February 21, 2021

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

Re: ENSC 405W/440 Functional Requirements Specification for Cylindrotech's Plot-Hole

Dear Dr. Scratchley and Dr. Jannesar,

The purpose of Cylindrotech's Plot-Hole is to accurately automate and simplify the pothole reporting process. Plot-Hole's automated ability to detect potholes, classify their size, identify their locations, and report pertinent information to the city would reduce vehicle damage and ultimately improve road safety. By equipping city vehicles such as street sweepers with this device, frequented roads could be surveyed and potholes could be identified and addressed.

This requirement document provides details of feature requirements of Plot-Hole in its Proof of Concept, Prototype, and Final Product stages. Requirements and justified functionalities of hardware, electrical and software components of this product are listed, as well as safety and sustainability concerns. This document is intended to lay the groundwork for the future phases of the project, while also conveying the project's ideas to its audience.

Cylindrotech is comprised of five engineers: Evan Lam and Bifei (Elvira) Huang in computer engineering; Jonathan Wong and Yuxin (River) Zhang in electronics engineering; and Samantha Betts in engineering physics. The team's eclectic dynamic is a liaison between passionate students who work with a diverse skill set. Unlike a large company, Cylindrotech's small team ensures that everyone has a direct voice in influencing a product.

Thank you for acknowledging Cylindrotech's requirements specification. Regarding communication and questions, please contact Cylindrotech at lamevanl@sfu.ca.

Sincerely,

Evan Lam

Evan Lam
Chief Communications Officer
Cylindrotech

CYLINDROTECH 

Requirements Specification
Plot-Hole

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Revision 1.0

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i. Abstract

To give readers a general knowledge on the proposed product, Plot-Hole, the document provides a requirements specification and includes a systematic overview. Plot-Hole is a solution for reporting potholes in their early stages through a timely detection and reporting mechanism. To achieve such functions, a hardware component, an electrical component, and a software component are included in the product. Functionality requirements of each component in different development stages (Proof of Concept , Prototype and Final Product) are listed out. A list of engineering standards demonstrates how Plot-Hole meets industry standards. The safety and sustainability section covers concerns on safety, legal and environmental issues. Furthermore, a test plan is included to evaluate how the product performs throughout its stages of development.

ii. Revision history

Revision	Revision Description	Date
1.0	First revision of document finished	2021-02-21

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Glossary

AI - Artificial Intelligence. In computer science, artificial intelligence describes a machine that learns (Machine/Deep Learning) and exhibits problem-solving.

CEPA - Canadian Environmental Protection Act. An act respecting pollution prevention, the protection of the environment, and human health in order to contribute to sustainable development.

CSA - Canadian Standards Association. A Canadian national standards organization that develops standards for Canada across numerous industries.

Deep Learning - The use of mathematical models to process input. The models are "trained" with hidden layers to analyze datasets.

Edge Device - A device that does real-time data processing at the source.

FOV - Field of View. In terms of vision, FOV describes the extent of the observable world that is seen at any given moment by a camera lens, an organism's eyes, or by an observing device such as binoculars.

FPS - Frames per second (Frame rate). The rate at which images are processed. Videos commonly play in 30 FPS or 60 FPS.

GPS - Global Positioning System. A navigation system that uses satellites to provide devices with geolocation (latitude and longitude) and time.

IEC - International Electrotechnical Commission. An international standards organization that publishes electronic and technological standards.

IEEE - Institute of Electrical and Electronics Engineers. An engineering association that seeks to advance engineering worldwide. The IEEE-SA (Standards Association) is an operating unit within IEEE that develops and publishes standards relating to engineering.

IMU - Inertial measurement unit. A combination of accelerometers and gyroscopes used to measure a body's speed, acceleration, and relative positioning in cartesian coordinates.

ISO - International Organization for Standardization. An international standard-setting body composed of representatives from various national standards organizations.

USB - Universal Serial Bus. An industry standard interface between computers and peripherals that allows for data transfer, charging, networking, and other functions. The standard is maintained and continually updated by the USB Implementers Forum.

1. Introduction

1.1 Background

Potholes are primarily caused by the freeze-thaw cycle of water seeped inside cracks in the road combined with the mechanical weakening of heavy traffic [1]. The Canadian Automobile Association reports that on average Canadians spend around $1.4 billion on pothole associated car damage [2]. These damages can range from tire punctures and bent wheels to undrivable suspension damage [3].

In British Columbia, municipalities are not legally bound to ensure roads to be road damages, including potholes [1]. Despite municipalities not being liable for the cost of vehicle damage due to imperfections in the road, the City of Vancouver plans to spend at least $350,000 this year (2021) fixing potholes [4]. The City of Vancouver estimates that more pothole-related requests will occur due to a funding cut to Translink's road repair budget. [5]. In Canada, the universal method of reporting potholes is by calling 311, or in the case of Vancouver, to use the VanConnect app [6].

The ticketing system on the VanConnect app (or City of Vancouver website) takes note of three main factors of a pothole.

1. Pothole location
2. Pothole size (cm or in)
3. Pothole depth (cm or in)

By automating the collection and submission of the three parameters above, the City of Vancouver can be better equipped to find and track potholes, saving costs of deploying crews to incorrect locations, and improving road safety to all drivers.

1.2 Scope

This document outlines the requirements of the hardware, electrical, and software systems. Safety, sustainability and the abidance of engineering standards are also highlighted in this document.

1.3 Intended Audience

This document is intended for all members of the instructional team. The non-technical document also serves an important role as a part of the development process as it is critical in developing design specifications. Were the company larger, then sales departments, marketing departments, and outside stakeholders would have access to the document. Examples of stakeholders would be cities with pothole problems, especially those that experience frequent freeze-thaw cycles.

1.4 Requirement Classification

The notation of the listed requirements are described as follows:

Req{Section number}{Requirement number} - {Development stage}

Usage of the words MUST and SHOULD distinguish mandatory aspects of the product as opposed to “nice to haves”.

The different components involved in the product’s design are given the following letter ID’s to indicated which aspect of the project they belong to:

The different stages in the development process are abbreviated as follows:

Development Stage	Requirement ID letter
Proof of Concept	C
Prototype	P
Final Product	F

Table 1.4 Stage Classification

2. Overview of System

The Plot-Hole system is designed to be “user-friendly”. After turning on the hardware device, no input is required from the user. The user also does not need to know any backend information about the software aspects of the product in order to successfully perform the pothole ticketing process.

As seen in Fig. 2.1, Plot-Hole consists of two main components: a modular vehicle attachment for collection of the pothole data and a web application. The vehicle attachment will be built to limit obstruction of the device with other essential components of the vehicle and to not distract or obscure the view of the driver. The vehicle attachment will consist of various sensors to measure the depth and dimensions of the pothole as well as the general GPS location. The pothole detection algorithm will be able to detect a pothole and communicate with the other sensors, such as an IMU in order to accrue more relevant information.

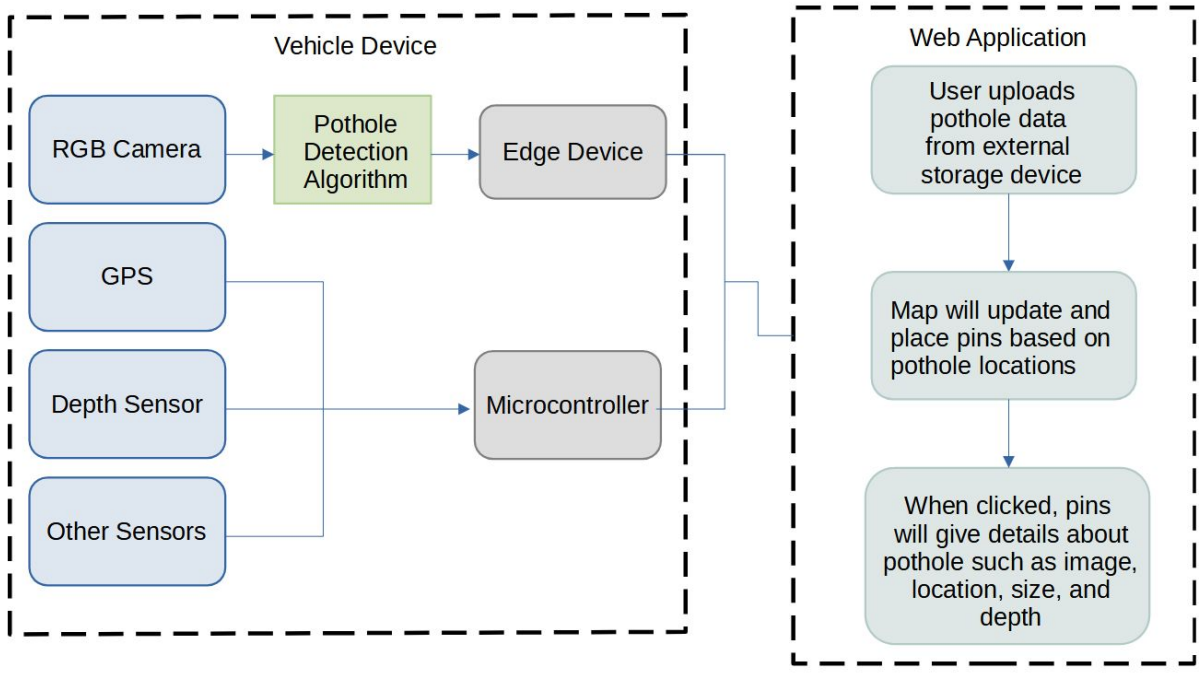

Fig. 2.1. - General Block Diagram of Plot-Hole Product

The user should then be able to detach external storage from the system and then plug it into a computer. The external storage will then be read and analyzed with the Plot-Hole web application. The web application will be developed to visually show the pothole locations on an interactive map with pins indicating a pothole location. When the pin is selected by the user, the software will display correlated pothole information, allowing the user to then submit a ticket for repair. The user can also remove a pothole from the system if it has been repaired or misreported. When the user "submits" a ticket, the web application will automatically fill out the VanConnect pothole report web form [6], as shown in Fig. 2.2.

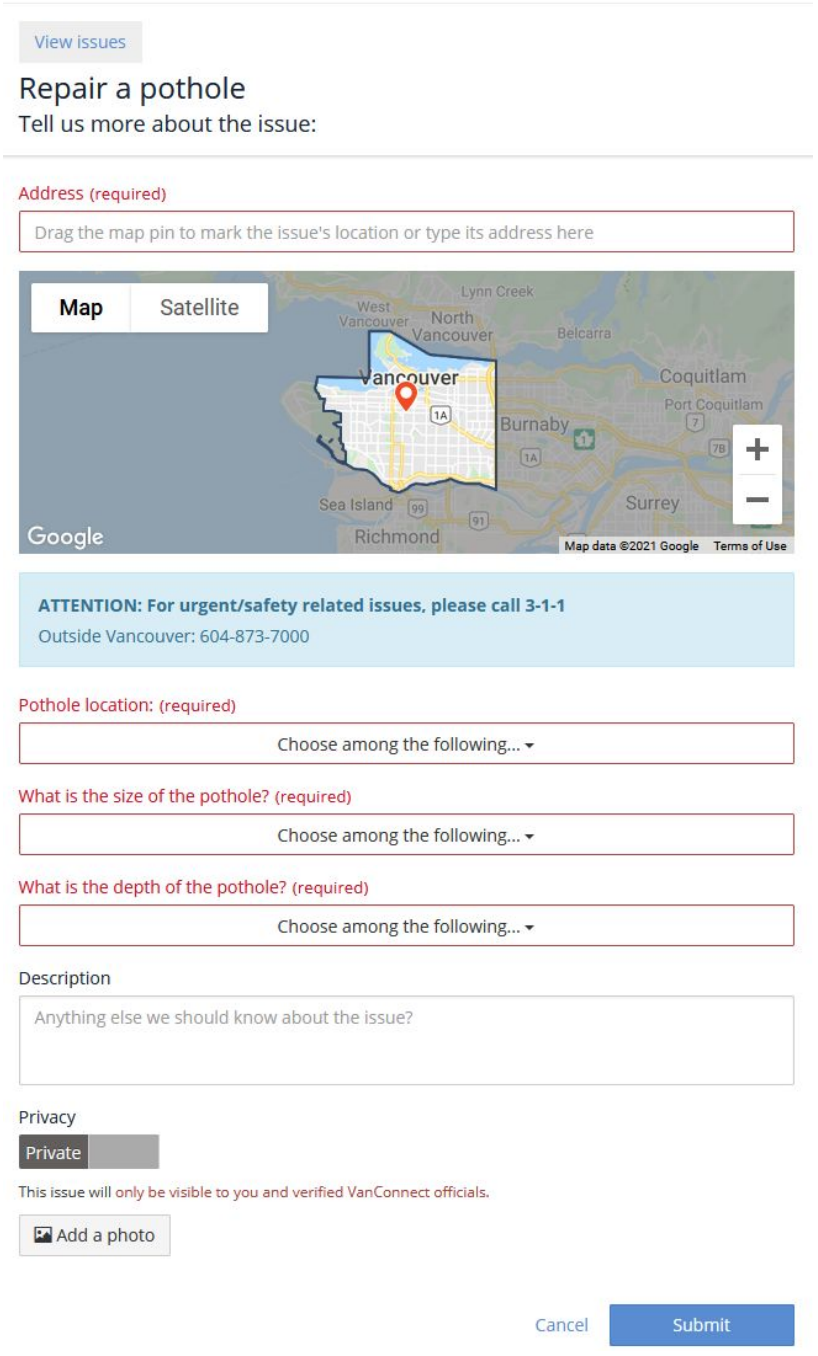

Fig. 2.2. - Vanconnect Pothole Repair Form [6]

3. Hardware Requirements

3.1 RGB Camera

The RGB camera is responsible for obtaining coloured images on the road that will be processed by a deep learning algorithm. This camera will be mounted at a similar angle to the RGB camera to provide a similar FOV to the used dataset. Note that a Canadian street sweeper moves at an average speed of 6km/h [7].

Requirements ID	Requirement Description
Req 3.1.1 F	The camera must be able to obtain images at a frame rate that produces clear images at a vehicle speed of 6km/h
Req 3.1.2 C	Data and power between the camera and the microcontroller should be provided via USB
Req 3.1.3 P	The camera must be capable of a resolution that can distinguish potholes with a diameter of 12 inches
Req 3.1.4 P	The camera should be protected against the weather
Req 3.1.5 P	The camera must be mounted at an angle with a FOV matching the images from the model's dataset

Table 3.1 RGB Camera Requirements

3.2 Ultrasonic Sensors

The ultrasonic sensors will be used to detect the depth and dimension of the pothole. An array will be built with multiple ultrasonic sensors in order to capture a wide FOV.

Requirements ID	Requirement Description
Req 3.2.1 C	The ultrasonic sensors must be powered by 5V
Req 3.2.2 C	Two data pins must be connected to a microcontroller with each sensor
Req 3.2.3 P	The ultrasonic sensors must be able to detect a minimum lateral resolution of 6 inches
Req 3.2.4 P	The ultrasonic sensors must be able to detect a minimum depth resolution of 2 inches
Req 3.2.5 F	The ultrasonic sensors should be mounted inside a weatherproof enclosure

Table 3.2 Ultrasonic Sensors Requirements

3.3 GPS Sensor

One or more GPS sensors will be used to provide location data and time.

Requirements ID	Requirement Description
Req 3.3.1 P	The GPS sensor(s) should have a precision of within 3 metres
Req 3.3.2 P	The GPS sensor(s) must store its latitude/longitude data on attached storage in a readable format
Req 3.3.3 P	The GPS sensor(s) must be able to operate outdoors, especially within the main commercial and business area of a municipality

Table 3.3 GPS Sensor Requirements

3.4 Enclosure

The enclosure's primary function is to house all the major electronic components such as the microcontrollers, battery, and hard drives. It should protect its housed components from inclement weather and provide a secure mounting system to the test vehicle and the street sweeper.

Requirements ID	Requirement Description
Req 3.4.1 F	The enclosure must be able to protect its components from the weather
Req 3.4.2 F	The enclosure should be water-proof
Req 3.4.3 F	The enclosure must include a secure and modular mounting system to attach to a street sweeper or a personal vehicle

Table 3.4 Enclosure Requirements

3.5 Computing Devices

The computing devices used will be an edge device for deep learning, a microcontroller to process the ultrasonic and GPS sensors, and an external storage device for storing data.

Requirements ID	Requirement Description
Req 3.5.1 C	The microcontrollers must have a adequate number of GPIO pins to support the ultrasonic sensor array and GPS sensors
Req 3.5.2 P	The external storage must be fast enough to avoid IO bottlenecking
Req 3.5.3 P	The computing devices must be able to not overheat inside an enclosure

Table 3.5 Computing Devices Requirements

4. Electrical Requirements

4.1 Wiring

The requirements of the wiring of the system are outlined to ensure the safety of all users.

Requirements ID	Requirement Description
Req 4.1.1 P	Most of the main wiring should be done in the enclosure
Req 4.1.2 P	Any exposed cables must be securely placed and meet the appropriate compliance standards detailed in Section 6.3 - Wiring Standards
Req 4.1.3 P	Any outside wiring must not obscure the driver or any of the essential functions of the vehicle

Table 4.1 Wiring Requirements

4.2 Power Supply

Power supply requirements state the guidelines to follow when choosing an appropriate battery for the system, including features such as safety, power rating, and battery capacity.

Requirements ID	Requirement Description
Req 4.2.1 C	The power supply must be able to deliver enough power to all components
Req 4.2.2 F	The product must be able to run longer than eight hours on battery power
Req 4.2.3 C	The battery must be rechargeable
Req 4.2.4 P	The power supply must be in the enclosure and securely fastened to avoid damage
Req 4.2.5 F	The battery should be able to operate in cold temperatures

Table 4.2 Power Supply Requirements

5. Software Requirements

The requirements for software represent the algorithm for determining if potholes exist. The requirements also represent a mapping and ticketing system designed for automatically showing where potholes exist.

Requirements ID	Requirement Description
Req 5.1 C	The software must store pothole data on a network
Req 5.2 C	The software must parse pothole photos and plot them on a road map
Req 5.3 C	The software must retrieve the pothole's location and time of logging and associate the data to the map's plot point
Req 5.4 C	The software must be accessible through a network web browser
Req 5.5 C	The software must have an interactable user interface
Req 5.6 C	The pothole detection algorithm must be able to operate at a higher fps than the RGB camera
Req 5.7 P	The pothole detection algorithm must have an accuracy of greater than 80%
Req 5.8 P	The pothole detection algorithm must be able to distinguish potholes from other road features
Req 5.9 C	The software should be able to be updated
Req 5.10 P	The software must be able to show pothole and map information to the user that the user chooses to see
Req 5.11 P	The software should allow the user to filter out data from a certain range of time
Req 5.12 C	The software should allow users to remove potholes that have been repaired or potholes that are false positives
Req 5.13 P	The software should be able to automatically input the pothole data into the City of Vancouver website
Req 5.14 F	The software can be adapted to other municipal pothole reporting systems

Table 5.1 Software Requirements

6. Engineering Standards

Since the product is intended to be used in North America, it is necessary to specify the applicable standards. As well, since the intended market is to be governmental, it is imperative that standards must be adhered to. IEEE professional standards apply to the software application of the product.

6.1 Ultrasonic Sensor Standards

Standard	Description
ISO/AWI 4773	Non-destructive testing — Method — Ultrasonic guided wave inspection using phased array technique [8].

Table 6.1 Ultrasonic Sensor Standards

6.2 Enclosure Standards

Standard	Description
IEC 60529 Ed. 2.2 b:2013	Guidelines for degrees of protection provided by enclosures (IP Code). Applies to the classification of degrees of protection provided by enclosures for electrical equipment with a rated voltage not exceeding 72,5 kV. Has the status of a basic safety publication in accordance with IEC Guide 104 [9].
CSA C22.2 NO. 94.2:20	Standards that apply to enclosures for electrical equipment, environmental considerations (Trinational standard with NMX-J-235/2-ANCE-2020 and UL 50E) [10].

Table 6.2 Enclosure Standards

6.3 Wiring Standards

Standard	Description
Canadian Electrical Code CSA C22.1:21 - 12-100 - Types of insulated conductors and cables	Insulated conductors and cables shall be suitable for the location in which they are installed with respect to, but not limited to, a) moisture, if any; b) temperature; c) degree of enclosure; and d) degree of mechanical protection [11].
Canadian Electrical Code CSA C22.1:21 - 12-102 - Installation of insulated conductors and cables	1) Insulated conductors and cables shall not be handled or installed when the ambient temperature is sufficiently low as to be liable to cause damage to the insulation. 2) Such insulated conductors and cables shall not be installed so as to permit flexing or movement of the conductors or cables after installation if the ambient temperature is liable to become low enough to damage the insulation during flexing or movement [11].

Table 6.3 Wiring Standards

6.4 Power Supply Standards

Standard	Description
General Requirements for battery-powered appliances: CSA C22.2 No. 0.23:15 - 25.1	Battery packs with a USB output for recharging or powering electronic devices shall comply with a Low-Power Circuit as determined by Annex B (in CSA C22.2 No. 0.23:15) [12].
General Requirements for battery-powered appliances: CSA C22.2 No. 0.23:15 - 17.1	Internal wiring shall comply with the applicable requirements of the end-product standard for those battery operated appliances containing hazardous voltages [12].
CSA C22.2 No. 62133-2:20 (IEC 62133-2:2017, MOD)	If batteries or portable cells are used, their standards are prescribed. Secondary cells and batteries containing alkaline or other non-acid electrolytes — Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications [13][14].

Table 6.4 Power Supply Standards

6.5 Software Standards

Standard	Description
ISO/IEC/IEEE 29148-2018	International Standard for Systems and software engineering - Life cycle processes - Requirements engineering - Entire document (sections 5-9) [15]
ISO/IEC/IEEE 12207	Systems and software engineering — Software life cycle processes [16]
ISO/IEC/IEEE 24748-3	Systems and software engineering — Life cycle management — Part 3: Guidelines for the application of ISO/ IEC/IEEE 12207 (software life cycle processes) [17]
ISO 9241-210:2019	Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems. Planning and integration of all phases of the product life cycle, i.e. conception, analysis, design, implementation, testing and maintenance [18].
ISO/TR 22100-5:2021	Safety of machinery — Relationship with ISO 12100 — Part 5: Implications of artificial intelligence machine learning. Addresses how artificial intelligence can impact the safety of machinery and machinery systems. The software product will be developed with machine learning hazards in the risk assessment process [19].
ISO/IEC TR 24028	Information technology — Artificial intelligence — Overview of trustworthiness in artificial intelligence. The document surveys topics related to trustworthiness in AI systems. AI Trust, engineering pitfalls, threats, risks, and mitigation techniques are described [20].

Table 6.5 Software Standards

6.6 Safety Standards

Standard	Description
ISO 26262	Road vehicles - functional safety. Part 2: Management of functional safety. The standard involves safety goals and safety requirements of individual automotive products [21]
ISO/IEC 27701:2019	Security techniques - Extension to ISO/IEC 27001 and ISO/IEC 27002 for privacy information management [22]

Table 6.6 Safety Standards

6.7 Sustainability Standards

Standard	Description
CEPA 1999 - Vehicle, Engine and Equipment Standards	The product will not invalidate a national emissions mark applied to any vehicle. The product will not emit any substance that is not in conformity with the Canadian Environmental Protection Act (in terms of vehicular emissions) [23].

Table 6.7 Sustainability Standards

7. Safety and Sustainability Requirements

7.1 Safety

As the Plot-Hole system is mounted at the front of vehicles, the safety of the product itself and the drivers are essential. This product satisfies the following safety requirements to ensure it does not cause any potential dangers to any users.

Requirements ID	Requirement Description
Req 7.1.1 C	This product must be water resistant
Req 7.1.2 C	The enclosure must have no sharp corners or edges
Req 7.1.3 C	The product must not protrude beyond the sides of the vehicle
Req 7.1.4 P	The product must be securely mounted without loosening from the vehicle due to engine vibration or bumpy road
Req 7.1.5 C	The product must not create any visibility issues for drivers
Req 7.1.6 C	The product must not affect the protection of the bumpers
Req 7.1.7 P	The product should be able to function without human operation and create no distraction for drivers
Req 7.1.8 C	The product must not interfere with any of the vehicle's functions
Req 7.1.9 C	All wiring and electrical components of the product must be insulated
Req 7.1.10 C	The FOV of RGB camera should be fixed to the surface of roads and not invade the pedestrians' privacy

Table 7.1 Safety Requirements

7.2 Sustainability

Cylindrotech's Plot-Hole should not only consider the market and financial requirements, but also the components' service life. Product manufacturing and life cycle use can have adverse impacts on the environment and human society [24]. The design of Plot-Hole will be sure to follow the cradle-to-cradle model [25], in which all product components will either be recycled, reused, or repurposed for other products. The components may also be contributed to future capstone groups. Based on sustainability, Cylindrotech's Plot-Hole shall be adhering to the following requirements:

Requirement ID	Requirement Description
Req 7.2.1 C	The whole system must be able to be remounted on different vehicles
Req 7.2.2 C	The system should not be damaged by an unfavorable climate
Req 7.2.3 P	The barrier that protect cameras from dirt and dust should be cheap and be easily cleaned or replaced
Req 7.2.4 P	Individual sensors in the system can be easily upgraded or replaced
Req 7.2.5 F	The power consumption should not use an excessive amount of energy
Req 7.2.6 F	Every part of the hardware system should be able to be separated and recycled or reused

Table 7.2 Sustainability Requirements

8. Acceptance Test Plan

A proof of concept demo is planned for the end of the 405W term.

The demo is expected to have a vehicle drive over a pothole-ridden road. A group member will drive the vehicle at a steady speed, in clear weather. At a point in this stretch of road, a specific pothole shall be targeted for detection in the system. The damaged road should cause the pothole detection system to pick up a pothole. After being detected, the pothole should be manually uploaded to the web application where the pothole details can be amalgamated. After confirming the pothole is valid, an automatic software process combines the details of the pothole, GPS information, and other pertinent information. The final step involves the user utilizing the web application to automatically report a pothole to the City of Vancouver's online pothole reporting system.

More details about testing the aspects of the hardware and software components of the product are outlined in the test sheet in Appendix A.

9. Conclusion

Cylindrotech's Plot-Hole is designed to provide a superior pothole detection and reporting process to local governments. Its use of deep learning, ultrasonic sensors, and GPS combined with an intuitive automated web application allows for potholes to be more quickly identified. As each pothole can be located and fixed accurately, vehicle damage costs from potholes can be reduced and overall road safety can be improved.

The requirements specified in this document illustrates the functionality of each system, and provides a guide on meeting the applicable engineering standards. Safety and Sustainability responsibilities are listed and discussed, a test plan is included to evaluate key features of the product. For the three intended development stages to the project (Proof of Concept, Prototype, and Final Product), the documents are intended for use in the iterative development process. Rigor and care are taken to ensure the guidelines and goals are met.

By completing the requirements specification, stakeholders and other interested groups can have a better understanding of the product's purpose, the target market, and feasibility. Costs of missed requirements increase exponentially as a project progresses through development. The benefits of completing an effective requirements specification include reducing the total cost of the product, causing less refactoring; reducing risks, meaning unexpected things do not show up later; and defining what is required for a prototype, ensuring on-time delivery.

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Appendix

A. Proof of Concept Acceptance Test Plan

Proof of Concept Acceptance Test Plan Page (1/2)		
Hardware		
Test:	Pass/Fail:	Comments:
GPS can accurately collect latitude and longitude data		
The system can successfully detect a pothole		
Pothole depth can be measured		
Pothole dimensions can be measured		
No sensors become loose during the entirety of the test		
Software		
Test:	Pass/Fail:	Comments:
The GPS coordinates are successfully converted to a street address		
The deep learning algorithm can detect a pothole with accuracy greater than 80%		
A map should be generated based on the GPS data and pins will be placed where potholes are located		
The map should be able to pull up pothole information when the pins are selected		
The system should be able to differentiate pothole measurements from other road features		

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Software — Continued		
Test:	Pass/Fail:	Comments:
User should be able to plug in an external storage device and upload relevant information to the web application		
The software should automatically input the data onto the City of Vancouver website when the user prompts it to		