

June 13, 2022
Dr. Craig Scratchley
School of Engineering Science
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British Columbia, V5A 1S6



RE: ENSC 405W/440 Requirements Specification for Nature Coolers

Dear Dr. Scratchley,

This requirement specification document for Ember Trailer was prepared by Nature Coolers for ENSC 405W/440. The purpose of our capstone project is to provide wildfire responders with assistance while they are “dry-mopping”, a process by which they search for remaining hotspots that could reignite a wildfire. Ember Trailer is meant to be used after a wildfire has been suppressed or contained by wildfire responders.

This document will cover the functionality and requirements for our product along with its implementation and intended use. It will provide a high-level overview of the system operation and outline the requirements for mechanical, electrical, hardware, software, and sustainability of Ember Trailer. Also included will be the stage that each requirement must be fulfilled at, for example, whether an electrical requirement will be implemented in the alpha (proof-of-concept) phase, the beta (refined prototype) phase, or the production phase.

The Nature Coolers team is made up of a diverse group of experienced senior engineering students: Rachel Djauhari, Kevin Lo, Jake Mix, Richesh Patel, Alfred Rodillo, and Xixuan Song. Our group specializes in the disciplines of computer and systems engineering with some experience in electrical and mechanical fields.

Our team would like to thank you for taking the time to read and review our requirements specifications document. If you have any further questions, please feel free to contact me at jmix@sfu.ca.

Sincerely,

A handwritten signature in black ink, appearing to read 'Jake Mix'.

Jake Mix
Chief Executive Officer
Nature Coolers



NATURE COOLERS

Requirements Specification: Ember Trailer

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Abstract

The Ember Trailer is a module that is intended to be mounted on a drone or UGV to help wildfire responders contain and battle the heavy blazes of wildfires that have become commonplace during the hot summer season around the world. Designed to target the most underappreciated and dirty work in the final moments of a forest fire, Ember Trailer will help detect stray embers and transport suppressant to quell any remaining flames and embers.

The series of sensors used ensures that no stray flames will go undetected, even embers beneath the ground. With the ability to not only detect but also suppress small blazes, courtesy of a top-mounted hose, the Ember Trailer will help to alleviate some work from wildfire responders as they tackle bigger fires.

The requirements in this document for Ember Trailer is divided into 6 main sections:

1. General Requirements
2. Electrical Requirements
3. Mechanical Requirements
4. Hardware Requirements
5. Software Requirements
6. Safety and Sustainability Requirements

To conclude this document there will be an acceptance test plan outlining the deliverables for both the proof-of-concept to be demonstrated in August 2022 as well as the refined prototype to be completed by December 2022.

Glossary

The following table includes a list of terms mentioned throughout the paper.

Table 1. Glossary Definitions

Term	Definition
UGV	Unmanned Ground Vehicle
Dry-Mopping/ Mopping-Up	Process of extinguishing residual fires and/or embers to ensure the fire does not spread outside of a containment zone
Cold Trailing	Process of inspecting the perimeter of a partly dead fire, feeling the area with the hand for any hot spots, digging out live spots, and trenching any live edges.

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1. Introduction

Nature Coolers is creating the Ember Trailer, a module that will assist in wildfire suppression efforts across British Columbia and the around the world. Designed to alleviate the work required from firefighters and wildfire responders, the Ember Trailer will be able to detect leftover embers, deep underground, and transport water supplies to be used in fire suppression. The task of ensuring no reignition of wildfire after they are partly or completely extinguished is a tedious and underappreciated part of fighting these blazes. Many hours of careful searching, digging trenches, and hauling water are required to ensure the fire is fully contained. The technique used is called Dry Mopping, or some other form of “Mopping” [1].

The Ember Trailer module can help firefighters and responders with this mopping task and ideally, allow them to perform this rough work more efficiently. The module would attach to a UGV, an unmanned ground vehicle, and would be controlled remotely by an operator to patrol the perimeter of a fire and allow the operator to perform tasks required when Dry Mopping. There would be two parts to this system: the detection of embers and hot spots, and the suppression of anything dangerous that would reignite the wildfire. The first portion will be accomplished by using a series of sensors and cameras to allow the operator to navigate and recognize any potential threats. The suppression portion will be a mechanical arm hose which can extinguish any embers found while also transporting the water supply for the wildfire responders.

1.1 Background

Wildfires have become a major issue across the globe and the impact is being heavily felt closer to home too. In 2017, a historic wildfire consumed nearly 7000 hectares of forested land and threatened the Williams Lake airport [2]. In 2021, a record heatwave caused countless fires across the province of British Columbia and destroyed the small town of Lytton, one of the worst tragedies to date. The forecasts show no signs of letting up in the coming years, potentially getting even worse. Firefighters and wildfire responders from around the world come to assist in the battle against these blazes, but numbers are still stretched thin. Technologies have been developed to minimize the damage done and optimize the responders’ time and energy.

Mentioned previously, a mop-up of a fire is an unglamorous yet crucial part in ensuring a fire is completely dead. Traversing the perimeter of a partly or fully extinguished fire, workers must keep a sharp eye out for surface embers while also feeling the ground for any unusual heat that may suggest subterranean embers. If anything is found, the ground must be dug up, typically several feet deep, and the embers extinguished using some water source. Oftentimes, a lot of machinery must be used to cut, chop, and chainsaw roots and branches to dig up all the hot material to be cooled down.



Fig. 1. Firefighters undergoing a "mop-up" procedure of embers in the forest

1.2 Scope

This document outlines any requirements that need to be met by the Ember Trailer module as determined by the team at Nature Coolers. These requirements include general functional requirements, electrical requirements, software requirements, mechanical requirements, hardware requirements, and safety and sustainability requirements. The development phase (alpha phase, beta phase, or production phase) that each requirement should be completed by will be indicated by the requirement ID as specified in the Requirement Classification section. Finally, this document will also include any Engineering Standards that need to be conformed to throughout the development of the module as well as during the production.

1.3 Intended Audience

This document serves to outline the requirements for the Ember Trailer module for the members of Nature Coolers, Dr. Craig Scratchley, teaching assistants, and potential clients and partners for the product.

The intended use for the module will be for wildfire responders around the world to have a remote system for Cold Trailing and Mopping Up extinguished wildfires. With forest fires being such a global issue due to the constant rise in summer temperatures, the market is quite wide for this module and there is plenty of potential to develop it into its own independent UGV.

1.4 Requirement Classification

The requirements listed in each requirements section will be classified as follows:

R{Section}.{Subsection}.{Requirement Number} {Development Phase}

If the requirements are not listed under a specific subsection, then '0' will be used to indicate that no subsection applies.

For the development phase, the different phases are listed below with the encoding that will be used.

Table 2. Development Phase Encoding

Encoding	Development Phase
A	Alpha Phase

B	Beta Phase
P	Production Phase

The Alpha Phase specifies requirements that must be completed by the end of ENSC 405W which ends in August 2022. This portion will contain our proof-of-concept prototype. The Beta Phase specifies requirements that must be met by the end of ENSC 440 which ends in December 2022. This portion will contain the refined prototype ideally ready to go into production. The Production Phase is the phase that would happen after ENSC 440 when the product will be packaged and ready to be sold.

2. System Overview

At its core, the Ember Trailer module will be a series of sensors, transceivers, and a mechanical suppression system to locate and help extinguish embers found during the mop-up process. The module will be attachable to a UGV based on the Boston Dynamics' athletically intelligent robot dog, "Spot" [3]. The product will only focus on the module for detection and suppression; the UGV is assumed to be manually controlled by an operator or, ideally, autonomous. There will be 3 main systems to the module: the detection sensors, transceiver modules, and the suppression system.

The sensor system will contain both an infrared camera and a temperature probe. The camera's purpose is to spot any surface level embers or unusual heat signatures that may require specific attention from firefighters and wildfire responders. The temperature probe will be mounted on the underside of the UGV and will be periodically plunged into the ground to sense for any deep embers that require excavation. Using these two sensors in tandem will allow for the Ember Trailer to detect anything that may cause a reignition of the forest fire.

The transceiver module will be relaying the position of the UGV, as well as relevant sensor data, back to an HQ laptop so the mop-up mission can be tracked in real time. Real time tracking is important in the event a major fire is spotted that a mop-up team cannot handle alone. With Nature Cooler's Ember Trailer module, fire zone HQ can see the coordinates of the fire and send a bigger team to engage before it gets out of control.

A suppression system will be mounted on the top side of a UGV and will consist of a spray nozzle and a tank of suppressant or water. The nozzle will be able to rotate, approximately, 180 degrees facing forward to tackle embers in most directions. With the water supply mounted on the back and fed into the nozzle via a carefully placed hose, most small fires should be able to be suppressed.

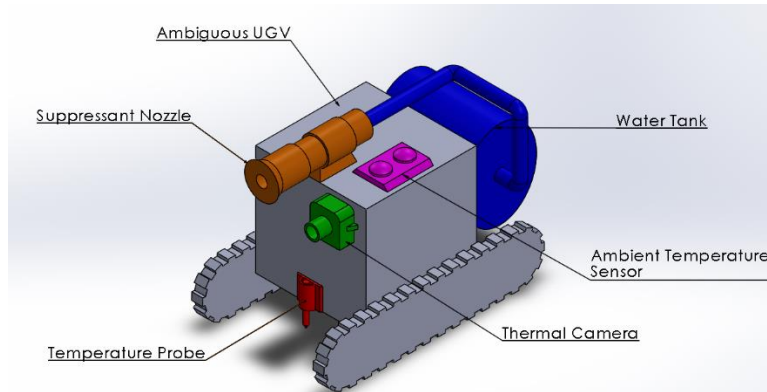


Fig. 2. Conceptual Model of the Ember Trailer Module

3. General Requirements

The following table describes the general system requirements of the wildfire detection and suppression module, Ember Trailer.

Table 3. General System Requirements

Requirement ID	Requirement Description
R3.0.1 B	The system will consist of a power supply and 3 components: detection, suppression, and communication.
R3.0.2 B	The detection component will consist of a microcontroller, an infrared camera, temperature sensors, and a gas sensor.
R3.0.3 B	The suppression component will consist of a tank, and a hose arm.
R3.0.4 B	The communication component will consist of transceiver modules, and a GPS module.
R3.0.5 B	The module must be attachable to a drone/UGV.
R3.0.6 B	The module must not impede a drone or UGV's operation.
R3.0.7 A	The module must be able to detect surface hotspots and embers.
R3.0.8 A	The module must be able to detect subterranean hotspots and embers.
R3.0.9 B	The module must be able to alert responders of hotspots that could reignite the wildfire.
R3.0.10 B	The module must be able to cool down smaller embers and hotspots.

4. Electrical Requirements

4.1 Power Supply

Table 4. Power Supply Requirements

Requirement ID	Requirement Description
R4.1.1 A	The power supply shall output 12V.
R4.1.2 A	The power supply shall effectively power all components in the system.
R4.1.3 B	The power supply shall be able to withstand high temperatures.
R4.1.4 A	The power supply shall be rechargeable.
R4.1.5 A	The power supply shall be charged through a 120V AC wall outlet
R4.1.6 B	The module shall have a battery life of at least 6 hours.

4.2 Wiring

Table 5. Wiring Requirements

Requirement ID	Requirement Description
R4.2.1 A	There shall be no loose connections between each component and wires in the device.
R4.2.2 B	The wiring shall be sufficiently protected from heat and other external obstacles.
R4.2.3 B	The wiring shall be suitably organized to optimize temperature in the module.

5. Mechanical Requirements

Table 6. General Mechanical Requirements

Requirement ID	Requirement Description
R5.0.1 B	The Ember Trailer's weight shall not hinder the UGV.
R5.0.2 B	The Ember Trailer shall be resistant to high temperatures.
R5.0.3 B	The Ember Trailer shall be resistant to external pressure.
R5.0.4 B	The Ember Trailer shall be placed onto the UGV without removing itself.
R5.0.5 B	The Ember Trailer shall shield all hardware components from damage.
R5.0.6 B	The Ember Trailer shall shield all hardware components from high temperatures.

5.1 Suppression Module

Table 7. Suppression Module Requirements

Requirement ID	Requirement Description
R5.1.1 B	Suppression hose must be able to extinguish embers.
R5.1.2 B	The tank payload shall not hinder the UGV.
R5.1.3 B	The suppression module shall operate in high temperatures.
R5.1.4 A	The suppression hose shall not twist in a way that hinders water flow.
R5.1.5 A	The suppression hose shall not extend beyond the UGV's body.

6. Hardware Requirements

6.1 Drill Module

Table 8. Drill Module Requirements

Requirement ID	Requirement Description
R6.1.1 A	The drill module shall have enough force to drill into the ground.
R6.1.2 B	The drill module shall operate in high temperatures.
R6.1.3 A	The drill module shall not damage the UGV.
R6.1.4 A	The drill module shall not damage the probe sensor.
R6.1.5 B	The drill module shall not interfere with the operation of the UGV.
R6.1.6 A	The drill module shall not interfere with the operation of Ember Trailer.

6.2 Communication Module

Table 9. Communication Module Requirements

Requirement ID	Requirement Description
R6.2.1 A	The communication module shall gather data from all sensors and the camera.
R6.2.2 B	The communication module shall operate in high temperatures.
R6.2.3 A	The communication module shall accept inputs from the user.
R6.2.4 A	The communication module shall output data to the user.

6.3 Camera

Table 10. Camera Requirements

Requirement ID	Requirement Description
R6.3.1 A	The camera shall be able to detect heat radiating off an object.
R6.3.2 A	The camera shall be able to distinguish between various objects.
R6.3.3 A	The camera shall be able to distinguish different temperature readings.
R6.3.4 B	The camera shall have sufficient field of view to see the desired area.
R6.3.5 B	The camera shall operate in high temperatures.
R6.3.6 B	The camera shall be protected from external physical damage.

6.4 Probe Temperature Sensor

Table 11. Probe Temperature Sensor Requirements

Requirement ID	Requirement Description
R6.4.1 A	The probe temperature sensor shall measure the temperature of the ground.
R6.4.2 B	The probe temperature sensor shall operate in high temperatures.
R6.4.3 A	The probe temperature sensor shall give accurate readings.
R6.4.4 B	The probe temperature sensor shall withstand external pressure.
R6.4.5 B	The probe temperature sensor shall withstand pressure while being driven into the ground.

6.5 Ambient Temperature Sensor

Table 12. Ambient Temperature Sensor Requirements

Requirement ID	Requirement Description
R6.5.1 A	The ambient temperature sensor shall measure the internal temperature of the module.
R6.5.2 B	The ambient temperature sensor shall operate in high temperatures.
R6.5.3 A	The ambient temperature sensor shall give accurate readings.

6.6 Gas Sensor

Table 13. Gas Sensor Requirements

Requirement ID	Requirement Description
R6.6.1 A	The gas sensor shall measure the gas concentration in the surrounding atmosphere.

R6.6.2 B	The gas sensor shall operate in high temperatures.
R6.6.3 A	The gas sensor shall give accurate readings.

6.7 GPS Module

Table 14. GPS Module Requirements

Requirement ID	Requirement Description
R6.7.1 A	The GPS module shall transmit the UGV's location in longitude and latitude format.
R6.7.2 A	The GPS module shall transmit the location when the conditions for a fire have been met.
R6.7.3 B	The GPS module shall operate in high temperatures.
R6.7.4 A	The GPS module shall transmit accurate coordinates.

7. Software Requirements

7.1 Telemetry

Table 15. Telemetry Requirements

Requirement ID	Requirement Description
R7.1.1 B	The module must be able to wirelessly communicate with HQ up to 2 kilometers in distance.
R7.1.2 A	The module shall transmit data consisting of status and location periodically.
R7.1.3 A	The module shall receive data consisting of status information periodically.
R7.1.4 A	The module shall transmit, and HQ should receive data when an event occurs (small and large threats, module stuck/overheating, no battery/suppressant etc.) as soon as possible.
R7.1.5 A	The HQ should transmit, and the module should receive data when a command is sent from HQ (power off/on, ignore fires, etc.).
R7.1.6 B	The module/HQ will verify data integrity of each message.
R7.1.7 B	The module/HQ will resend dropped messages up to 5 times, until it will declare disconnected, and try to initiate reconnect.

7.2 UI Design

Table 16. UI Design Requirements

Requirement ID	Requirement Description
R7.2.1 B	The program will ask the user for credentials after idling for 10 minutes to prevent unauthorized access.
R7.2.2 B	The program must have color and font size options for the visually impaired.
R7.2.3 A	The program must represent the current volume of the battery.
R7.2.4 A	The program must display the location of the module.
R7.2.5 B	The program will display a map highlighting hotspots, extinguished hotspots, and the UGV/module position.
R7.2.6 B	The program must have controls for power on/off the module.
R7.2.7 A	The program must display a warning when the battery level falls below 15%.
R7.2.8 A	The program must display a warning when the equipment is overheating.
R7.2.9 A	The program must display a warning with the last known location when the signal is lost and attempting to reconnect.
R7.2.10 A	The program must inform the field team the specific orientation in longitude and latitude when the module detects a potential wildfire.
R7.2.11 A	The program must inform the field team the specific orientation in longitude and latitude when the module detects surface or subterranean embers.

7.3 Performance

Table 17. Software Performance Requirements

Requirement ID	Requirement Description
R7.3.1 A	The module software must be able to run on a Raspberry Pi 4 and Arduino Uno.
R7.3.2 A	The HQ software must be able to run on a basic computer.
R7.3.3 B	The software must be able to recover from brief signal disconnects.
R7.3.4 B	The software must be able to recover from a reboot or shutdown and continue operating were last online.

8. Safety and Sustainability

The wildfire detection and suppression module will interact a lot with the environment and, more specifically, wildfires. This could pose dangers regarding the heat tolerance of electronics and circuitry when dealing with embers, hotspots, or small fires during the aftermath of the wildfire. Additionally, while suppressing/cooling down hot material left over from the fire which could cause it to reignite, caution must be taken to ensure that no toxic contaminants are mixed in with the environment.

8.1 Packaging

Table 18. Packaging Requirements

Requirement ID	Requirement Description
R8.1.1 P	The packaging for small components shall contain warnings for choking hazard.
R8.1.2 P	The packaging must conform to the product labeling requirements outlined by ISO 28219:2017 [4].
R8.1.3 P	The packaging must contain a warning for sharp material included in the module.
R8.1.4 P	The packaging of the module shall use recyclable/reusable material.
R8.1.5 P	The packaging shall contain instructions to dispose the packaging material safely and sustainably.
R8.1.6 P	The packaging shall contain instructions to safely dispose the module if module becomes broken and irreparable.
R8.1.7 P	The packaging shall contain clear instructions regarding how to properly attach the module to a drone/UGV.
R8.1.8 P	The packaging shall contain clear instructions regarding how to operate the module correctly.

8.2 Electrical Safety

Table 19. Electrical Safety Requirements

Requirement ID	Requirement Description
R8.2.1 B	The electronics shall be fully enclosed and not exposed.
R8.2.2 B	The electronics must be able to handle heat that would radiate from small fires, embers, and/or hotspots.
R8.2.3 B	The battery and circuitry shall not pose an additional fire or explosion threat in higher-than-normal operating temperatures.
R8.2.4 B	The module shall safely power off and alert its users in an event where the heat becomes too high for the electronic components to operate safely.

8.3 Hardware Safety

Table 20. Hardware Safety Requirements

Requirement ID	Requirement Description
R8.3.1 P	Hardware with sharp edges shall be safely covered/guarded so as not to cause any injuries when handling the product.
R8.3.2 B	The module shall not be constructed using any materials that would be toxic to living beings or the environment.

8.4 Software Safety

Table 21. Software Safety Requirements

Requirement ID	Requirement Description
R8.4.1 B	The program for HQ will be password protected in the case it is left unattended to prevent unwanted operators.
R8.4.2 B	The data log files shall be encrypted to prevent any data being stolen and misused.

8.5 Environmental Sustainability

Table 22. Environmental Sustainability Requirements

Requirement ID	Requirement Description
R8.5.1 B	The suppressant used shall not contain any toxic contaminants that would be harmful to living beings or the environment.
R8.5.2 B	The method of suppression used shall only minimally disturb the natural environment, if necessary, when cooling down hot embers/material.
R8.5.3 P	Any discarded components of the module that cannot be repaired shall go through the recycling process for electronics.
R8.5.4 P	Any discarded component of the module that can still work shall be repurposed depending on what component was discarded.

9. Engineering Standards

Adhering to industry standards is important for our product to enter the market. The following sections contain the standards published that will be relevant to the development of the product.

9.1 Electrical Standards

Table 23. Electrical Standards

Standard	Standard Description
CSA C22.2 NO 0	General requirements — Canadian Electrical Code, Part II [5]
CSA C22.2 NO. 0.23:15	General requirements for battery-powered appliances [6]

CSA C22.2 NO 61508-1:17	Functional safety of electrical/electronic/programmable electronic safety related systems - Part 1: General requirements [7]
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9.2 Hardware Standards

Table 24. Hardware Standards

Standard	Standard Description
NFPA 1801	Standard on Thermal Imagers for the Fire Service [8]
CSA C22.2 No. 100-14	Motors and generators [9]

9.3 Software Standards

Table 25. Software Standards

Standard	Standard Description
ISO 9241-125:2017	Ergonomics of human-system interaction - Part 125: Guidance on visual presentation of information [10]
NFPA 950	Standard for Data Development and Exchange for the Fire Service [11]

9.4 Environmental Standards

Table 26. Environmental Standards

Standard	Standard Description
ISO TS 19677	Guidelines for assessing the adverse impact of wildland fires on the environment and to people through environmental exposure [12]
CSA ISO 14004	Environmental management systems - General guidelines on implementation [13]

10. Conclusion

The Ember Trailer is an attachable module for drones and UGVs that will be pivotal in assisting wildfire responders with mopping up after a major wildfire has been extinguished. Equipped with temperature sensors and a fire suppression system, the Ember Trailer ensures that no stray flame will go unnoticed. Additionally, tracking positional data in real time and relaying this to responders allows this module to provide important, time-sensitive updates as it works.

This document has provided an overview of the functionality of Ember Trailer and its requirements. Descriptions of the electrical, mechanical, hardware, software, and general system requirements have been detailed. Also included are the engineering and safety standards that the team at Nature Coolers will adhere to in the development of this product. Information about the sustainability of the module outlines how we will keep this product environmentally friendly with intelligently designed parts and enclosures, as well as appropriate fire suppression methods to have minimal impact on nature.

11. Technical Appendices

10.1 Acceptance Test Plan

**Note: the criteria highlighted in yellow are requirements that should be satisfied by ENSC 405W end-of-term demonstration.*

Test Sheet	
Company 3 — Nature Coolers	Date:
Electrical Components	
Power Supply	Comments:
Life: >6hours <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
Low Battery: Alert <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
Mechanical Components	
Suppression Module	Comments:
Rotation: 180° <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
Cooldown Hot Material <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
General System	Comments:
Weight: <30lbs <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
Hardware Components	
Drill Module	Comments:
Penetrates the Ground <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
Communication Module	Comments:
Sends and Receives Data <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
Sensors	Comments:
Detects and Distinguishes Heat Signatures <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
Reads Temperature of the Ground <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
Correctly Identify Embers <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
Software Components	

Telemetry	Comments:
Distance: 2km <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
Logs Data <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
Dropped Messages Resend Up To 5 Times <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
User Interface	Comments:
Correctly Indicate Embers When Found <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
Asks for Credentials After Idling 10 Minutes <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
Relevant Sensor Data is Displayed to User <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	
GPS Location of the Module is Displayed <input type="checkbox"/> Yes (pass) <input type="checkbox"/> No (fail)	

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