LifeAutomation

Feb 21, 2021

Dr. Craig Scratchley
School of Engineering Science
Simon Fraser University
Burnaby, BC, V5A 1S6

Re: ENSC 450W/440 Requirements Specification for an Autonomous Waste Cart System

Dear Dr. Scratchley,

Please find the document attached below that outlines the requirements for implementing our smart moving waste cart, Bin Buddy. The purpose of Bin Buddy is to eliminate the need of people having to manually bring out their own garbage, which can be a cumbersome chore. After the easy initial calibration of the boundaries by the homeowners, Bin Buddy will take care of moving the waste carts at scheduled days and times.

The document enclosed lists out the product requirements throughout its development lifecycle, from the proof of concept to the final product. Included in this document are the underlying system requirements, engineering standards, and safety and sustainability outlines for the product Bin Buddy.

Four computer engineering students and one systems engineering student - Aigerim (Ayoka) Omirbekova, Emily Chen, Jeongwon (Julia) Kim, Kira Nishi-Beckingham and Sheetal Puri - make up our amazing LifeAutomation team. Strong with the computer engineering background, our team brings our software experience to the table with a blend of robotics to tinker our project into realization.

Thank you for your time in reviewing our requirements specification. Should there be any questions regarding the document, please reach out to our Chief Operations Officer, Jeongwon (Julia) Kim, via email jka183@sfu.ca or phone at (604) 441-7044.

Sincerely,

Kira Nishi-Beckingham
Chief Executive Officer
LifeAutomation

Enclosed: Requirements Specification for an Autonomous Waste Cart System

Requirements Specification

Bin Buddy

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Abstract

Bin Buddy is an autonomous waste cart moving system that navigates itself and the attached waste cart to and from the waste collection area, following the city's collection schedule. Bringing out the garbage every week is a mundane chore that can be carved out from people's lives, especially for elderly and disabled people. By using ultrasonic sensors and setting boundaries to simplify our problem to a hallway problem, Bin Buddy will be able to detect large obstacles while navigating itself. Since Bin Buddy will be navigating in the vicinity of homes, it must adhere to safety and engineering standards as well as follow the municipal bylaws. To simplify communication with the user, Bin Buddy must also have a user interface. The following document dives into the details of the necessary requirements for our Bin Buddy system to operate in certain cities.

Changelog

Table 0. 1: Changelog

Date	Version	Notes
2021-02-21	1.0.0	Published

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Glossary

Active Hours: Bin Buddy's program should be on, ready to receive instructions and/or operate, for 1 hour each before and after the scheduled window of time.

Calibration: A process that involves a general product setup.

Idle Mode: The state of powering only the fundamentally necessary parts of the product. In other words, an eco-mode to conserve energy following a prolonged inactivity defined as outside of active hours.

Large Obstacles: Cars, waste carts, bikes.

Small Obstacles: Branches and stones less than 3.5 cm in height.

Stuck: The state when product is not able to move around a large obstacle, also, when the product is not standing straight (i.e. tipped over).

1. Introduction

Stand-alone or semi-detached houses follow waste collection schedules that are established individually within each city. To date, most cities adopt a rotating bi-weekly collection schedule for the different carts (organics, recyclables, and garbage) and have by-laws set, imposing narrow time windows to place the carts out [1] [2] [3]. With these restrictions, bringing the waste cart to the front of the driveway becomes a cumbersome task, resulting in a missed collection due to timing, or the wrong cart placed on the curb. Additionally, this repetitive chore can pose a physical challenge and put a strain on the elderly or disabled, especially for those who are living independently.

Over the last decade, many cities have transitioned to an automated waste collection service using mechanical arms, including the top 3 companies in the North American waste market: Waste Management, Republic Services, and Waste Connections [4]. However, bringing the waste cart out for pickup remains a manual task for residents. LifeAutomation believes that Bin Buddy will be a solution to automating the waste collection service. Bin Buddy attaches to existing city waste carts, autonomously wheeling the cart to the front of the driveway and back after being emptied on waste collection days. The smart waste cart system will detect large obstacles, such as cars on the driveway while navigating to its docking location using ultrasonic sensors and preset virtual or physical boundaries tailored to driveways of different lengths. Because waste collection schedules vary by region, users can specify and modify the schedule as desired using Bin Buddy's user-friendly interface. A general overview of the Bin Buddy system is outlined in Figure 1.1.

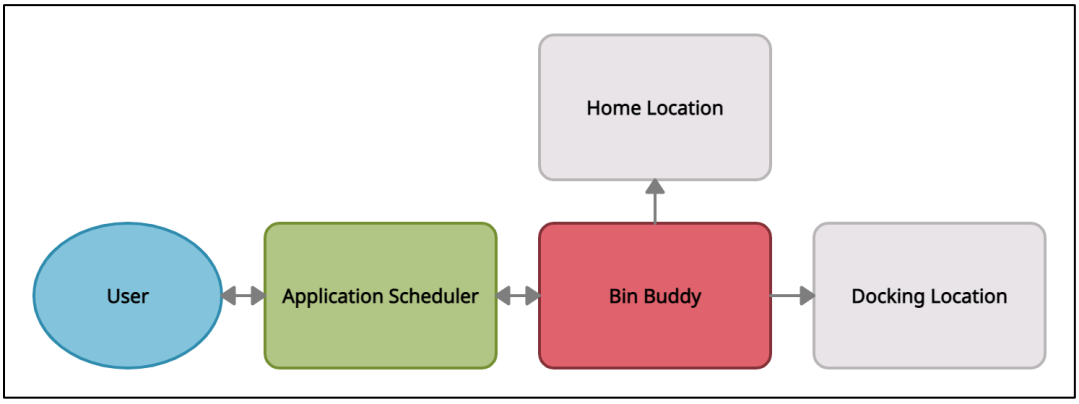

Figure 1. 1: General Overview of the Bin Buddy system

The requirements for Bin Buddy are detailed in this document as followed:

1. Functional Requirements
    - Describe Bin Buddy's system requirements: high-level, hardware, and software.
2. Engineering Standards
    - Outline specific engineering standards that apply to Bin Buddy.
3. Sustainability and Safety
    - Analyze issues related to the sustainability and safety of Bin Buddy using the cradle-to-cradle cycle.

1.1 Scope

The purpose of this requirement document is to detail the non-functional and functional requirements of the Bin Buddy device. Engineering standards that apply to our device in addition to the sustainability and safety in the design of this device are also considered. All requirements are classified into one of the three phases of the project: proof-of-concept, engineering prototype, or production phase.

1.2 Intended Audience

1.2.1 Product

Bin Buddy is a solution for people living in stand-alone or semi-detached houses in the cities with waste management systems that use trucks with semi-automated arms to collect the waste. This product is especially important for people with accessibility issues (i.e. elderly, people with disabilities) as a way to avoid the costs associated with hiring people to help with everyday tasks that may pose a challenge, such as taking out waste carts. Bin Buddy also targets to resolve issues with fines issued due to city by-laws that impose narrow time windows to take out the cart.

1.2.2 Document

This document will serve as LifeAutomation's structural and functional requirements guide for the LifeAutomation team, potential clients/partners, Dr. Craig Scratchley, Dr. Shervin Jannesar, Dr. Andrew Rawicz, and the teaching assistants.

1.3 Requirements Classification

The three stages of the project are categorized in the following format:

Req {Section}.{Sub-Section}.{Sub-Requirement (optional)}-{Product Phase Acronym}

Each product phase has an associated acronym for better readability.

Table 1. 1: Product Phases

Product Phase	**Acronym**
Alpha Phase (Proof of Concept)	POC
Beta Phase (Engineering Prototype)	EP
Production Phase (Final Product)	FP

2. System Overview

Bin Buddy consists of two main components: the main Bin Buddy attachment, and the user application. A conceptual design of the Bin Buddy is shown in figure 2.1. The main body of Bin Buddy is attached to existing city waste carts and is composed of the microcontroller controlling the drive system, and the various sensors to assist in the navigation from a home location to a docking location on the driveway. This system is paired with the user application, which takes a waste cart schedule as an input to be relayed to the microcontroller via the Wi-Fi module. Additionally, when the Bin Buddy attachment requires assistance, alerts will be sent to the user application from the microcontroller. Figure 2.2 illustrates a high-level overview of the system.

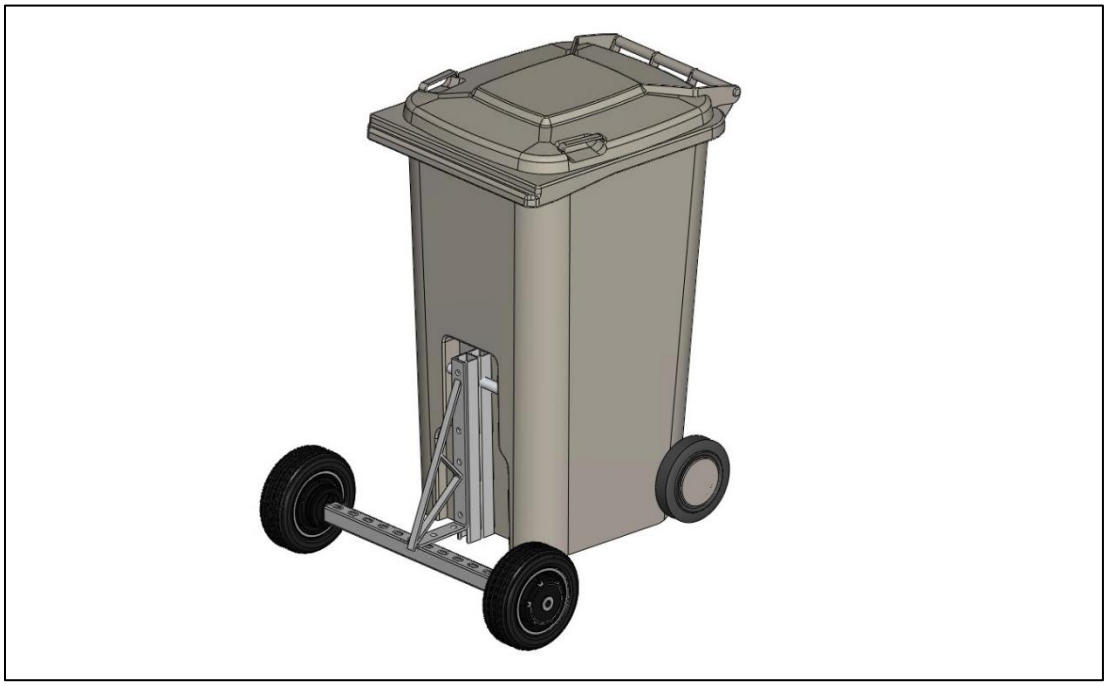

Figure 2. 1: Conceptual Design of the Bin Buddy Attached to a 210 L Waste Cart

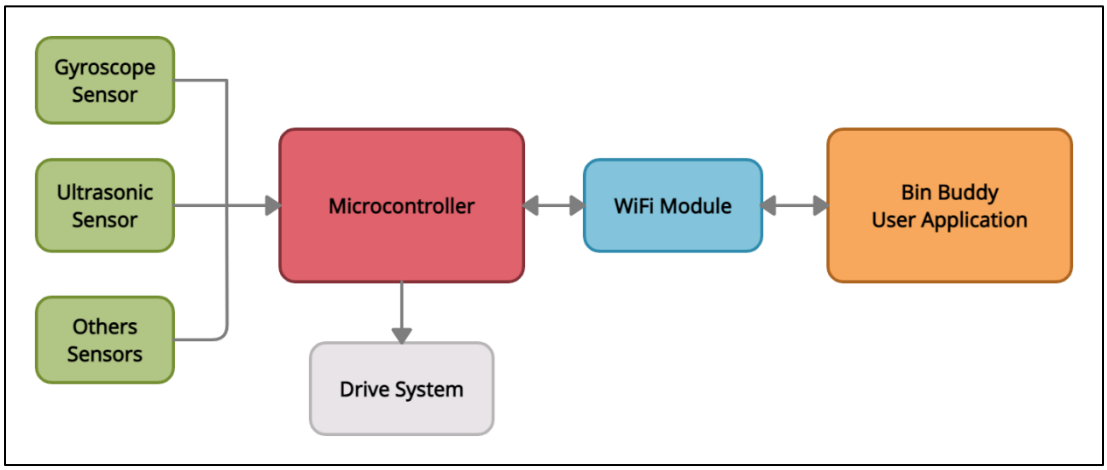

Figure 2.2: General System Diagram

3. High-Level Requirements

Bin Buddy will be attached to the waste cart and will navigate itself to and from the waste pick-up area on a set schedule without deviating away from its path, without driving over defined obstacles and without toppling over. The following are the high-level requirements.

Table 3. 1: POC Requirements for the System

Requirement ID	Requirement Description
3.1.1 - POC	The product must be capable of moving from a defined point A to a defined point B.
3.1.1.1 - POC	The product shall be able to navigate and stay within the preset virtual or physical boundaries.
3.1.2 - POC	The product must travel back and forth without tipping over.
3.1.3 - POC	The product shall drive over **small obstacles**[1].
3.1.4 - POC	The product shall detect **large obstacles**[2].

Table 3. 2: EP Requirements for the System

Requirement ID	Requirement Description
3.2.1 - EP	The product must be capable of recognizing the designated point A (where the user stores their waste cart) and the designated point B (waste pick-up area).
3.2.1.1 - EP	The product must stop within 10 cm of either docking station.
3.2.2 - EP	The product must turn away from **large obstacles** without bumping into them, given that there is at least 90 cm of room to operate in.
3.2.3- EP	The product shall follow the waste collection schedule input by the user.
3.2.4 - EP	The product shall be able to safely travel up and down a driveway slope of maximum 10^{o} without toppling over.
3.2.5 - EP	The product shall be able to recognize when it is stuck and alert the user.
3.2.6 - EP	The device must be able to be set up in less than 1 hour by a moderately mobile person of age 12 or above.

[1] See glossary for definition
[2] See glossary for definition

Table 3. 2: Continued

Requirement ID	Requirement Description
3.2.7- EP	The product must allow the user to input a monthly collection schedule.
3.2.7.1 - EP	A person with 1-2 years of experience using a smartphone shall be able to figure out how to input a monthly collection schedule in less than 20 minutes.

Table 3. 3: FP Requirements for the System

Requirement ID	Requirement Description
3.3.1 - FP	The product shall cost less than $500.
3.3.2 - FP	The product shall be rechargeable at the docking station.

4. Mechanical

Mechanical requirements will outline the physical limitations of our system. Since city bylaws restrict the weight of a 120L waste cart to be under 50kg, our final product aims to be lighter than 5kg [5]. While not being too heavy, Bin Buddy must be able to withstand the load imposed by the mounted waste cart. The requirement to be able to withstand and drive with the load should be met in the Beta phase.

Since Bin Buddy will be taking the approach of virtual or physical boundaries to navigate itself, the turn radius must be small enough to stay within the boundaries, but cannot be too small as it must also consider the weight and size of the load to not tip over.

As the mechanical component of our system is integral to our core functionality of bringing out the waste carts to its destinations, proper design techniques and appropriate materials should be considered.

Table 4. 1: Mechanical Requirements

Requirement ID	Requirement Description
4.1.1 - EP	The product's height should be less than 53 cm.
4.1.2 - EP	The product's depth should be less than 38 cm to leave enough clearance between the waste pick-up truck's arm and the product.
4.1.3 - EP	The center of gravity of product and waste cart system must be contained within the system especially on inclines of 10^{o}.
4.1.4 - EP	The wheels must have enough traction to navigate with minimal slippage.
4.1.5 - EP	The turn radius for chassis drive wheels shall be between 40-90 cm.
4.1.6 - EP	The product must be secured tightly onto the city waste cart.
4.1.7 - EP	The product structure shall use light weight 6105-T5 aluminum bars or similar.
4.1.1 - FP	The weight of the product shall not exceed 5kg.
4.1.1.1 - FP	The product structure shall use anodized colored aluminum alloy that is of light weight.
4.1.1.2 - FP	The product enclosure casing shall weigh under 1kg.
4.1.2 - FP	The product casing shall be made to minimize enclosure space.
4.1.3 - FP	The product casing shall be made using techniques to protect product aesthetic and minimize cost per part, such as SLA 3D printing (for 1-1000 parts) or injection molding (for ~5000 parts)

5. Hardware

The following section discusses the hardware requirements for Bin Buddy to be able to operate.

5.1 Microcontroller/Microcomputer Unit (MCU)

Bin Buddy system requires a microcontroller unit to manage embedded functionalities of the product. In particular, the MCU allows the sensors, motors, and other parts of the device to communicate with each other, and process and transfer the data for automation purposes. The further details of the microcontroller must satisfy are displayed in Table 5.1.

Table 5. 1: Microcontroller Requirements

Requirement ID	Requirement Description
5.1.1 - POC	MCU must have Wi-Fi capabilities.
5.1.2 - POC	MCU must have a 5V/2.5A DC unit.
5.1.3 - POC	MCU must have up to 3A capacity.
5.1.4 - POC	The GPIO (General Purpose Input/Output) header must consist of 40 pins.
5.1.5 - POC	MCU must have at least one USB 2.0 port for powering up and uploading.
5.1.6 - POC	MCU should have a micro-SD port to support loading an operating system and storing data.

5.2 Power Supply

Bin Buddy will be travelling from the home location to the docking location and back on a biweekly or weekly schedule. Because waste collection cart schedules operate in a time window and not a fixed time, the power supply must be sufficient to power this roundtrip travel time in addition to the power lost at the docking station when Bin Buddy is idle, waiting for the collection truck to arrive. Further requirements for the power supply are detailed in Table 5.2.

Table 5. 2: Power Supply Requirements

Requirement ID	Requirement Description
5.2.1 - POC	The power supply must be able to power the sensors and motors
5.2.1 - EP	The power supply must last 3 roundtrip cycles before a battery recharge
5.2.2 - EP	The power supply must be able to power the chassis motor continuously for at least 5 minutes one way on a driveway that is about 20m long.
5.2.1 - FP	The power supply must be able to self-recharge at docking station.

5.3 Chassis Motor System

Bin Buddy will require a chassis motor system that has two degrees of freedom for navigating the driveway while generating enough force to drive up and down inclines of less than 10^{o} with a full bin load.

Table 5. 3: Chassis Motor Requirements

Requirement ID	Requirement Description
5.3.1 - POC	The chassis must be able to go forwards and backwards at less than 10km/h.
5.3.2 - POC	The chassis must be able to steer right or left to change directions.
5.3.1 - EP	The chassis drive motor must be able to pull the load of the waste cart and the product up an incline of 10^{o}.
5.3.2 - EP	The chassis drive motor shall be reasonably quiet while operating.
5.3.1 - FP	The chassis drive motor shall last a reasonable lifespan of the product.
5.3.2 - FP	The chassis drive motor must be able to support a load of 50kg (45kg maximum for waste cart and 5kg maximum for product).

In addition to motors and power supply, sensors are critical in enabling Bin Buddy to operate safely while reasonably meeting its core functionalities.

5.4 Inertial Sensor

With an inertial sensor, Bin Buddy will detect when the waste cart has been dumped out by detecting the angle change of 180^{o} to determine when it is ready to return to its home base.

Choosing an inertial sensor to detect an angle change over another type of sensor is a design choice to simplify our empty cart detection mechanism. There are a lot more variables to consider if we were to adopt a weight sensor, such as being able to distinguish if the change in weight is indeed due to waste carts being emptied out by waste collection trucks or due to an accidental detachment of the waste cart from Bin Buddy. Relying on the weight parameter also makes it difficult to tell if Bin Buddy has been put down on the ground after being emptied out or if it is still midair, but now emptied out. Changes that are as drastic as the angle change of 180^{o} to Bin Buddy itself would rarely occur unless a waste cart is being emptied out by the waste collection truck. The chance of getting an angle change of 180 degrees from Bin Buddy toppling over severely would be rare, especially with having the load as heavy as the waste cart mounted on top of it and if that type of incident were to happen, Bin Buddy will recognize that it is unable to travel due to being flipped over and alert the user for user intervention.

Table 5. 4: Inertial Sensor Requirements

Requirement ID	Requirement Description
5.4.1 - POC	Gyroscope sensor must be able to detect a rotational change between 40-180 ^{o} with respect to the base frame.
5.4.1 - EP	Gyroscope sensor must be able to distinguish between a rotational change of 40-90 ^{o} and 90-180 ^{o} to determine if Bin Buddy fell over or being emptied out.

5.5 Ultrasonic Sensor

An ultrasonic sensor is one of the most important components of Bin Buddy. The sensors will help Bin Buddy from driving into large obstacles that it cannot avoid, preventing property damage or bodily harm.

While an infrared sensor is another option that we could have chosen, we have decided to go with ultrasonic sensors considering the environment that our product will operate in. Infrared sensors are cheap alternatives but are not the most optimal performers in an outdoor environment with natural sunlight interfering [6]. There are other types of sensors that we could have chosen, but ultrasonic sensors are the most suitable for our purposes in terms of its fairly cheap cost and setting that Bin Buddy will operate in.

Table 5. 5: Ultrasonic Sensor Requirements

Requirement ID	Requirement Description
5.5.1 - POC	The sensor must be able to detect large obstacles, given that the obstacles are within 180 cm.
5.5.2 - POC	The sensor must directly connect to the microcontroller.
5.5.3 - POC	The sensor shall have a current consumption of less than 2 mA.
5.5.4 - POC	The sensor shall be connected to a power supply of around 5V DC.
5.5.1 - EP	The sensor must detect large obstacles on each side of the waste cart for at least three sides.

5.6 Virtual/Physical Boundary

To assist the navigation of the waste cart from point A to point B, a virtual or physical boundary will be used. Although this will limit Bin Buddy's degree of movement or the directness of the path taken, this boundary will play a key role in ensuring Bin Buddy's arrival to its destination by narrowing the scope of its available travel area. If large obstacles, as defined in the glossary, are within this virtual or physical boundary, and there is space available for Bin Buddy to avoid this obstacle while staying within this boundary, Bin Buddy will avoid the obstacle. Otherwise, Bin Buddy will request assistance from the user.

Table 5.6: Virtual/Physical Boundary Requirements

Requirement ID	Requirement Description
5.6.1 - POC	This virtual or physical walls shall contain the product's navigational path to within the width of the waste cart system 20 cm on each side.

6. Software

The software of the Bin Buddy system will be divided into two major components: the software on the microcontroller that enables performing the core functionalities, and the software to directly interact with the user.

The software on the microcontroller will be used to communicate with the sensors needed for operating the product. The high-level key software components related to the sensors are navigation, obstacle detection, and collision avoidance. Additionally, the software will be responsible in communicating with the user application.

The second software component will be an interface for users to schedule Bin Buddy. It will also receive notification alerts from the microcontroller when the product requires attention. These notification alerts will occur in real-time while the inputting and fetching the schedule can occur periodically.

Table 6. 1: POC Software Requirements for the System

Requirement ID	Requirement Description
6.1.1 - POC	The product shall be able to navigate itself within the preset boundary.
6.1.2 - POC	Important error messages and data from all the sensors on the product must be logged for troubleshooting (hidden from the user, but can be accessed by a technician).
6.1.3 - POC	The software shall limit the speed to a maximum of 10 km/h.

Table 6. 2: EP Software Requirements for the System

Requirement ID	Requirement Description
6.2.1 - EP	Any interrupts to the software that have been considered shall fail-safe and not result in unsafe system behavior.
6.2.2 - EP	There must be an interface for users to communicate with the product with little to no user expertise and training.
6.2.3 - EP	The interface shall correctly display the product's destination.
6.2.4 - EP	The product shall detect and attempt to avoid large obstacles on route to its destination.
6.2.4.1 - EP	If unable to move around the large obstacles without deviating away from the preset boundary, Bin Buddy shall alert the user.

Table 6.1: Continued

Requirement ID	Requirement Description
6.2.5 - EP	The product shall maintain a distance of at least 90 cm from obstacles to avoid bumping into them.
6.2.6 - EP	The software must alert the users in case of needing attention/user action - theft, stuck somewhere.

Table 6. 3: FP Software Requirements for the System

Requirement ID	Requirement Description
6.3.1 - FP	The software shall boot up within 60 seconds.
6.3.2 - FP	Any major, unexpected and unaccounted interrupts or failures shall alert the user.

7. Engineering Standards

Engineering standards ensures that the quality and safety of a product are met. Bin Buddy will adhere to the standards established by the organizations: CSA, IEEE, and ISO. Applicable standard IDs and their descriptions pertaining to the development and construction of the product are listed in Table 7.1. The final product phase shall ensure the compliance of the product to the engineering standards identified below.

Table 7. 1: Engineering Standards

Standard	Description
CSA C22.2 No. 0.23-15 (R2020)	General requirements for battery-powered appliances [7]
IEEE/ISO/IEC 12207-2017	Systems and software engineering - Software life cycle processes [8]
CAN/CSA-C22.2 No. 94.2-07 (R2012)	Enclosures for Electrical Equipment, Environmental Considerations [9]
CAN/CSA-C22.2 No. 60529:16	Degrees of protection provided by enclosures (IP Code) [10]
CSA-Q830-03 (R2014)	Model Code for the Protection of Personal Information [11]
CAN/CSA-ISO/IEC 9126-1:02 (R2007)	Software Engineering - Product Quality - Part 1: Quality Model [12]
CSA-Q830-03 (R2014)	Model Code for the Protection of Personal Information [13]
ISO 31022:2020	Risk Management [14]
ISO/IEC TR 25060:2010	Systems and Software Engineering - Product Quality Requirements and Evaluation [15]
Open Source Initiative	Open Standards Requirement for Software [16]

8. Safety

Because Bin Buddy will be located outdoors, the design of the product must be carefully considered. This includes safe operation during normal conditions and ensuring a fail-safe system is integrated. The safety regarding the circuitry, drive system, environment, and product design are further detailed in Table 8.1. With these standards in place, user risks will be significantly reduced.

Table 8. 1: Safety Standards

Requirement ID	Requirement Description
8.1.1 - POC	The product must have an emergency/power button to disconnect the system from the power supply.
8.1.1 - EP	The product's circuitry must be enclosed in a case.
8.1.2 - EP	The product must travel below the speed of 10km/h to avoid inflicting bodily harms, especially children and pets.
8.1.3 - EP	The product must have a braking system that locks the wheels in place to prevent rolling away while not in motion.
8.1.4 - EP	The product must be securely attached to the waste cart such that it does not fall off while the waste is getting collected.
8.1.5 - EP	The product design must be stable as to not tip and fall when going over small branches, rocks, and inclines of less than 10°
8.1.1 - FP	The exterior casing of the product must be waterproof to protect the internal circuitry from the exposure to water, reducing user risks.
8.1.2 - FP	The product must have cautionary labels on the electrical components, including instructions for safe disposal of the battery.
8.1.3 - FP	All wiring shall be insulated and cleared out of the way of the product's moving parts.
8.1.4 - FP	The product shall operate normally under temperatures between -20°C to +40°C.
8.1.5 - FP	The product's battery shall be detachable from the rest of the system in case of emergencies.

9. Sustainability

The cradle-to-cradle (C2C) system strives to be sustainable through a technology cycle where materials used are recycled or reused while still providing the same or higher standard quality [17]. LifeAutomation will adopt the cradle-to-cradle system wherever applicable in the design of the product.

Recyclable and reusable materials will be given priority if feasible. For example, the final product will use a rechargeable power supply to increase the number of charge cycles and lifespan of the product. Electronic components will also be recyclable or be repurposed by the Canadian Electronic Recycling Association.

Table 9. 1: Sustainability Standards

Requirement ID	Requirement Description
9.1.1 - FP	The product shall use a power supply that is rechargeable.
9.1.1.1 - FP	The battery life cycle shall last 300 charge cycles.
9.1.1.2 - FP	To conserve energy, the product shall enter **idle mode** outside of its window of **active hours**.
9.1.2 - FP	The product shall use recyclable materials wherever appropriate.
9.1.3 - FP	The product shall minimize the need to replace individual parts by optimizing the lifetime of circuits and hardware used.
9.1.4 - FP	Electronic components shall be recycled or repurposed by the Electronic Recycling Association [18]

10. Conclusion

Bin Buddy allows home dwellers to automate a part of their mundane chore routines. With a scheduled frequency following the city's waste collection schedule, Bin Buddy will bring out waste carts to and from the pick-up area while avoiding large obstacles within a virtual or physical boundary.

The key requirements are highlighted below, to be achieved and developed over the course of three incremental phases:

1. Mechanical
    - The weight of the product must not exceed 5kg.
    - The product must be able to withstand the load imposed by the waste cart.
2. Hardware
    - The sensors must detect and determine the product's distance away from large obstacles to avoid them.
    - The sensors must be able to detect the waste pick-up and home locations.
3. Software
    - The product must be able to navigate itself after its initial calibration of boundaries.
    - The product must have an interface for users to communicate with the product with little to no user expertise and training.
    - The software must alert the user in case of needing user intervention and fail-safe in case of any interrupts.
4. Engineering Standards
    - Bin Buddy must adhere to city bylaws regarding garbage collection and relevant engineering standards, such as the general requirements for battery-powered appliances.
    - The Bin Buddy application must consider the privacy of users.
5. Sustainability and Safety
    - Any circuitry in the product must be enclosed in a waterproof compartment.
    - Bin Buddy must limit its maximum travel speed as 10 km/hour.
    - The product will use recyclable materials wherever appropriate.

The requirements outlined in this document will initially be tested following the guidelines dictated by the acceptance test plan for our core functionalities in the Alpha (Proof-of-Concept) phase while more robust, real-world testing will be conducted for our Beta (Engineering Prototype) phase. The anticipated completion date of the Alpha build is April 2021 and the Beta build is expected August 2021.

Any future revision to the requirements can be found on our team's web page: https://csil-git1.cs.surrey.sfu.ca/capstone-1211-company-2/capstone-project/-/wikis/Bin-Buddy-Home

References

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Appendix: Acceptance Test Plan – Alpha

Table A.1 outlines the proposed tests for the proof of concept acceptance test plan. The proposed test plan is designed such that they the product's core functionalities are tested. Requirements are combined into a single test where feasible.

Table A. 1: Alpha Tests

Requirements Tested	Proposed Test
3.1.3 - POC	Small obstacles will be placed in the path of the product and the product will be monitored to ensure it can go over them.
3.1.4 - POC 5.5.1 - POC	Large obstacles will be placed in the path of the product and the product will be monitored to ensure that it sends an alert when large obstacles are within 180 cm of it.
3.1.2 - POC	The product will be sent down a driveway with an angle of 10^{o} and monitored to ensure it does not tip over.
5.4.1 - POC	A waste collection will be simulated by lifting the waste cart and turning it upside down and then placing it back on the ground. The product will be monitored to ensure the gyroscope has detected a change in angle.
3.1.1 - POC 3.1.1.1 - POC 5.3.1 - POC 5.3.2 - POC 5.6.1 - POC 6.1.1 - POC 6.1.3 - POC	The product will be scheduled 3 times and monitored to ensure it reaches the second docking station within 20 cm, does not stray from the boundaries more than 10 cm, and does not travel at a speed higher than 10 km/h.
5.2.1 - POC 5.5.2 - POC 5.5.3 - POC 5.5.4 - POC 6.1.2 - POC	All of the sensors will be attached to the microcontroller and powered through the power supply. The sensors will be tested to ensure they function appropriately including the logging of errors and data.
8.1.1 - POC	The emergency/power button will be pressed to ensure the system disconnects safely and the motor does not have a sudden voltage spike (flyback).