of a lawn: watering, fertilizing, mowing, and weeding, among many others. In the 21-century, most of these activities have been mechanized if not automated, with many special machinery and robots created for lawn care. Today, lawn mowing robots are some of the most advanced home-based robots on the market, utilizing cutting-edge technologies in artificial intelligence and robotics to steer lawn mower machinery towards obsolescence. Despite their high cost of purchase, the lawn mower robot market is expected to reach $1.3 billion in 2020 [1]. Demonstrating a real desire to fully automate aspects of lawn care.

One such aspect of lawn care that has thus far escaped the attention of robotics companies the collection of leaves from the lawn. In many settlements across North America and beyond, it is common to see lawns that are adjacent to deciduous trees, which drop leaves during autumn time and require manual labor to clean up. Municipal governments will even organize special clean-up efforts for roadside fallen leaves on an annual basis. In this application, simply blowing leaves away is not sufficient, as the leaves must be collected into recycle bins for collection by the local garbage disposal service or used in composting.

1.2. Scope

The purpose of this requirement specification document is to mention the concept of design and functional needs of our product. Also, it emphasizes the Engineering Standards with considerations of sustainability and safety for all components of our product.

1.3. Intended Audience

This requirement specification document will be used by Maple Robotics as a guide for all functional requirements of the Lawnsweeper Mark I. The supervising professors Dr. Craig Scratchley, Dr. Shervin Jannesar, Dr. Andrew Rawicz and their associated Teaching Assistants will also participate in design observation, product feedback and provide insight during each stage of development.

1.4. Market and Competition

Our product is designed for lawn owners. The aim of the product is to automatically clean up leaf and dry grass from the lawn. The global lawn sweeper market size is projected to reach $250 million USD by 2025 [2]. Technological advancements to save time, energy, and cost such as the advent of robotic lawn sweepers is expected to open new avenues for industry growth over 2015-2025 [3].

Currently, the most common solution to leaf collection is manual labor. Homeowners use hand tools such as rakes, brushes, or manual push lawn sweepers to gather leaves on the ground, before moving the leaves into recycling bins by hand. On a larger commercial scale, tractor-towed mechanical devices have been made to collect leaves using a harrow-like device.
As such, there exists an unfulfilled niche for a small-scale automated robotic solution to this problem, akin to the Roomba or robot lawn mowers. We at Maple Robotics propose the Lawnsweeper Mark I as the labour-saving solution to the problem of lawn-based leaf collection: a lawnmower-sized, highly-automated robot, capable of sweeping up and collecting fallen leaves and other small organic debris from lawns. It can navigate around typical lawn terrain and obstacles using pathfinding AI and a sensor suite, and can be controlled via a mobile application.

1.5. Requirement Classification

For consistency purposes, all requirements of this document will be written and follow the convention below :

Req {Domain Abbreviation}.{Requirement Number} - {Stage of Production}

The requirement classification of different stages is shown in the table below:

Table 1.1: The Convention Code of each Stage

Stage of Production	**Code**
Proof of Concept (Alpha)	A
Prototype (Beta)	B
Final Product	F

The Proof of Concept stage is an essential requirement that should be achieved by the end of ENSC 405W. The Prototype stage should be met by the end of ENSC 440. For the Final Product stage, functionalities and any additional requirements to be satisfied before entering the market are defined.

Table 1.2: Requirement Domain Abbreviation

Requirement Domain	**Abbreviation**
General	GE
Leaf Collection System	LC
Robotics System	RO
Sensor System	SE
Navigational System	NV
Boundary Detection System	BD
Mobile Application	MA
Obstacle Avoidance	OA
Power Supply	PS
Sustainability	SU
Safety	SA

2. System Overview

The Lawnsweeper Mark I is composed of hardware and software systems, each being composed of various subsystems to accomplish the tasks of navigating a residential lawn in an efficient manner while also collecting fallen leaves. **Figure 2.1** provides a system overview diagram of the various subsystems and their respective interactions.

The software system is composed of three subsystems: firmware, movement, and user controls. The firmware directly controls the hardware of the robotics and collection subsystems, mainly pertaining to various movements of the rover while also controlling the collection system. The movement subsystem processes data retrieved from the sensor subsystem and makes decisions regarding movement, and relays these decisions to the firmware to respond to any external environmental factors. User interaction with the system such as scheduling and observation of system status is done via the mobile application of the user control subsystem.

The hardware system is composed of three subsystems: the robotics, collection, and sensors subsystems. The robotics subsystem is composed of the rover, which provides movement for the entire system, containing motors and wheels, housing the collection subsystem, as well as housing the rest of the system’s internal components. The collection subsystem consists of the leaf collection system, who’s functionality is to sweep fallen leaves from the ground and collect them in a durable, reusable polyethylene bag to be emptied afterwards. The sensor subsystem collects data from the external environment including obstacle location and the system's current location, which is processed by the movement software subsystem, and also contains components to enable communication with the mobile application as a part of the user control software subsystem.

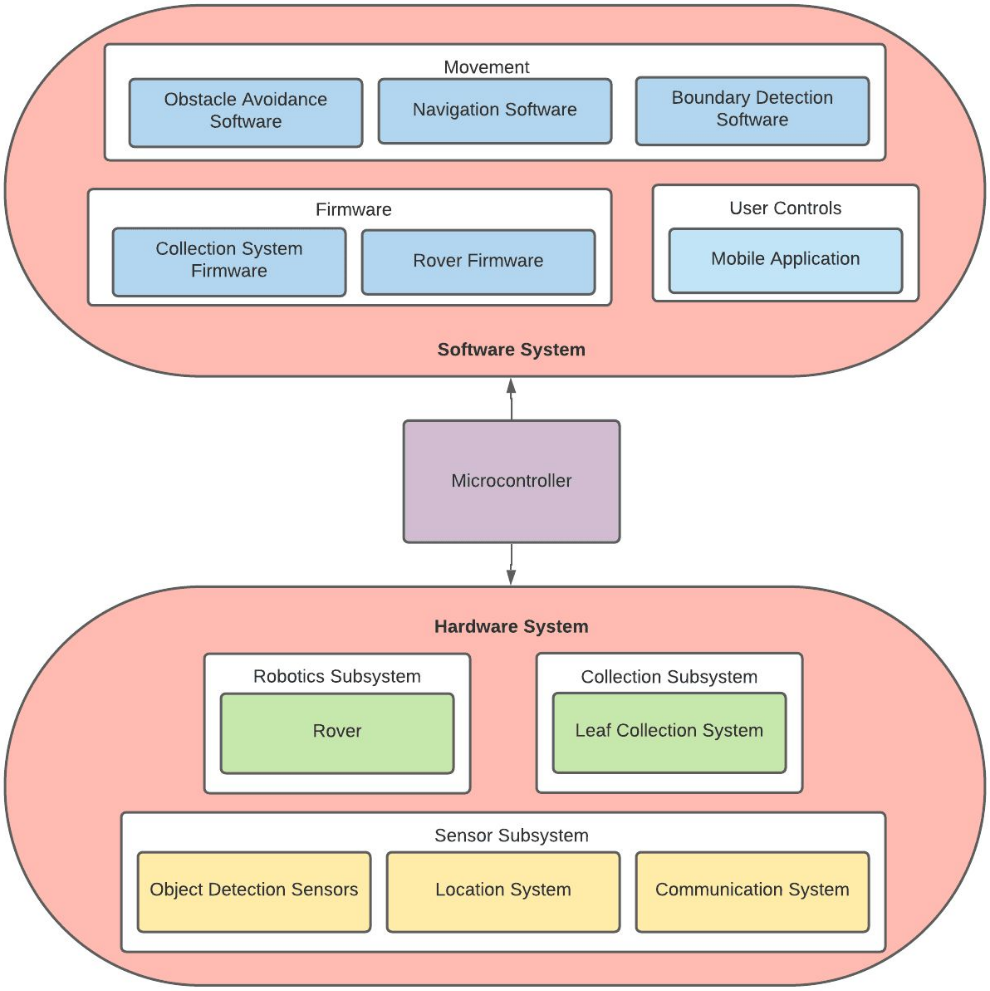

Figure 2.1: System Overview Diagram

A color-coded diagram explaining the relationship between the subsystems of the Lawnsweeper Mark I through the centralised microcontroller. Software related systems are highlighted in blue, robotic related systems in green, and sensor systems in yellow.

3. General Requirements

The rudimentary purpose of the Lawnsweeper Mark I is to efficiently navigate a residential yard and collect fallen leaves. Consequently, to successfully accomplish this task the system is composed of a series of interdependent subsystems as described in the system overview. Sections 3 to 6 further describe each of these subsystems by highlighting the requirements associated with each. Moreover, the product is split into three phases of development: the proof of concept (Alpha) phase, the prototype (Beta) phase, and the final product. Section 3 provides a detailed breakdown of the general requirements of each phase of development.

Table 3.1: General Requirements

Req GE.1 - A	Lawnsweeper Mark I shall operate on a battery powered system.
Req GE.2 - A	Lawnsweeper Mark I must collect 80% of leaves placed in front of the system in a testing environment to ensure adequate leaf collection.
Req GE.3 - A	Lawnsweeper Mark I must be able to traverse flat terrain in a straight path.
Req GE.4 - A	Lawnsweeper Mark I should be an adequate weight to minimize structural and motor strain.
Req GE.5 - A	Lawnsweeper Mark I shall carry up to 20 pounds of organic matters including but not limited to fallen leaves to minimize the number of emptying times.
Req GE.6 - A	Lawnsweeper Mark I should connect to a mobile application which provides basic control functionality regarding movement.
Req GE.7 - B	Lawnsweeper Mark I must be able to navigate a residential yard in an efficient, linear model minimizing 'bouncing' between obstacles using local UWB RF beacons.
Req GE.8 - B	Lawnsweeper Mark I must be able to detect and avoid obstacles in a manner minimizing stray from the original path to minimize power consumption.
Req GE.9 - B	Lawnsweeper Mark I should connect to a mobile application which provides control and scheduling capabilities.
Req GE.10 - F	Lawnsweeper Mark I should include light-weight plastic cover to provide protection for internal electronic components.

To verify functionality of Lawnsweeper Mark I, the robot must be able to satisfy the requirements indicated in **Table 3.1** in a controlled testing environment.

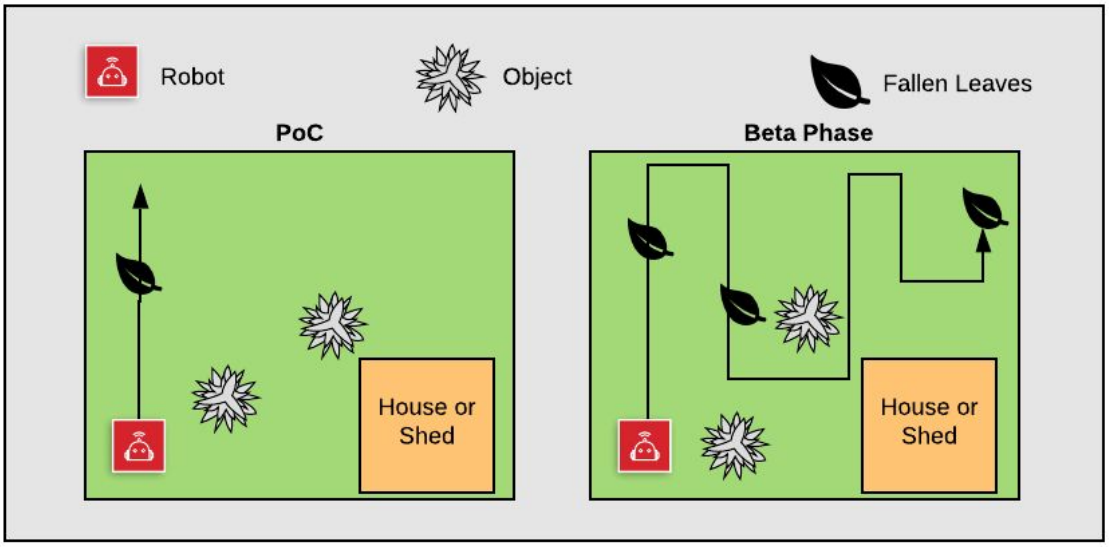

Figure 3.1: PoC vs. Beta Phase Navigation

A figure illustrating the fundamental difference between the PoC phase and the Beta Phase. In the Beta phase, pathfinding and obstacle avoidance algorithms are implemented to navigate a lawn in an efficient manner, minimizing aimless ‘bouncing’ to avoid obstacles.

4. Hardware Requirements

As described in the system overview, the Lawnsweeper Mark I navigates a yard and uses brushes to sweep fallen leaves into a collection bag. Therefore, a robotics system is required to control the leaf collection system and provide real-time information regarding external environmental factors via the sensor system. The sensor system must also contain components to provide the user with various controls of the robot and information regarding the system status via mobile application.

4.1. Leaf Collection System

Table 4.1: Hardware Requirements Leaf Collection System

Req LC.1 - A	This system must receive feedback from the robotics system.
Req LC.2 - A	This system must have adequate ports for power and motor control signals.
Req LC.3 - A	This system must be connected to a 12V power supply to provide adequate power to the system.
Req LC.4 - A	This system must include a reusable, polyethene bag to hold collected leaves.
Req LC.5 - A	This system must include a driven motor rotating brushes to be able to sweep leaves up and collect leaves to the collection bag.

Lawnsweeper Mark I's collection system is a mechanism designed to collect leaves and additional organic matters in the yard. It must have several ports for powering motors and control signals as mentioned in **Req LC.2 - A**. An important requirement of the collection system is outlined in **Req LC.5 - A**, which is a high priority target of the proof of concept.

4.2. Robotics System

Table 4.2: Hardware Requirements Robotics System

Req RO.1 - A	The drive-motors must be able to provide adequate torque for the rover to move at a top speed of 0.8 meter per second on a lawn no greater than 30° slope.
Req RO.2 - A	This system must be connected to a 12V power supply.
Req RO.3 - A	This system must have control of the Leaf Collection System run status.

Req RO.4 - A	This system should have 2 motors to power four wheels to do the movements.
Req RO.5 - A	This system must be controlled by a processor.
Req RO.6 - A	The rover must be able to traverse a well maintained yard with grass no longer than 2 inches.
Req RO.7 - A	Lawnsweeper Mark I should possess a length of two feet. a width of one foot, and a height of one and a half feet.
Req RO.8 - B	This system should avoid obstacles in the yard and redirect its path by taking datas from the sensor system.
Req RO.9 - B	Robot must be able to withstand the weight of the battery and leaf collection system.
Req RO.10 - F	This system should have a waterproof cover to prevent the unexpected weather.

The requirement of Lawnsweeper Mark I's robotic system is to enable Lawnsweeper Mark I to move in the yard, as mentioned in **Req RO.4 - A**, **Req RO.6 - A** , **Req RO.8 - B** and **Req RO.9 - B**. As indicated in **Req RO.5 - A,** a central processor is needed for the operation of Lawnsweeper Mark 1 which controls and ties together the various subsystems.

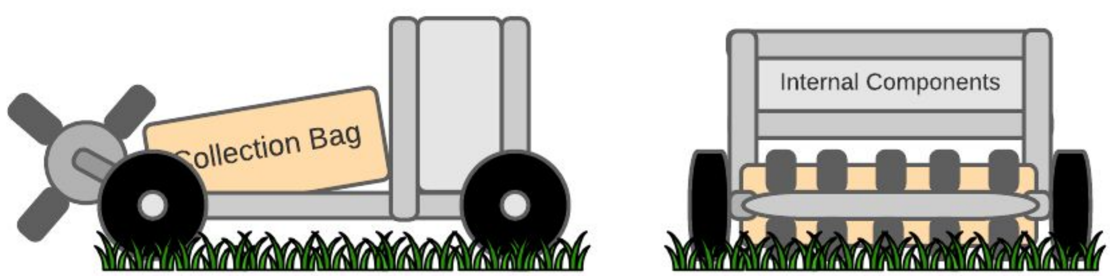

Figure 4.1: Robotics System and Collection System Example
A simple figure illustrating a rudimentary design for The Lawnsweeper Mark I; overall design of the system is subject to change at a later date following creation of the design specification document.

4.3. Sensor System

Table 4.3: Hardware Requirements Sensor System

Req SE.1 - A	This system must include a bluetooth module that has AT mode to communicate with user's phones.
Req SE.2 - A	This system must be powered by battery.
Req SE.3 - B	This system should possess the capability to locate itself via triangulation or trilateration a yard in an efficient manner.
Req SE.4 - B	This system must have proximity sensors to detect obstacles including but not limited to plants, lawn furniture, and tree stumps in the operating path of the robot.
Req SE.5 - B	This system must collect datas from all sensors and send datas to the robotics system in real-time.
Req SE.6 - B	This system should include a sensor to provide information regarding system heading to be used in navigational calculations.
Req SE.7 - F	This system should be able to evaluate the ground's environment to avoid any potential risks.
Req SE.8 - F	This system should be able to evaluate the bag's capacity.
Req SE.9 - F	This system must be reliable over long term usage.
Req SE.10 - F	This system should be water-resistant.

The sensor system is an important part of Lawnsweeper Mark I, as it contains necessary sensors such as proximity sensors, beacon sensors and navigation sensors to get needed surrounding environment information, as outlined in **Req SE.3 - B**, **Req SE.4 - B** and **Req SE.6 - B**. A feature in the alpha phase is the bluetooth module outlined in **Req SE.1 - A**, which allows the user to remote control of the robot in addition to retrieving robot status at any given time.

5. Software Requirements

5.1. Navigational System

Table 5.1: Software requirements for the navigational system

Req NV.1 - A	The robot must be able to move forward in a straight line by correcting any path deviation.
Req NV.2 - B	The robot, if undisturbed by boundaries or obstacles, should move in antiparallel paths, the direction of which are implied by the initial heading of the robot.
Req NV.3 - B	The robot must be able to rotate on the spot according to any specified angle.
Req NV.4 - B	The robot must be able to create a path for itself to cover all of the working area.
Req NV.5 - B	The robot must be able to respond to large impossible slopes by avoiding it as if it were an obstacle.
Req NV.6 - B	The robot must be able to recognize when it is stuck and unable to move.
Req NV.7 - B	The robot should choose the lawn to its left to work on first, whenever presented when untouched lawn on either side.

The navigational system software refers to the controlling logic for robot movement in the absence of boundaries and obstacles. It is responsible for controlling the forward and turning movements by maintaining correct speed and direction. Using these basic functionalities, pathfinding and progress tracking are used to create and monitor the robot's path on the lawn. Any large slopes can escape obstacle sensors, and must be detected by a gyroscope and avoided by the robot. In anycase, if the robot still gets stuck, it must at least be aware of its predicament, and stop futile attempts at movement.

5.2. Boundary Detection System

The boundary system relies on the boundary hardware to create a working area for the robot. The primary purpose of this is to establish an area in which the robot's leaf collection system is operational. The user should take the utmost care to only include areas suitable for the robot within the boundary to minimize chances of the robot getting stuck. Inside the working area, the robot interacts with the boundary in 2 ways: by bouncing off the boundary into an adjacent antiparallel path if the boundary is in front, or moving right along the boundary if it is on the side. The latter case only happens when the chosen direction for the robot's path is parallel to the boundary's orientation.

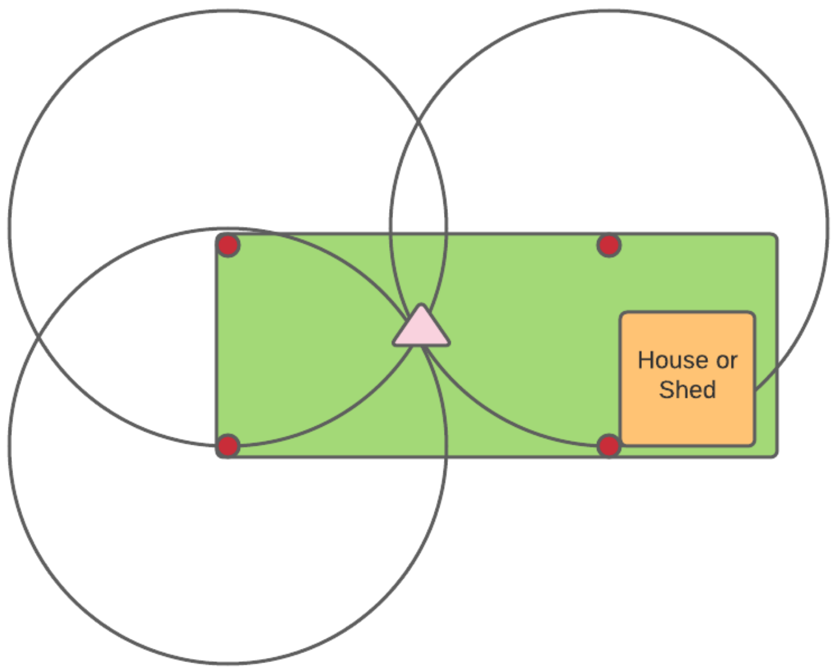

Figure 5.1: Demonstration of Trilateration Process

Beacons (shown as red circles in **Figure 5.1**) will be used alongside the robot (shown as the pink triangle in **Figure 5.1**) for both boundary demarcation and location tracking purposes. The beacons emit a UWB signal which is received by the robot. As long as the robot receives a signal from at least 3 beacons, its location can be uniquely determined and accurately tracked in near-real-time.

Table 5.2: Software requirements for the boundary detection system

Req BD.1 - B	The robot must recognize when it has reached the boundary of the working area.
Req BD.2 - B	The robot, after touching the boundary head on, must move to an adjacent antiparallel path to the right of the current path.
Req BD.3 - B	The robot must be able to work while moving parallel alongside a boundary on its side without prematurely moving away.
Req BD.4 - B	The robot must be able to recognize when it has covered the entire working area.
Req BD.5 - F	The robot must turn off the leaf collection system if it leaves the working area for any reason.
Req BD.6 - F	The robot must check that it is within the working area before starting the leaf collection process.

5.3. Obstacle Avoidance System

Table 5.3: Software requirements for the obstacle avoidance system

Req OA.1 - B	The robot must attempt to avoid obstacles in front of it by treating it as a boundary and move to an adjacent parallel path to the right of the current path, in the opposite direction.
Req OA.2 - B	The robot should consider all obstacles static and not compensate for movement of the obstacle.
Req OA.3 - B	The robot should consider all obstacles to be solidly filled with no semi-enclosed area to be covered.
Req OA.4 - B	The robot must be able to back out of simple dead-ends that does not contain any turns.

The obstacle avoidance system treats obstacles as boundaries and bounce off of their surface, the area behind the obstacle will be taken care of by **Req NV.8 - B** which ensures the robot moves to that area. A consequence of the combination of this logic and **Req BD.2 - B** is **Req OA.3 - B**, which states that if an obstacle contains a hollow area whose opening is not aligned with the chosen direction of travel, then the hollow area is ignored. In practice, we expect these situations to be quite rare.

5.4. Mobile Application

Table 5.4: Software requirements for the mobile application

Req MA.1 - A	The application must be able to pair with the robot via Bluetooth.
Req MA.2 - A	The application must be able to turn the robot on and off.
Req MA.3 - B	The application must be able to display the current battery level and expected remaining working time of the robot.
Req MA.4 - B	The application must alert the user if the robot has been disabled.
Req MA.5 - B	The application must alert the user if the robot is stuck and unable to free itself.
Req MA.6 - F	The application should alert the user if the robot battery charge has reached 20% and 0%.
Req MA.7 - F	The application must alert the user if the collection bag on the robot is nearing capacity.
Req MA.8 - F	The application should be able to display the shape of the working area.
Req MA.9 - F	The application must be able to display the robot's current location within the working area.
Req MA.10 - F	The application must be able to schedule the robot to start working autonomously.
Req MA.11 - F	The application can display current weight of collected leaves as well as total weight of leaves collected during current session.

We are targeting the android operating system for our mobile application due to its low cost of entry, further the application will not require any registration or information gathering from the user. However, it will require permission to access Bluetooth functionality of the smartphone device to communicate with the robot, and local storage for saving settings and statistics.

6. Electrical Requirements

6.1. Power Supply

Table 6.1: Electrical Requirements Power Supply

Req PS.1 - A	The battery must be able to provide enough power for the system to operate for at least 30 minutes with stable 12 Volts output.
Req PS.2 - A	The battery should functionally work between 0℃ to 40℃ - from Spring to Fall as leaf collection is not conducted in the Winter.
Req PS.3 - B	The battery must be rechargeable.
Req PS.4 - F	The battery should have a protection circuit in case of electrical surges that may burn the processor.

The power supply and battery is important as it's the main driving force behind the entire robot. As mentioned in **Req RO.2 - A**, the system requires a battery capable of supplying the system with 12 volts. The battery chosen should provide sufficient power for the Lawnsweeper Mark I to operate under suitable conditions. Consequently, the requirements specified in **Table 6.1** ensure that adequate power is being supplied to the system while also ensuring safe usage by preventing any potential risks associated with power surges.

7. Engineering Standards

To achieve and satisfy the safety, quality, and extensibility for Lawnsweeper Mark I, it is necessary to follow various engineering standards defined by CSA, IEC, ISO and IEEE. The system of Lawnsweeper Mark I is composed of multiple fields such as mechanical systems, electronic devices, software, communication protocols, and hardware to ensure the durability and sustainability of the product. Thus, the relevant standards of these fields should be considered and covered as guidelines to follow during development. The environmental standards also need to be considered, as the design and operation of Lawnsweeper Mark I should not be harmful to the environment system nor any living creatures.

7.1. Mechanical and Safety Standards

Table 7.1: Mechanical Standards

Standards	Description of Standard
ISO 14123-1:2015	Safety of machinery - Reduction of risks to health resulting from hazardous substances emitted by machinery - Part 1: Principles and specifications for machinery manufacturers [4]
ISO 14123-2:2015	Safety of machinery — Reduction of risks to health resulting from hazardous substances emitted by machinery — Part 2: Methodology leading to verification procedures [5]
ISO 12100:2010	Safety of machinery — General principles for design — Risk assessment and risk reduction [6]

While the Lawnsweeper Mark I is designed and manufactured, the engineer will be exposed to the harmful substances produced by materials. For instance, the melting 3D printing materials such as PLA may emit VOC which can irritate nose, eyes, and throat. Sometimes, the engineers may not realize that they breathed the harmful substances until they have symptoms. Thus, these two mechanical standards, ISO 14123-1:2015 and ISO 14123-2:2015, will be utilized to provide the technical guide for designers and manufacturers to verify and identify the harmful sources which have impact for the exposure of engineers. Therefore, to ensure that the engineers can have necessary protection to reduce the risk of hazardous substances ISO 12100:2010 standard should be observed and followed during design and development of the Lawnsweeper Mark I.

7.2. Robotic Standards

Table 7.2: Robotic Standards

Standards	Description of Standard
ISO 9787:2013	Robots and robotic devices — Coordinate systems and motion nomenclatures [7]
ISO 22166-1:2021	Robotics — Modularity for service robots — Part 1: General requirements [8]
ISO 18646-2:2019	Robotics — Performance criteria and related test methods for service robots — Part 2: Navigation [9]

Lawnsweeper Mark I's systems will utilize a navigation system with various movement related systems such as path planning, robot movement, leaves collection, and obstacle detection and avoidance. Thus, formatting and unifying the definition and vocabulary of our terms for the robotic device will have advantages for future developers, designers and potential customers to understand the concept of the product. The ISO 9787:2013 standard will be a good resource to be followed by the Maple Robotics team. To ensure the extensibility and flexibility of Lawnsweeper Mark I, Maple Robotics will refer to ISO 22166-1:2021 to formulate a modular robot framework. The ISO 22166-1:2021 standard represents common requirements to modular designs to aid designers, manufacturers or robot integrators in servicing the robot modules. ISO 18646-2:2019 will be the baseline standard for Maple Robotics to evaluate the navigation performance of the Lawnsweeper Mark I, for example, relating the robots ability to detect and avoid obstacles.

7.3. Electrical Standards

Table 7.3: Electrical Standards

Standards	Description of Standard
CAN/CSA C22.2 NO. 107.2-01	Battery Chargers [10]
CSA C22.2 No. 0.23-15	General requirements for battery-powered appliances [11]
CSA C22.2 No. 100-14	Motors and Generators [12]
CAN/CSA-C22.2 No. 61508-1:17	Functional safety of electrical/electronic/programmable electronic safety related systems — Part 1: General requirements [13]

Maple Robotics will strictly follow CSA C22.2 No. 0.23-15 and CAN/CSA C22.2 NO. 107.2-01 to guarantee the safety of the power supply system and charging system of Lawnsweeper Mark I. Maple Robotics will also reference CSA C22.2 No. 100-14 to correctly install and use electric motors and generators. To ensure the safety and reliability of programmable electronic devices, like the Raspberry Pi, the CAN/CSA-C22.2 No. 61508-1:17 standard will be tracked.

7.4. Wireless Standards

Table 7.4: Wireless Standards

Standards	**Description of Standard**
ISO/IEC 27033-6:2016	Information technology — Security techniques — Network security — Part 6: Securing wireless IP network access [14]
IEEE 802.15.1-2002	Telecommunications and Information Exchange Between Systems - LAN/MAN - Specific Requirements - Part 15: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs) [15]
IEEE C95.7-2005	IEEE Recommended Practice for Radio Frequency Safety Programs, 3 kHz to 300 GHz [16]
IEEE 802.15.4z-2020	Low-Rate Wireless Networks--Amendment 1: Enhanced Ultra Wideband (UWB) Physical Layers (PHYs) and Associated Ranging Techniques [17]

To implement information transfer between mobile smartphones and Lawnsweeper Mark I via Bluetooth, Maple Robotics will use IEEE 802.15.1-2002 as a wireless standard. It emphasizes a standard of low power consumption and low complexity wireless connectivity, and explains the standards of various aspects of Bluetooth technology. Since Lawnsweeper Mark I needs to be connected to the users' private devices, Maple Robotics has the responsibility and obligation to protect users' privacy and their wireless network security. With regard to the users' virtual property protection, we will follow ISO/IEC 27033-6:2016. Lastly, the Lawnsweeper Mark I contains boundary and obstacle detection systems using the technology of UWB RF, resulting in the IEEE C95.7-2005 and IEEE 802.15.4 - 2015 standards being followed.

7.5. Environmental Standards

Table 7.5: Environment Standards

Standards	Description of Standard
IEEE 1680-2009	IEEE Standard for Environmental Assessment of Electronic Products [18]
ISO/TR 14062:2002	Environmental management — Integrating environmental aspects into product design and development [19]

When the Lawnsweeper Mark I is designed and manufactured by Maple Robotics, the chosen electronic materials will be based on the IEEE 1680-2009 standard to reduce the environmental impact. IEEE 1680-2009 also explains the various product standards such as energy conservation and product life cycle. Maple Robotics will refer to ISO/TR 14062:2002, aiming to forge an environmentally-friendly product using recyclable and biodegradable materials during product design, development and manufacturing.

7.6. Software Standards

Table 7.6: Software Standards

Standards	Description of Standard
ISO/IEC/IEEE 15288:2015	Systems and software engineering — System life cycle processes [20]
ISO/IEC/IEEE 24765:2017	International Standard - Systems and software engineering -- Vocabulary [21]

The ISO/IEC/IEEE 15288:2015 standard provides a detailed life cycle model, regarding how to improve the quality of software during the overall development process. Following the ISO/IEC/IEEE 24765:2017 standard and utilizing universal terminology for the software system will help future developers and designers better understand and modify the software of the product.

7.7. Hardware Standards

Table 7.7: Hardware Standards

Standards	Description of Standard
IEEE Std 2700-2017	IEEE Standard for Sensor Performance Parameter Definitions [22]

IEEE Std 2700-2017 standard encompasses various sensors and provides definitions of their performance parameters. Maple Robotics will follow this standard when utilizing sensors on the Lawnsweeper Mark I.

8. Sustainability & Safety Requirements

8.1. Sustainability Requirements

Table 8.1: Sustainability Requirements

Req SU.1 - A	3D printed components shall use Polylactic acid (PLA), which is biodegradable and can be produced from renewable resources.
Req SU.2 - B	The leaf collection bag shall be reusable polyethylene plastic.
Req SU.3 - B	The power supply must be rechargeable.
Req SU.4 - F	The final product must be efficient to minimize power consumption.

In order to maintain sustainability, our product will incorporate environmental sustainability into our designs and follow the Cradle to Cradle development cycle[23]. We aim to use recyclable plastic in the outer-casing of our hardware component and primarily select environmentally friendly components for our product.

8.2. Safety Requirements

Table 8.2: Safety Requirements

Req SA.1 - A	The product should not cause damage to the lawn.
Req SA.2 - B	All electrical components must be fully enclosed.
Req SA.3 - B	Mechanically moving parts must be isolated from the user.
Req SA.4 - B	The protection of power supply must handle extreme sunlight.
Req SA.5 - F	The product must mitigate any potential danger by powering off all electrical components in the event of the system becoming disabled.
Req SA.6 - F	The leaf collection system must be covered by a protective casing.

Our product contains a variety of electrical and mechanical components that may cause various safety issues. In order to ensure the safety of our customers, it is required that potential risks to safety from electrical and moving parts are eliminated. The final product will ensure that the electrical and mechanical components meet our safety requirements.

9. Conclusion

This requirements specification document provides a high level overview of the components and architectural requirements of the various subsystems. To ensure the success of our product requirements must be researched, considered and met both individually and as a whole while adhering to engineering, environmental, sustainability and safety standards.

The summary of the key requirements are as follows:

1. **Hardware**
    - As a robot with many moving parts, the hardware must be adequate to handle the terrain and environment
    - While traversing the terrain, leaves and additional organic matters are simultaneously swept into a collection system
2. **Software**
    - Navigation and pathing of the lawn requires the robot to be semi aware, and detect obstacle then path around them
    - Mobile application will allow for real-time monitoring of the robot's status
3. **Electrical**
    - The power supply must provide sufficient power for the entire system while covering the entirety of the yard
4. **Engineering Standards**
    - Robotics, electrical, wireless, environment, software and hardware standards are researched and will be considered during development to minimize violations to ensure a safe and efficient product
5. **Sustainability & Safety**
    - During development 3D printed objects shall use PLA that is biodegradable and safe to handle
    - Electronic waste will be safely disposed and recycled if applicable

The development of Lawnsweeper Mark I by Maple Robotics will be split over two phases with a potential third stage required for bringing the product to market. The first phase will be the proof of concept phase where a minimal viable product consisting of the core functionalities will be built and tested in a controlled environment before April 2021. The second phase or Beta phase which will be realized by August 2021 is where core components and various subsystems will be integrated and tested in a real-world environment. Throughout each of these phases, continuous development will be made to ensure completion of the project in a timely manner while following standards and requirements as defined throughout the document.

Appendix: Acceptance Test Plan

This acceptance test plan is a checklist that may be used to demonstrate that the Proof of Concept prototype meets the requirements for the ENSC 405W demo.

<table>
<tr><th colspan="3">Test Sheet</th></tr>
<tr><td colspan="2"></td><td>Date:</td></tr>
<tr><th colspan="3">Hardware Requirements</th></tr>
<tr><td colspan="2">1. Leaf Collection System</td><td rowspan="2">Note/Comments:</td></tr>
<tr><td>The leaf collection system is able to collect leaves from the ground into the collection bag.</td><td>❏ Pass
❏ Fail</td></tr>
<tr><td colspan="2">2. Robotic System</td><td rowspan="3">Note/Comments:</td></tr>
<tr><td>The rover is able to drive in a straight line unassisted.</td><td>❏ Pass
❏ Fail</td></tr>
<tr><td>The rover is capable of carrying the load of battery and leaf collection system.</td><td>❏ Pass
❏ Fail</td></tr>
<tr><th colspan="3">Electrical Requirements</th></tr>
<tr><td colspan="2">1. Power Supply</td><td rowspan="2">Note/Comments:</td></tr>
<tr><td>Power supply is able to provide power to the system for at least 30 minutes.</td><td>❏ Pass
❏ Fail</td></tr>
<tr><th colspan="3">Software Requirements</th></tr>
<tr><td colspan="2">1. Mobile Application</td><td rowspan="3">Note/Comments:</td></tr>
<tr><td>The app can relay commands to start and stop the leaf collection system.</td><td>❏ Pass
❏ Fail</td></tr>
<tr><td>The app can relay commands for the rover to move straight and stop.</td><td>❏ Pass
❏ Fail</td></tr>
</table>

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