Autonomous Ground Vehicle for Real-Time Human Survival Detection
System Requirements Specification
Version 1.9
10/31/2024

Document Control

Distribution List

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Change Summary

The following table details changes made between versions of this document:

Version	Date	Modifier	Description
1.0	10/24/2024	Alessia Tripaldelli	First Draft on the document introduction
1.1	10/27/2024	Alessia Tripaldelli	Part 1 of the documentation finalized (1.1-1.5)
1.2	10/28/2024	George Pozek	Completed sections 2.3 - 2.7
1.3	10/28/2024	Matthew Berkowitz	7.2, 3.3, 5.4
1.4	10/28/2024	Andrea Gamble	7.1.1-7.1.6, 4.5, 5.3.2-5.3.3, 4.3, 8
1.5	10/28/2024	Joel Steuber	Sections 3.1, 3.2, & 3.4
1.6	10/28/2024	Peter Nguyen	Database req, use case diagram
1.7	10/30/2024	George Pozek	Added more requirements to help fill in various sections
1.8	10/31/2024	Everyone	Added more requirements to each section and went through a final checking process
1.9	10/31/2024	Joel Steuber	Formatting to table + sequentially numbering requirements

Table of Contents

1. Introduction

1.1. Purpose and Scope

In modern autonomous vehicle systems, detecting and classifying objects is important for navigating safely and effectively, especially in potentially hazardous situations. Thus, the Autonomous Ground Vehicle for Real-Time Human Survival Detection (AGV-HSD) is designed to locate and identify human survivors in disaster zones. The system addresses the need for accurate detection of survivors by asking for a vocal response and detecting heartbeat and body temperature.The lack of accurate detection systems in challenging environments prompted us to develop a reliable and cost-effective AGV that provides precise identification of survivors, reduces misclassification, and speeds up rescue operations.

The AGV-HSD includes multiple sensor systems, communication protocols, and software algorithms to provide real-time data transmission and survivor classification. The system includes hardware development for vehicle's movement and sensors, communication setup for data transmission, and software implementation for autonomous operation and human detection. However, the project will not include any type of autonomous medical intervention.

This system could be beneficial in disaster zones, increasing rescue accuracy and response times, and avoiding human rescuers entering dangerous areas. The main focus of the project is real-time human detection and communication with the Ground Station to perform safer and more efficient search and rescue operations.

1.2. Intended Audience and Reading Suggestions

This document is intended for developers, project managers, testers, and users. In particular, developers would benefit from this project by analyzing and studying the technical requirements and system architecture needed to build and implement the AGV. They would need to focus on reading the purpose and scope, product perspective, features, functional and behavioral requirements. Project managers could use this document to understand the project's scope, objectives, and team roles, focusing on reading the purpose, scope, and general description of the project. Testers could inspect the documentation to learn more about the system requirements and expected outcomes for planning and conducting tests. They would need to focus on understanding behavioral and functional requirements as well as the design and implementation constraints. Finally, users could review the document to understand the AGV's features and functionalities, and how they apply to real life. They would benefit from reading the sections regarding purpose and scope, general description, and user documentation.

1.3. Document Conventions

This document follows specific conventions for clarity and consistency. Bold text is used for section titles and key terms, while italicized text shows important concepts. Numbered lists describe requirements in a sequence, while bulleted lists are used for general information or descriptions. Each requirement is assigned a priority level (e.g., High, Medium, Low), with no assumption of priority inheritance. Acronyms are defined upon first mention and listed in a glossary for reference, and technical terms are explained in simple and clear language. The document uses a standard font, with headings in larger sizes.

1.4. Project References

This section includes references related to the development of the Autonomous Ground Vehicle for Real-Time Human Survival Detection (AGV-HSD). They include communication protocols, sensors and object detection, object tracking and navigation, and a technical literature review. The resources used to develop the AVG are listed below:

1. Communication Protocols:

   Nesti, T., et al. (2023). Ultra-Sonic Sensor based Object Detection for Autonomous Vehicles. CVPR Workshop. This document provides insights into efficient communication systems like Profinet for AGV communication.

   Stój, J., Kampen, A.-L., et al. (2023). Industrial Shared Wireless Communication Systems—Use Case of Autonomous Guided Vehicles with Collaborative Robot. Sensors, 23(1), 158. This paper discusses wireless communication systems relevant to AGVs.

   M. Zhan and K. Yu, "Wireless Communication Technologies in Automated Guided Vehicles: Survey and Analysis," IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society, Washington, DC, USA, 2018, pp. 4155-4161, doi: 10.1109/IECON.2018.8592782. keywords: {Wireless communication;ZigBee;IEEE 802.11 Standard;Control systems;Reliability;Wireless sensor networks;industrial automation;wireless control;automated guided vehicles;ZigBee;IEEE 802.11},

   J. Smith, A. Lee, and R. Carter, "Towards an AI-enabled Connected Industry: AGV Communication and Sensor Data Integration," IEEE Transactions on Industrial Informatics, vol. 19, no. 2, Feb. 2023, pp. 1012-1024, doi: 10.1109/TII.2023.3235567.

   P. Davis and T. Brown, "Three Keys to Building Reliable Wireless Communications for AGVs," Automation Journal, July 2022, [Online]. Available: https://www.automation.com/en-us/articles/july-2022/building-reliable-wireless-communication-agvs. Keywords: Wireless reliability; AGV networks; Industrial-grade communication; Dynamic environments; Automation systems.

   L. Wang, S. Patel, and H. Kim, "A Review of Recent Advances in Automated Guided Vehicle Technologies: Integration Challenges and Research Areas for 5G-Based Smart Manufacturing Applications," IEEE Access, vol. 8, 2020, pp. 184299-184315, doi: 10.1109/ACCESS.2020.3017814.

2. Sensors and Object Detection:

   Vargas, J., Alsweiss, S., et al. (2021). An Overview of Autonomous Vehicles Sensors and Their Vulnerability to Weather Conditions. Sensors, 21(16), 5397. This reference discusses the performance of LiDAR and radar in diverse conditions, guiding sensor selection.

Mahboob, H., et al. (2023). DCP-SLAM: Distributed Collaborative Partial Swarm SLAM for Efficient Navigation of Autonomous Robots. Sensors, 23(2), 1025. This work contributes to the understanding of bandwidth optimization in LiDAR systems.

Faroni, M., Pedrocchi, N. & Beschi, M. Adaptive hybrid local–global sampling for fast informed sampling-based optimal path planning. Auton Robot 48, 6 (2024). https://doi.org/10.1007/s10514-024-10157-5

3. Object Tracking and Navigation:

Yang, Y., et al. (2024). Sampling-Efficient Path Planning and Improved Actor-Critic-Based Obstacle Avoidance for Autonomous Robots. Science China Information Sciences, 67(5). This article informs the development of algorithms for object detection and path planning in AGVs.

Bi-AM-RRT: A Fast and Efficient Sampling-Based Motion Planning Algorithm in Dynamic Environments" by Ying Zhang et al. (2023). This paper introduces the Bi-AM-RRT algorithm, which optimizes robot motion planning in dynamic environments by incorporating an assisting metric to enhance performance and employing bidirectional search strategies to reduce search time.

4. Technical Documentation:

Liu, Y., et al. (2021). An Autonomous Positioning Method for Fire Robots with Multi-Source Sensors. Wireless Networks. This paper aids in understanding multi-sensor integration for the AGV’s detection capabilities.

Fink, J., et al. (2012). Robust Control for Mobility and Wireless Communication in Cyber–Physical Systems. Proceedings of the IEEE, 100(1), 164–178. This document helps design the control and mobility aspects of the AGV.

G. Dudek et al., "AQUA: An Amphibious Autonomous Robot," in Computer, vol. 40, no. 1, pp. 46-53, Jan. 2007, doi: 10.1109/MC.2007.6.https://ieeexplore.ieee.org/document/4069194?denied=

Yaqoob, I., & Bajwa, I. S. (2023). Performance evaluation of mobile stereonet for Real Time Navigation in Autonomous Mobile Robots. Multimedia Tools and Applications, 83(12), 35043–35072. https://doi.org/10.1007/s11042-023-16710-1

Müller, S., Müller, T., Ahmed, A., & Horst-Michael Gross. (2023). Laser-Based Door Localization for Autonomous Mobile Service Robots. Sensors, 23(11), 5247. https://doi.org/10.3390/s23115247

Hassan, N., Aubry Clément, Solatges, T., Xavier, S., Rossi, R., & Boutteau Rémi. (2021). LiDAR-based Structure Tracking for Agricultural Robots: Application to Autonomous Navigation in Vineyards. Journal of Intelligent & Robotic Systems, 103(4)https://doi.org/10.1007/s10846-021-01519-7

S. Acharya, M. Bharatheesha, Y. Simmhan and B. Amrutur, "A Co-Simulation Framework for Communication and Control in Autonomous Multi-Robot Systems," 2023 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Detroit, MI, USA, 2023, pp. 11087-11094, doi: 10.1109/IROS55552.2023.10342407

1.5. Definitions, Acronyms, and Abbreviations

This section provides a glossary of terms, acronyms, and abbreviations used throughout the document to allow readers to clearly understand the technical aspects.

1.5.1. Definitions

Table 1: Technical Definitions

Term	Definition
Autonomous Ground Vehicle	A mobile robot designed to move autonomously and detect human survivors in disaster scenarios
Human Survival Detection	System's function to identify survivors based on vocal recognition, heartbeat and body temperature.
Light Detection and Ranging	A sensor technology used for creating high-resolution 3D maps of the environment.
Radio Detection and Ranging	A sensor that uses radio waves to detect objects and determine their range, angle, or velocity.
Long Range	A communication protocol for wireless data transmission with low power consumption, used for AGV communication with Ground Stations.
Peer-to-Peer	A communication model used to establish direct connections between devices to provide data transfer without a centralized server.
Raspberry Pi	A small computer used in the AGV system for processing data and controlling components.
Software Requirements Specification	A document that describes the software system's requirements, functions, and design specifications.
Simultaneous Localization and Mapping	A method used by robots to build a map of their surroundings while tracking their location.
Universal Asynchronous Receiver-Transmitter	A computer hardware device used for asynchronous serial communication between devices.

Ground Station	A device used to communicate with the AGV.

1.5.2. Acronyms

Table 2: Acronyms

Term	Definition
AGV	Autonomous Ground Vehicle
HSD	Human Survival Detection
LiDAR	Light Detection and Ranging
Radar	Radio Detection and Ranging
LoRa	Long Range
P2P	Peer-to-Peer
Rpi	Raspberry Pi
Rpi5	Raspberry Pi 5
SRS	Software Requirements Specification
SLAM	Simultaneous Localization and Mapping
UART	Universal Asynchronous Receiver-Transmitter
SQL	Standard Query Language
IP	Internet Protocol
USB	Universal System Bus

1.5.3. Abbreviations

Table 3: Abbreviations

Term	Definition
e.g.	For example
i.e.	That is
etc.	And so on

2. General Description

2.1. Product Perspective

The AGV built for HSD is a new, self-contained system designed to assist search and rescue teams by detecting human survivors in disaster zones. The AGV is not a follow-on member of an existing product family, nor is it replacing any previous system. It is an independent solution specifically built to enhance rescue efforts by identifying survivors based on heartbeat and body temperature in challenging environments.

Within the customer's organization, the AGV will function as a tool for search and rescue missions, improving response time and increasing the accuracy of locating survivors. The vehicle will provide real-time data to rescue teams, helping them prioritize rescue efforts and allocate resources effectively. Its primary functionalities include real-time detection of survivors, secure communication with external systems, and accurate mapping of survivor locations.

The AGV interfaces with external systems through wireless communication protocols, such as LoRa, allowing for seamless data exchange with ground control stations. These stations can then manage and monitor the AGV's movements, detection results, and communication. The AGV's software integrates with sensors and mapping components, working as part of a larger rescue operation network, but it is self-sufficient and capable of operating independently.

2.2. Product Features

The Autonomous Ground Vehicle for Real-Time Human Survival Detection (AGV-HSD) is designed to assist search and rescue missions by detecting and locating human survivors in disaster zones. The AGV's core features focus on accuracy, reliability, and seamless communication with ground control systems.

The first feature is real-time human detection, where the AGV uses sensors to identify survivors by detecting heartbeat and body temperature. This detection system is designed to minimize false positives, providing accurate results even in complex environments. Another key feature is autonomous navigation, where the AGV leverages radar sensors for real-time mapping and obstacle avoidance. The vehicle employs SLAM algorithms, enabling it to create maps of its surroundings and navigate through debris-filled areas independently.

The AGV also supports secure communication, using LoRa-based wireless protocols to exchange real-time data with ground control stations. Additionally, P2P connections enable direct communication between the vehicle's components, maintaining reliability even in unstable network conditions. The vehicle's survivor location mapping feature allows it to accurately map detected survivors' positions relative to its location, which helps rescue teams in planning targeted interventions, reducing response time, and increasing rescue success rates. Lastly, the AGV offers a ground control interface, which allows users to remotely monitor the vehicle, access graphical interfaces for object detection and mapping, and send real-time commands to adjust settings or navigation paths. This combination of features makes the AGV a tool that supports search and rescue operations by providing timely, accurate information while operating in disaster-stricken areas.

2.3. User Classes and Characteristics

The AGV is designed to support various user classes, each with distinct characteristics and roles. Below are the user classes, their characteristics, and how they interact with the system.

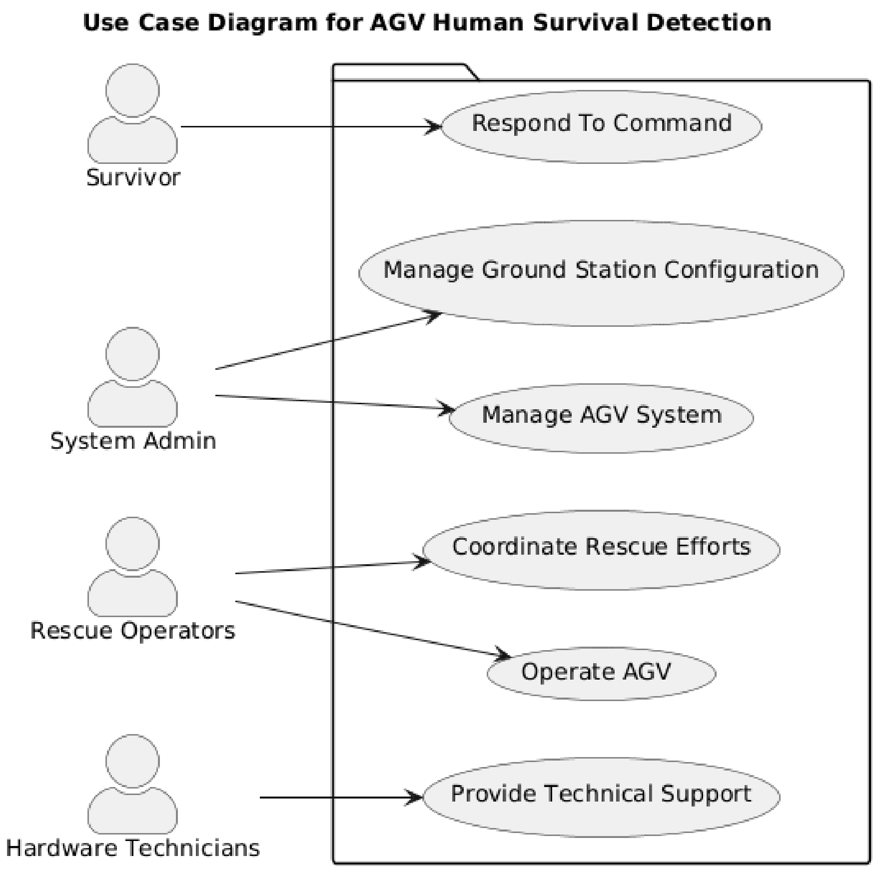

Figure 1: Use Case Diagram

2.3.1. Actors

This section presents the actors in the system.

- **Rescue Operators**
    - ***Function:*** These users are responsible for operating the AGV and oversee the entire rescue operation, including managing AGV deployments and coordinating ground teams.
    - ***Location:*** At the Ground Station and/or disaster zones
    - ***Devices:*** Laptop that can connect to the Ground Station and read the data received from the AGV

- ***Characteristics:*** Moderate technical expertise. High-level decision-making skills. Experience in disaster management and rescue coordination. Basic understanding of the Ground Station's interface
- ***Number:*** 1 per every AGV
- ***Usage:*** They use the AGV to detect survivors, receive real-time data, and control the AGV's navigation and settings. Using the data received to coordinate with rescue teams on the scene

- **System Administrators**
  - ***Function:*** These users manage the AGV's software, the Ground Station, and overall system configuration.
  - ***Location:*** External command and/or maintenance centers
  - ***Devices:*** Laptops or desktop computers that can interface with both the AGV and the Ground Station
  - ***Characteristics:*** High technical expertise. Familiarity with software and hardware troubleshooting. Responsible for system updates and communication protocols.
  - ***Number:*** 2-3 per every AGV
  - ***Usage:*** They perform software updates, manage the communication system, and ensure the AGV and Ground Station is ready for operations.

- **Hardware Technicians**
  - ***Function:*** Provide technical assistance during AGV deployment, handle any hardware repairs, and monitor system performance.
  - ***Location:*** At the Ground Station or near a disaster zone
  - ***Devices:*** Laptops and handheld diagnostic tools.
  - ***Characteristics:*** Moderate technical skills. Capable of handling hardware repairs and system checks. Proficient in communication protocols and device troubleshooting.
  - ***Number:*** 1-2 per every AGV
  - ***Usage:*** Support real-time operations by addressing any issues regarding the hardware and ensuring continuous AGV performance.
- **Survivor**
  - ***Function:*** Responds to the AGV indicating the person is alive and does not need help.
  - ***Location:*** At the disaster zone
  - ***Devices:***
  - ***Characteristics:*** Can wave and talk to the rover in response to a question or command from the rover.
  - ***Number:*** Multiple

2.3.2. Use Cases

- **Operate AGV**
  - ***Users:*** Rescue Operators
  - ***Description:*** Users deploy the AGV in disaster zones, receive detection alerts, and navigate the vehicle to potential survivor locations.
- **Coordinate Rescue Efforts**
  - ***Users:*** Rescue Operators
  - ***Description:*** Coordinators receive detection data, plan rescue interventions, and communicate with ground teams.
- **Manage AGV System**
  - ***Users:*** System Administrators
  - ***Description:*** Admins maintain and update the AGV's software, manage configurations, and ensure system readiness.
- **Manage Ground Station Configuration**
  - ***Users:*** System Administrators
  - ***Description:*** Admins maintain and update the Ground Station, ensuring system readiness through constant stress testing.
- **Provide Technical Support**
  - ***Users:*** Hardware Technicians
  - ***Descriptions:*** Staff troubleshoot technical issues, perform repairs, and ensure the AGV's continuous operation during and outside of missions.

2.3.3. Scenarios

This section presents scenarios for each use case described in the previous section.

Scenario 1: Deploy AGV

Description: The rescue operator deploys the AGV for a search and rescue mission.

Actors: Rescue Operator.

Precondition: The AGV is fully operational and connected to the ground control interface.

Trigger Condition: The operator initiates deployment.

Steps:

1. The operator selects deployment location via ground control interface.
2. The AGV is activated and starts looking to detect survivors.

3. The AGV sends detection results to the operator if they find someone.
3.1. The AGV tracks where the person needing to be rescued is located.
3.2. Use case continues at step 2.

Scenario 2: AGV System Maintenance

Description: The system administrator performs a software update, or fixes any error within the AGV's software

Actors: System Administrator.

Precondition: The AGV is in standby.

Trigger Condition: The system administrator schedules a software update/patch.

Steps:

1. The system administrator connects with the raspberry pi used to control the AGV's system.
2. The update is conducted.
    2.1. If the update fails the system administrator retries from step 1 after a new update is released.
3. The AGV reboots and confirms the update completion.

Scenario 3: Ground Station System Maintenance

Description: The system administrator performs a software update, or fixes any software error within the Ground Station itself.

Actors: System Administrator.

Precondition: The Ground Station is not deployed.

Trigger Condition: The system administrator schedules a software update/patch.

Steps:

1. The system administrator connects with the raspberry pi used as the Ground Station system.
2. The updated is conducted.
2.1. If the updated fails the system administrator retries from step 1 after a new update is released.
3. The Ground Station reboots and confirms the update completion.

Scenario 4: Technical Repairs

Description: The hardware technician fixes any problems that the hardware is having.

Actors: Hardware Technician.

Precondition: The AGV is in standby.

Trigger Condition: The hardware technician schedules a routine maintenance on the AGV.

Steps:

1. The hardware technician tests all pieces of hardware to make sure they work.
1.1. If one or more of the parts doesn't work then the hardware technician takes note and orders them.
1.2. After replacing the broken parts the hardware technician begins from step 1 again.
2. The AGV is then tested again to ensure proper hardware capabilities.
2.1. If the AGV fails any of the tests the technician restarts from step 1.
3. The AGV is prepped to be redeployed.

Scenario 5: Coordination of Rescue Efforts

Description: The rescue coordinator sends information gathered from the AGV to any authorities on the scene.

Actors: Rescue Operator.

Precondition: The AGV is deployed.

Trigger Condition: The AGV has detected survivors and pinpointed where they were.

Steps:

1. The AGV marks the location of survivors.
2. The Rescue Coordinator sends that location data to local authorities.
3. The Rescue Coordinator continues while the AGV is detecting survivors.

2.4. General Constraints

The AGV must operate in low-resource environments, making power efficiency crucial. It relies on battery power, limiting processing capacity, memory, and sensor operation, which constrains onboard software performance. Additionally, the AGV must provide real-time detection and data transmission with minimal latency, a requirement that challenges both hardware and communication protocols, particularly in network-unstable disaster zones. The vehicle must withstand extreme weather conditions such as heavy rain, dust, and fluctuating temperatures, which impacts material selection and requires robust sealing and cooling mechanisms.

The AGV's communication systems must ensure secure and reliable data exchange with ground control stations, incorporating encryption to prevent unauthorized access. Given the rugged terrains and harsh conditions in which it operates, the AGV's design needs to be durable and light while able to carry heavy equipment. Budget constraints further limit the development process, requiring cost-effective solutions in terms of sensors, hardware, and software tools.

The AGV will primarily be developed using Python on Raspberry Pi hardware, influencing programming standards and limiting the selection of tools and software libraries to those that support the hardware. The robot will need to be able to use memory to store the location where survivors are located within the disaster zone. In terms of maintenance, the vehicle's design must allow for easy repairs and part replacements in the field, with minimal tools. Lastly, the system must include safety mechanisms, such as collision detection and emergency stops, to prevent harm during rescue missions.

2.5. Operating Environment

The AGV is designed to operate in disaster zones and needs to be able to efficiently operate within extreme temperature ranges, from as low as -10°C (14°F) to as high as 50°C (122°F), without experiencing performance degradation. It must also operate under varying light levels, including low-light or night conditions, requiring sensors to perform well under limited visibility. The system should be equipped with sufficient protection against dust, debris, and moisture, ensuring that all electronic components and sensors are properly sealed and insulated.

The AGV will use a Raspberry Pi 5 as its hardware platform, running on a Linux-based operating system, which is compatible with the onboard sensors and communication systems. This includes components such as radar modules, heartbeat sensors, speakers, cameras and thermal cameras. The system must also coexist with external devices such as ground control stations and communication devices, ensuring seamless interaction with wireless communication protocols like LoRa.

The AGV's software components, primarily written in Python, must integrate smoothly with sensor drivers, mapping tools, and communication protocols, supporting real-time data processing and transmission. Given unstable network conditions within disaster zones, the system must maintain connectivity and communication in areas with limited signal strength. Additionally, the AGV's design must enable easy adaptation to different terrains, ranging from urban rubble to rugged natural landscapes, ensuring stable movement and navigation.

2.6. User Documentation

The AGV will be accompanied by comprehensive user documentation to ensure successful deployment, operation, and maintenance. The user documentation components will include:

- **User Manual**
  - This manual will provide step-by-step instructions on operating the AGV, including deployment, navigation, and communication with ground control systems.
  - It will include sections on system setup, real-time detection, troubleshooting, and safety guidelines.
  - The user manual will be available in PDF format.
- **Maintenance Guide**
  - A separate guide will outline maintenance procedures, including hardware checks, software updates, and part replacements.
  - It will include detailed instructions for both routine and emergency maintenance, ensuring the AGV operates safely and efficiently.
  - The guide will be available in digital PDF format.
- **Quick Start Guide**
  - A condensed version of the user manual, this guide will offer essential information for quick deployment and basic operation of the AGV.
  - The guide will be available in digital PDF format.
- **Technical Specifications Sheet**

- This document will provide detailed technical information about the AGV's components, sensors, software requirements, and communication protocols.
- It will be provided as a PDF document.

All documentation will be created following established user documentation standards, ensuring clarity, accessibility, and ease of use. The documentation will be compatible with screen readers and follow accessibility guidelines to support a wider range of users.

2.7. Assumptions and Dependencies

The development of the AGV is based on several assumptions and dependencies that affect the system's requirements as outlined in this SRS. These factors are not design constraints but are expected conditions that, if changed, will impact the requirements and overall development. The following assumptions and dependencies have been identified:

- **Hardware Availability**
    - It is assumed that Raspberry Pi 5 units will be available and fully functional for use as the primary hardware platform. If the Raspberry Pi 5 is not available, the SRS will need to be adjusted to accommodate a different hardware platform.
    - It is also assumed that all required sensors (e.g., radar, heartbeat sensors) will be available, compatible, and operable with the Raspberry Pi 5.
- **Operating System Support**
    - The development assumes that a Linux-based operating system will be available and compatible with the AGV's hardware components, particularly the Raspberry Pi.
- **Third-Party Components**
    - The system relies on third-party communication protocols like LoRa and certain software libraries for sensor integration and real-time mapping (e.g., SLAM libraries). It is assumed that these components will be accessible and function as expected. Changes in the availability or performance of these third-party components will necessitate revisions to the SRS.
- **Network Connectivity**
    - It is assumed that network connectivity will be available for the AGV to communicate with ground control systems, though it may be intermittent or weak in disaster zones. The system design anticipates temporary network disruptions, but prolonged lack of connectivity may affect the system's performance and require changes to communication requirements.

- **Operational Environment**
  - The AGV is expected to operate in various weather conditions and terrains. It is assumed that the design will accommodate these environmental variables, but unforeseen extreme conditions (e.g., severe storms, deep water) may affect performance beyond the anticipated requirements.

3. External Interface Requirements

3.1. User Interfaces

[REQ 1] The system shall allow the user to interact with the AGV from the Ground Station.

[REQ 2] The system shall display a Graphical User Interface (GUI) to the user on the Ground Station.

[REQ 3] The system shall allow the user to see status updates of the AGV from the GUI.

[REQ 4] The UI shall display real-time sensor readings from the AGV.

[REQ 5] The UI shall display real-time vehicle status from the AGV.

[REQ 6] The UI shall display in real-time when a survivor is detected from the AGV.

[REQ 7] The UI shall support visual alerts to enhance proper critical event information.

[REQ 8] The UI shall support audio sounds to enhance proper critical event information.

[REQ 9] The UI shall provide a graphical representation of heartbeat sensor data in the form of a graph.

[REQ 10] The UI shall provide a graphical representation of body temperature data in the form of a heat map.

[REQ 11] The UI shall require user authentication for access.

3.2. Hardware Interfaces

[REQ 12] The system shall use 12V lithium-iron rechargeable batteries to power all electronic components on the AGV.

[REQ 13] The system shall use four 24V brushless motors to control movement on the AGV.

[REQ 14] The system shall use a 25A DC motor driver to control the four 24V brushless motors on the AGV.

[REQ 15] The system shall use jumper wires to connect the 25A DC motor driver to the control board.

[REQ 16] The system shall use a 110° field-of-view thermal imaging camera on the AGV.

[REQ 17] The thermal imaging camera shall use the I2C communication protocol.

[REQ 18] The system shall use a 5W speaker on the AGV.

[REQ 19] The 5W speaker shall utilize a Universal Serial Bus (USB) connection to the control board.

[REQ 20] The system shall use an 8MP, 120° field-of-view camera on the AGV.

[REQ 21] The system shall use a Pi5 Camera Serial Interface (CSI) connection to the control board.

[REQ 22] The system shall use a 5V, 60GHz mmWave heartbeat sensor on the AGV.

[REQ 23] The system shall use a battery charger on the Ground Station.

[REQ 24] The system shall use an aluminum framework chassis for the AGV.

[REQ 25] The system shall use a IWR6843AOPEVM 60GHz antenna-on-package (AoP) mmWave sensor.

[REQ 26] The system shall use a 6 Axis Full Metal Robotic Arm.

[REQ 27] The system shall use an aluminum framework chassis for the AGV.

[REQ 28] The system shall have a combined weight under 45 lbs.

[REQ 29] The system shall have access to a manual kill switch.

[REQ 30] The system shall adjust the position of the Heartbeat Sensor with the Robotic Arm.

[REQ 31] The system shall be recharged by an external AC power supply.

[REQ 32] The system shall commence recharging before power supply is completely depleted.

[REQ 33] The system shall include a manual control method for the Robotic Arm via wireless controller.

[REQ 34] The system shall include a structure to house the electrical components used to operate the AGV.

[REQ 35] The system shall include a structure to mount the battery to the chassis of the AGV.

[REQ 36] The system shall include structures for each radar to mount to the chassis of the AGV.

[REQ 37] The system shall include access for manual debugging of electrical components.

[REQ 38] The system shall use the Robotic Arm to make contact with a body.

[REQ 39] The system shall use the radars to adjust the positioning of the Robotic Arm.

3.3. Software Interfaces

[REQ 40] The system shall use the Raspberry Pi with a Linux based Operating System (OS) to interface with components on the AGV.

[REQ 41] The system shall use the Ubuntu version 20.04 of Linux OS.

[REQ 42] The system shall establish a P2P (Peer to Peer) connection between the Ground Station and the AGV.

[REQ 43] The system shall establish the Ground Station as a server.

[REQ 44] The system shall establish the AGV as a client.

[REQ 45] The system shall use OpenCV to connect camera operations.

[REQ 46] The system shall have the ability to process input from the temperature sensor.

[REQ 47] The system shall have the ability to process input from the heartbeat sensor.

[REQ 48] The system shall have the ability to process input from the thermal camera.

[REQ 49] The system shall integrate sensor data from the temperature sensor, heartbeat sensor, and thermal camera to improve accuracy in detection.

[REQ 50] The system shall support a graphical user interface to monitor the AGV status.

[REQ 51] The system shall support a graphical user interface to monitor the sensor readings.

[REQ 52] The system shall support a graphical user interface to monitor the detected survivors.

[REQ 53] The system shall support real-time error detection.

[REQ 54] The system shall support reporting mechanisms for real-time error detection.

[REQ 55] The system shall support version control through GitHub to manage software updates.

3.4. Communications Interfaces

[REQ 56] The system shall utilize LoRa to communicate between the AGV and the Ground Station.

[REQ 57] The system shall utilize LoRa with a spreading factor range from 7 to 10.

[REQ 58] The system shall be able to communicate with a Ground Station from a distance of half a mile.

[REQ 59] The system shall send GPS data from the AGV to the Ground Station.

[REQ 60] The system shall send movement commands from the Ground Station to the AGV.

[REQ 61] The system shall use two RPi5 with a LoRa hat for communications.

[REQ 62] The system shall have a radar communicating with the RPi5 about objects in the path of the AGV.

[REQ 63] The system shall transmit heartbeat data from the AGV to the Ground Station.

[REQ 64] The system shall transmit body temperature data from the AGV to the Ground Station.

[REQ 65] The system shall implement an automatic reconnection protocol if signal is lost.

[REQ 66] The system shall monitor the signal strength of the connection between the AGV and Ground Station.

[REQ 67] The system shall alert the Ground Station if communication strength falls below a safe threshold.

[REQ 68] The system shall send an error message to the Ground Station in events of complete connection failure.

[REQ 69] The system shall communicate battery status to the Ground Station.

[REQ 70] The system shall communicate remaining operation time from the AGV to the Ground Station.

4. Behavioral Requirements

4.1. Same Class of User

[REQ 71] The system shall have three levels of access privileges: Operator, Administrator, and Technician.

[REQ 72] User access privilege levels shall be stored using the following codes.

- 1: **Operator** – Provides access to basic AGV control functions, including navigation commands and monitoring sensor data.
- 2: **Technician** – Grants additional access to maintenance functions, including sensor calibration, diagnostics, and remote system reset.
- 3: **Administrator –** Provides full access to system settings, including software updates, access control management, and system configuration.

[REQ 73] The system shall assign access levels based on user roles, ensuring that each class of user has permissions appropriate to their function within the system.

[REQ 74] The system shall require authentication for each user at login and verify access privileges before allowing access to any restricted function.

4.2. Related Real-world Objects

[REQ 75] *The object model for the AGV system shall depict the relationships among main entities, including the AGV, Ground Station, Survivor Detection System, Sensors, Communication Module, and Environment Map.*

[REQ 76] *The AGV shall use location coordinates relative to its position as the origin to update survivor and obstacle locations on the Environment Map in real-time.*

[REQ 77] *The Ground Station shall log each detection event with timestamp, location, and detection confidence level, and display this data in the user interface.*

[REQ 78] *The Environment Map's origin shall be set to display in the upper-left corner, representing the AGV's current position and orientation in the scene.*

[REQ 79] *The AGV shall continuously update its Environment Map with coordinates of detected obstacles and terrain type as it navigates.*

[REQ 80] *The Survivor Detection System shall alert the Ground Station whenever a potential survivor is detected, including details on detection type and confidence level.*

[REQ 81] *The AGV shall adjust the Environment Map's planned route based on sensor*

data, including the detection of obstacles and terrain changes.

[REQ 82] *The Ground Station shall provide real-time monitoring of the AGV's position, battery status, and operational mode in the user interface.*

4.3. Stimulus

[REQ 83] If the heartbeat sensor detects a pulse within the human range, the system shall classify the detection as human to further investigate.

[REQ 84] If the vocal sensor detects the voice of a human survivor within the AGV range, the system shall classify the vocals as human to further investigate.

[REQ 85] If the thermal camera detects a temperature within the body temperature range, the system shall classify the detection as human to further investigate.

[REQ 86] If a survivor is detected, the system shall display an alert to the Ground Station within 1 second.

[REQ 87] If the Ground Station operator requests a real-time video of the AGV, the system shall begin the video feed within 4 seconds.

[REQ 88] If an obstacle is detected within 2 feet of the AGV, the system shall update the path to avoid the obstacle while maintaining the target location.

[REQ 89] If the AGV does not find a sustainable path to the target location, the system shall notify the Ground Station to further investigate.

[REQ 90] If the AGV battery drops below 40%, the system shall notify the Ground Station to adjust the target location to a recharge station.

[REQ 91] If a software update is available, the system shall notify the operator of the Ground Station of the request.

[REQ 92] If the AGV loses communication with the Ground Station for more than 10 seconds, the system shall automatically switch to standby mode and attempt to reconnect every 5 seconds until communication is restored.

[REQ 93] If the AGV encounters terrain classified as high-risk or unsteady (e.g., steep inclines or loose surfaces), the system shall reduce its speed by 50% and notify the Ground Station of potential hazards.

[REQ 94] If the heartbeat sensor or thermal camera experiences data inconsistencies or interruptions for more than 3 seconds, the system shall alert the Ground Station and flag the sensor for diagnostics.

[REQ 95] If the AGV receives a command to pause operations, the system shall halt all movement within 2 seconds and hold its current position until further instruction is received.

[REQ 96] If a detected temperature or pulse value is outside human ranges, the system shall classify it as non-human and suppress unnecessary alerts to the Ground Station.

[REQ 97] If the AGV's battery level falls below 15%, the system shall enter low-power mode, limiting sensor usage to essential functions and transmitting an urgent recharge request to the Ground Station.

[REQ 98] If the AGV's GPS data indicates a deviation from the planned route by more than 5 feet, the system shall correct its path and notify the Ground Station of the adjustment.

[REQ 99] If the AGV detects multiple survivors in close proximity (within 5 feet), the system shall classify the area as a high-priority zone and alert the Ground Station for immediate assistance.

[REQ 100] If environmental sensors detect rainfall exceeding safe operational levels, the system shall alert the Ground Station and initiate a return-to-base protocol to protect components from potential water damage.

[REQ 101] If the AGV's internal temperature rises above the recommended threshold (e.g., 60°C), the system shall alert the Ground Station and activate internal cooling mechanisms to prevent overheating.

4.3.1. Login Screen

[REQ 102] The system shall allow for text entry when asking for the user's username.

[REQ 103] The system shall allow for text entry when asking for the user's password.

[REQ 104] The system shall attempt to verify a user account, when the Login button is clicked, with the values entered into the SQL database.

[REQ 105] The system shall display a message saying the username and password is incorrect if the entry is not found in the SQL database.

4.3.2. Collision Stimulus

[REQ 106] If the AGV has stopped moving while moving to a destination, the system shall display that the AGV has collided with an object.

[REQ 107] If the AGV is reported to have collided with an object, the system shall halt all motor movement on the AGV.

[REQ 108] If the AGV is reported to have collided with an object, the system shall allow the AGV to perform remedial navigation.

[REQ 109] If the AGV is unable to move when attempting to move, the system shall display that the AGV is stuck.

[REQ 110] If the AGV is reported as stuck, the system shall halt all motor movement on the AGV.

4.3.3. Heartbeat Stimulus

[REQ 111] If the Ground Station has not reported a heartbeat reading from the AGV, and the AGV is not moving, the system shall display that the AGV has lost connection.

[REQ 112] If the Ground Station has not reported a heartbeat reading from the AGV, but the AGV is still moving, the system shall display that the AGV may have lost connection.

4.4. Related Features

[REQ 113] The system shall activate sensors to detect heartbeat and body temperature when it enters a survival area.

[REQ 114] The system shall connect securely to the Ground Station using wireless protocols when a communication request is initiated.

[REQ 115] The system shall log a survivor's physical coordinates once a survivor has been detected.

[REQ 116] The system shall log a detection timestamp once a survivor has been detected.

[REQ 117] The system shall adjust its navigation strategy when it encounters challenging terrain.

[REQ 118] The system shall initiate safe shutdown procedures when critical system failure is detected.

[REQ 119] The system shall initiate safe shutdown procedures when a manual shutdown is initiated.

4.5. Functional

[REQ 120] The system shall display live video feed of the AGV environment extracted from the camera to the Ground Station for communication.

[REQ 121] The system shall allow Ground Station controls to the AGV in the event of

manual motor control through camera view for obstacle avoidance.

[REQ 122] The system shall display on-screen notifications for any communication losses.

[REQ 123] The system shall display on-screen notifications for any system malfunction errors.

[REQ 124] The system shall implement back up communication methods in the event of communication loss.

[REQ 125] The system shall display a map of the environment to show AGV location.

[REQ 126] The system shall display a map of the environment to show survivors found.

[REQ 127] The heartbeat sensors shall detect human heartbeat to provide real-time data of human presence.

[REQ 128] The thermal camera shall detect body temperature readings to provide real-time data of detecting survivors.

[REQ 129] The system shall detect human vocal readings from the vocal sensors to provide real-time data of human survivors.

[REQ 130] The system shall transmit sensor data to the Ground Station.

[REQ 131] The system shall ensure communication between the AGV, sensors, and Ground Station.

[REQ 132] The system shall support feasible integration of additional sensors if necessary.

[REQ 133] The system shall attempt to automatically recover from software errors when possible.

[REQ 134] The AGV shall navigate through disaster zones to avoid obstacles.

[REQ 135] The AGV shall maintain sturdiness when transitioning between various weather conditions.

[REQ 136] The AGV shall maintain sturdiness when transitioning between various terrains.

[REQ 137] The AGV shall maintain sturdiness when transitioning between various elevation levels.

[REQ 138] The system shall send an automated dialog to potential survivors.

[REQ 139] The system shall support recharging of the AGV battery through a charging station.

[REQ 140] The system shall build a map of the AGV environment to coordinate the AGV environment.

[REQ 141] The system shall continuously update a map of the AGV environment to keep track of the AGV location.

[REQ 142] The system shall test AGV movements to ensure structured performance.

[REQ 143] The system shall have a radar determining when the AGV stops movement before detecting a body.

[REQ 144] The system shall have a radar determining whether obstacles are present in the path of the AGV.

[REQ 145] The system shall authenticate users based on a username and password.

5. Non-behavioral Requirements

5.1. Performance Requirements

[REQ 146] The system shall support up to **10 simultaneous users** accessing the Ground Station interface for monitoring and control during operations.

[REQ 147] The AGV system shall process **95% of sensor data readings within 500 milliseconds** to ensure real-time detection and response.

[REQ 148] The system shall transmit data packets between the AGV and Ground Station with a latency of no more than **200 milliseconds** in normal network conditions.

[REQ 149] The AGV shall handle an average data throughput of **5 MB per minute** for continuous sensor updates and system status reporting.

[REQ 150] The system shall support a minimum of **24 hours of continuous operation** on a fully charged battery under standard usage conditions.

[REQ 151] The system shall store up to **500 MB of data locally** on the AGV, including sensor logs, error logs, and navigation history, before requiring data transfer or clearing.

[REQ 152] The system shall be able to resume operation within **5 seconds** following a temporary communication loss with the Ground Station.

[REQ 153] During peak workload conditions, the system shall maintain performance, processing **90% of data packets without loss or delay** over a 1-hour operational period.

5.2. Safety Requirements

[REQ 154] The AGV shall implement an **automatic emergency stop** feature, halting movement immediately if an obstacle is detected within 0.5 meters to prevent collisions or harm.

[REQ 155] The AGV shall undergo a **battery health and temperature check** before each mission to prevent overheating or battery failure during operation.

[REQ 156] The system shall log all detection events and operational data with timestamps and require these logs to be **stored securely for 30 days** to support incident investigation if needed.

[REQ 157] The AGV shall comply with **ISO 13482** standards for safety in personal care robots, ensuring it meets regulatory safety guidelines for unmanned ground vehicles in close proximity to humans.

[REQ 158] The system shall restrict user access to navigation commands to **authorized**

operators only, with role-based access control to prevent accidental or unauthorized control.

[REQ 159] The AGV shall perform **self-diagnostic checks** on all sensors and communication modules before each mission to ensure operational safety and notify the Ground Station of any detected malfunctions.

[REQ 160] The system shall disable the AGV's movement commands if the battery falls below **15% capacity**, alerting operators of low battery levels to prevent loss of control in the field.

5.3. Qualitative Requirements

[REQ 161] The system shall have an **uptime reliability of 99.5%** during operational hours, ensuring minimal downtime for critical search and rescue missions.

[REQ 162] The AGV's user interface shall maintain a **response time of less than 1 second** for all control inputs and data displays, providing a smooth user experience in real-time monitoring.

[REQ 163] The system shall have a **user-friendly graphical interface** with intuitive controls, requiring no more than 30 minutes of training for new users to effectively operate the AGV.

[REQ 164] The AGV shall be able to operate in temperatures between **-10°C and 50°C** and maintain full functionality, demonstrating resilience to varying environmental conditions.

[REQ 165] The AGV shall be designed to be **weather-resistant** and demonstrate effective operation in moderate rain and dust conditions, with IP65-level protection for all exposed components.

[REQ 166] The system's data transmission between the AGV and Ground Station shall have an **error rate of less than 0.1%**, ensuring reliable data integrity during communication.

[REQ 167] The AGV shall support **modular component replacement**, allowing critical parts (e.g., battery, sensors) to be replaced in the field within 10 minutes, ensuring high maintainability.

5.3.1. Availability

[REQ 168] The system shall meet **ISO/IEC 25010 standards** for software quality, specifically focusing on attributes of functionality, usability, and reliability.

[REQ 169] The system shall maintain an **availability level of 99.5%** during mission operations, minimizing downtime to enhance reliability in rescue environments.

[REQ 170] The AGV shall perform **automatic system checkpoints** every 10 minutes, saving critical operational data (location, sensor status, battery level) to ensure continuity in case of interruptions.

[REQ 171] The system shall support **automatic recovery protocols**, allowing the AGV to resume its last known state within 5 seconds after a temporary power or network disruption.

[REQ 172] The AGV shall initiate a **soft restart option** from the Ground Station, enabling remote operators to reset the AGV's software without disrupting its navigation path or resetting the mission data.

[REQ 173] The system shall provide a **manual hardware restart option** accessible to field technicians, allowing a full system reboot within 60 seconds in case of critical failures.

[REQ 174] The AGV shall implement **redundant communication channels** to automatically switch to backup protocols if the primary LoRa communication fails, ensuring uninterrupted data transmission.

[REQ 175] The system shall conduct **self-diagnostics on startup and at each checkpoint** to verify sensor functionality, battery health, and communication strength, alerting operators immediately of any issues.

5.3.2. Security

[REQ 176] The system shall include a database to ensure user accounts are stored in a secure database.

[REQ 177] The system shall use specific IP addresses to ensure secure communication between connection devices.

[REQ 178] The system shall require a login system with password to support secure access between accounts.

[REQ 179] The system shall create a hash from text passwords using a hashing algorithm.

[REQ 180] The system shall allow the Ground Station to perform manual override on AGV motor controls.

[REQ 181] The system shall display a notification to the Ground Station in the event of AV tampering in the AGV environment.

5.3.3. Maintainability

[REQ 182] The system shall send notifications for maintenance issues within 5 seconds.

[REQ 183] The system shall spend 5 seconds doing automatic diagnostic testing and troubleshooting.

[REQ 184] The system shall send updated GPS location every 1 second for AGV tracking.

[REQ 185] The system shall send updated map integration every 5 seconds for AGV environment tracking.

[REQ 186] The system shall send real-time data from the AGV environment to the Ground Station every 5 seconds that the AGV is in motion.

5.3.4. Portability

[REQ 187] All Ground Station devices shall have Ubuntu version 20.04 as the device's Operating System.

[REQ 188] All Ground Station devices shall have Python 3.7 installed to run the source code.

[REQ 189] All Ground Station devices shall encompass SQLITE3 for account database management.

[REQ 190] The AGV shall allow USB port connectivity for software updates.

5.4. Design and Implementation Constraints

[REQ 191] The software shall be developed in Python 3.7 or higher.

[REQ 192] The software shall have one component on the Ground Station and one on the AGV.

[REQ 193] The software shall have a function allowing the AGV to move 90 degrees to the right.

[REQ 194] The software shall have a function allowing the AGV to move 90 degrees to the left.

[REQ 195] The software shall have functions allowing the AGV to move forwards and backwards.

[REQ 196] The software shall be able to use the thermal camera and get a correct temperature reading in degrees Celsius.

[REQ 197] The software shall be able to interact with the heartbeat sensor.

[REQ 198] The AGV shall have a max wheel speed of 122 RPM (rotations per minute).

[REQ 199] The robotic arm shall be able to be controlled via a handheld controller.

[REQ 200] The robotic arm shall be able to rotate in a 360 degree motion.

6. Other Requirements

6.1. Database Requirements

[REQ 201] The database shall include a table to store user account information with data type and constraints outlined in the table below.

USER table		
Attribute	**Data Type**	**Constraints**
username	string	not null, unique
hashed password	string	not null
role	enum string	not null

[REQ 202] The possible values for attribute role in user table in database is defined by the requirements in section 4.1 Same Class of User.

[REQ 203] The heartbeat sensor shall collect heartbeat beat rate.

[REQ 204] The thermal camera shall collect nearby temperatures in Celsius.

[REQ 205] The GPS shall collect location coordinates of its location.

6.2. Operations

[REQ 206] The AGV shall provide **user-initiated operations** such as start/stop navigation, sensor activation/deactivation, and communication checks, allowing operators to adapt the AGV's actions to mission needs.

[REQ 207] The system shall support **two primary modes of operation:** Autonomous Mode, where the AGV navigates and detects survivors independently, and Manual Mode, where the Ground Station operator controls navigation and sensor functions directly.

[REQ 208] The system shall include **periods of unattended operation** during Autonomous Mode, where the AGV continues data collection, detection, and communication independently unless interrupted by a command or critical event.

[REQ 209] The AGV shall perform **automated data processing functions** by continuously analyzing sensor input for survivor detection, navigation adjustments, and obstacle mapping, and transmitting processed results to the Ground Station in real-time.

[REQ 210] The Ground Station shall support **data export operations**, enabling operators to download mission data, including sensor readings, survivor locations, and error logs, at the end of each mission for further analysis and record-keeping.

[REQ 211] The system shall provide **backup and recovery functions** by saving all critical mission data (navigation paths, detected survivor data, sensor logs) to onboard storage every 10 minutes, ensuring data is retained in case of connectivity loss.

[REQ 212] The AGV shall implement **automatic system maintenance checks** every hour during operation to verify sensor health, communication status, and battery life, alerting operators if any parameter falls outside acceptable ranges.

[REQ 213] The system shall provide a **diagnostic mode** for technicians, allowing access to detailed system performance data, sensor calibration tools, and manual component testing during maintenance or troubleshooting.

7. Analysis Models

7.1. *Data Flow Model*

This section provides the data flow model for the system. This section includes the identified sources and sinks of data; the data dictionary; and the visual data flow model, which begins with the context diagram, followed by the level 1 data flow diagram, and additional level 2 and 3 diagrams.

7.1.1. Data Sources

The data sources and their inputs to the system identified in the data flow model are as follows:

- Temperature Sensor
  - Body temperature detection within the AGV's range
- Heartbeat Sensor
  - Data collection for presence of human heartbeat
- Speaker
  - Record sounds of the AGV's environment
  - Relay sounds to AGV's environment
- GPS and Radar
  - Collects data on the AGV's location and surrounding objects
- Camera
  - Detects bodies in cases when the thermal camera is not working
- Ground Station
  - Sends commands and control inputs to AGV
  - Receives status updates from AGV

7.1.2. Data Sinks

The data sinks and their system outputs identified in the data flow model are as follows:

- Data Processing Module
  - Processes sensor data
- Communication Module
  - Processed data from the AGV to the command center
- Navigation Module
  - Controls and monitors location and objects in AGV environment for navigation
- Ground Station
  - Displays real-time data
  - Displays locations of survivors and obstacles
  - Displays updated AGV status

7.1.3. Data Dictionary

The data types are described in the data dictionary below. This section includes the name of the data type; a description of the contained data; how the data is structured; and the range of values.

Name	***Description***	***Structure***	***Range***
TemperatureData	*Temperatures gathered from the thermal sensor*	*Float (°C)*	*15.0 - 45.0 °C*
HeartbeatData	*Identifies the presence or absence of a heartbeat gathered from heartbeat sensor*	*Boolean*	*True if Heartbeat* *else False*
LocationData	*GPS coordinates in latitude, longitude format gathered from communication sensor*	*Float*	*Lat: -90.0 to +90.0* *Long: -180.0 to +180.*
ObstacleData	*Data gathered from Radar to identify the distance and angles of obstacles in the AGV environment*	*Float, Float*	*Distance: 0.0 - 30.0 m* *Angle: -180.0 to +180.0*
SurvivorFound	*Value to identify if a survivor was found; gathered from thermal and heartbeat sensors*	*Boolean*	*True if survivor* *else False*
GroundStationCommands *(GSCommands)*	*Commands received from the Ground Station*	*String*	*Stop, Forward, Reverse, Left, Right*

7.1.4. Context Diagram (Level 0 Data Flow Diagram)

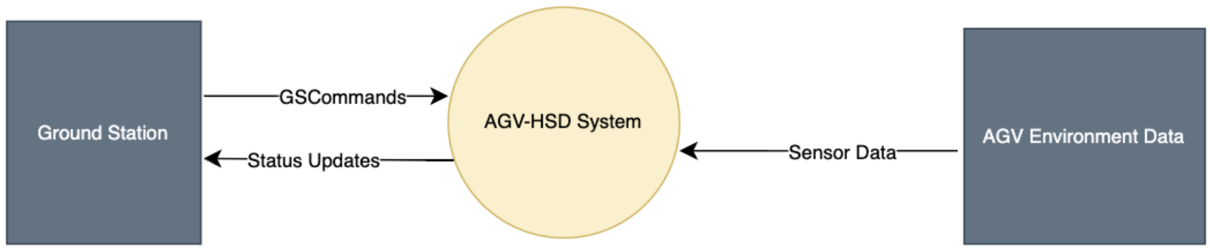

Figure 2: Context Diagram

7.1.5. Level 1 Data Flow Diagram

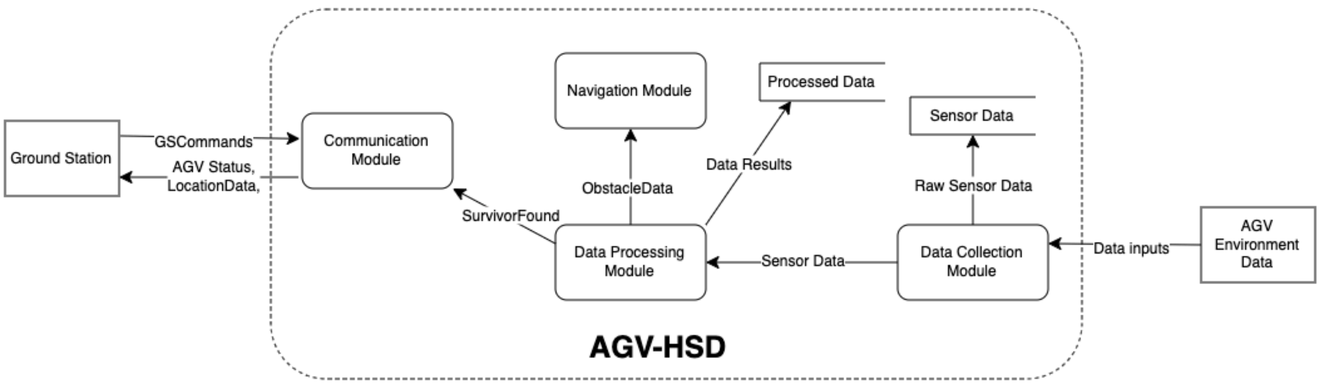

Figure 3: Data Flow Diagram Level 1

7.1.6. Level 2 Data Flow Diagram

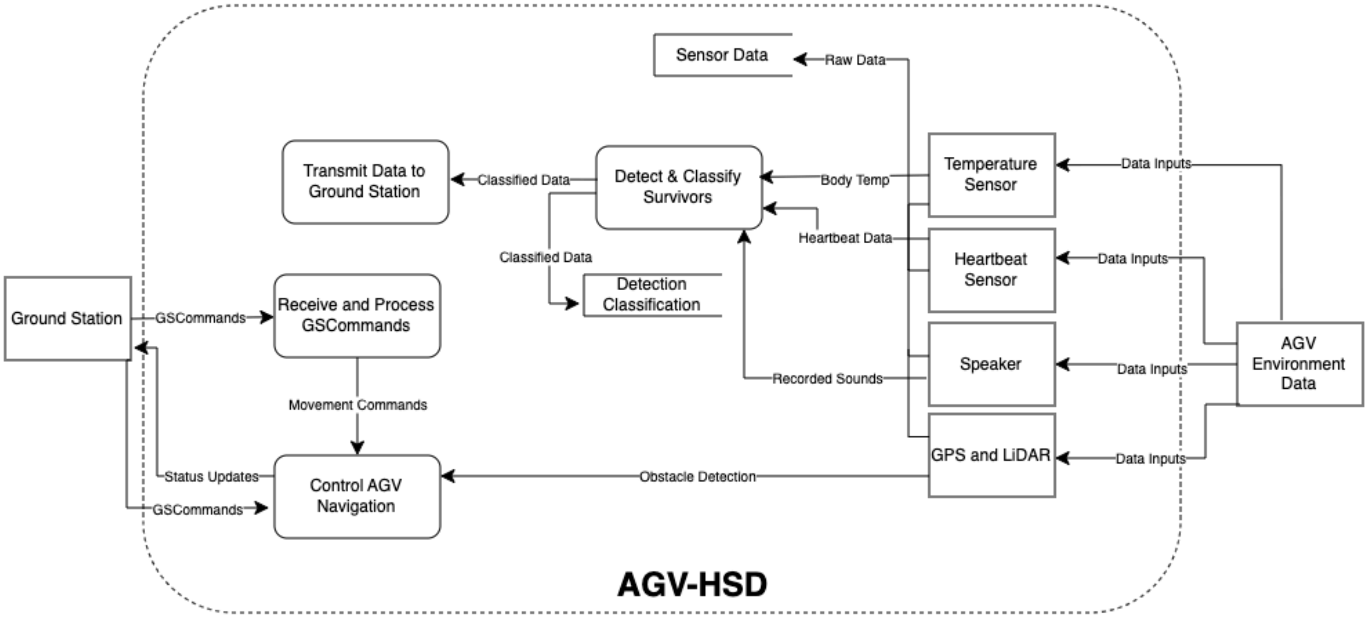

Figure 4: Data Flow Diagram Level 2

7.2. *Class Model*

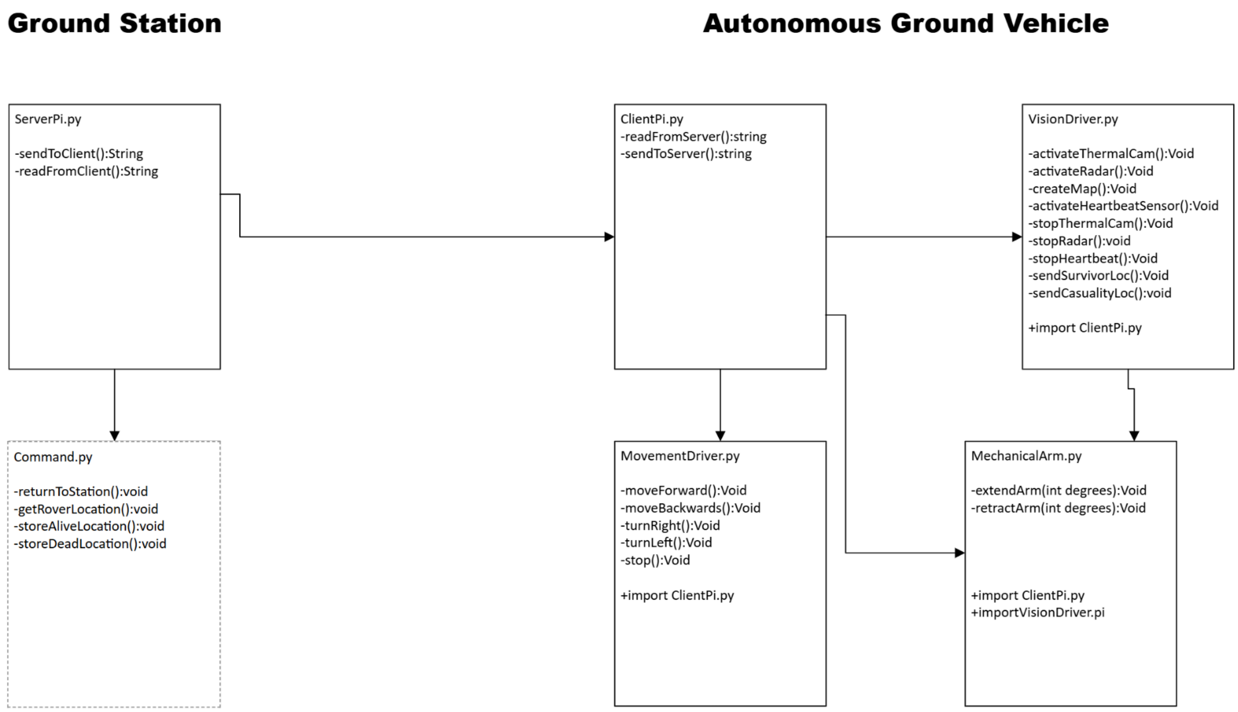

Figure 5: Class Model

7.3. *State Model*

The substate chart for the Logging In state is shown below.

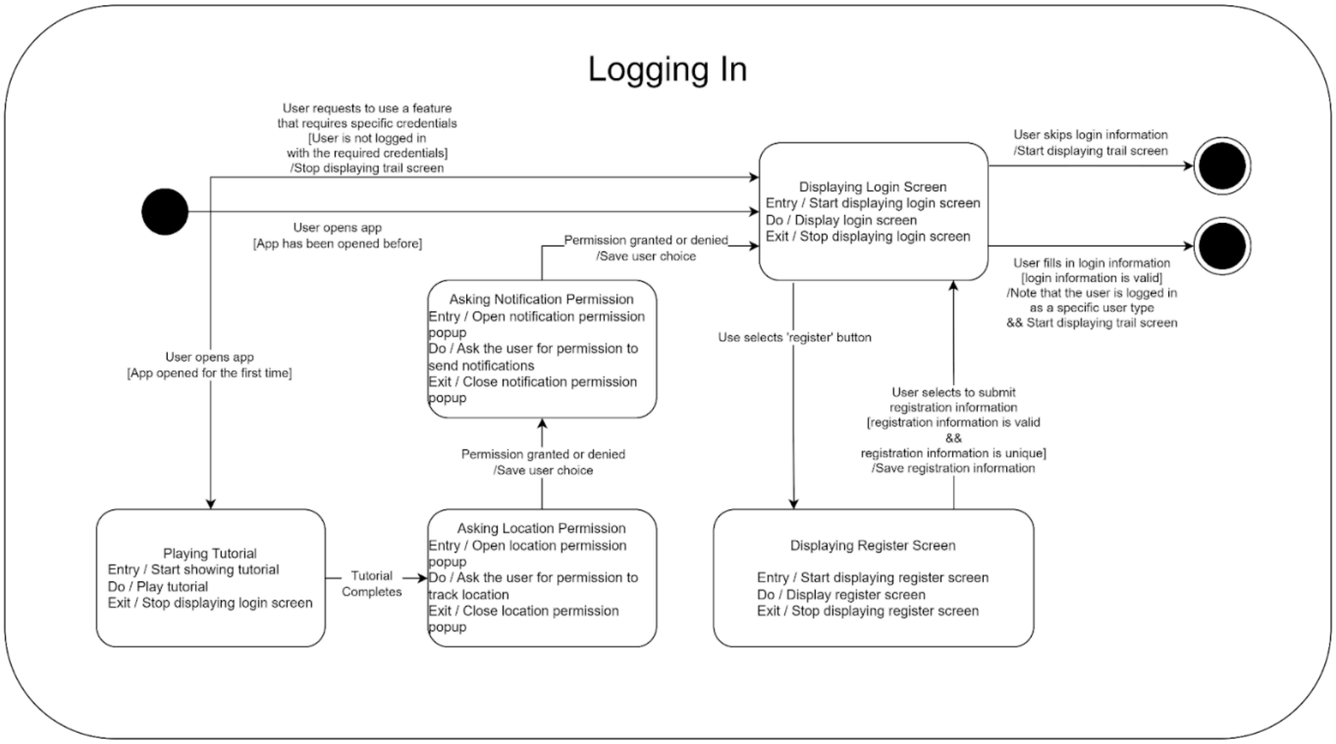

Figure 6: State Model

8. To Be Determined List

[TBD 1] Define the layout for the navigation menu in the user interface.

[TBD 2] Determine options for exiting notifications from the AGV to Ground Station.

[TBD 3] Define specific sensor activation algorithms for AGV operation.

[TBD 4] Determine features of the displayed map to Ground Station.

[TBD 5] Specify the battery operation time.

[TBD 6] Specify the temperature range the AGV can operate within.

[TBD 7] Specify humidity range the AGV can operate within.

[TBD 8] Determine exact network security measures to secure communication channels.

[TBD 9] Define a help section with troubleshooting tips for Ground Station operators.