Department of Computer Science & Engineering
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System Requirements Specification
CSE 4316: Senior Design I
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IGVC
Autonomous Ground Vehicle

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Revision History

Revision	Date	Author(s)	Description
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1 Product Concept

This section describes the purpose, use, and intended user audience for the Autonomous Ground Vehicle (AGV).

1.1 Purpose and Use

The AGV is a vehicle that is able to autonomously navigate to a user defined destination while avoiding obstacles on the way. It uses LIDAR and cameras to avoid obstacles and employs the use of a GPS device to reach its destination accurately. It could be used by companies as a base for autonomous delivery vehicles to solve the last mile delivery problem as the AGV is highly modular and can be built on easily.

1.2 Intended Audience

Autonomous Machines that are capable of autonomous path planning can have limitless potential and uses: transporting products/merchandise, Exploration of remote or disconnected areas, and space exploration if proper electronics are at use. In an example instance, Food delivery services, such as DoorDash, Uber Eats, etc. would be able to modify and use the AGV to deliver food to customers. On the other hand, the AGV could be used in defense applications such as explosive disarming. Other vehicle companies such as Toyota, GM, and Telsa, could make use of the object avoidance capabilities of the AGV and fit the technologies to meet their needs.

2 PRODUCT DESCRIPTION

This section provides the reader with an overview of the Autonomous Ground Vehicle (AGV). The primary operational aspects of the product, from the perspective of end users, maintainers and administrators, are defined here. The key features and functions found in the product, as well as critical user interactions and user interfaces are described in detail.

2.1 FEATURES & FUNCTIONS

The AGV is a ground vehicle equipped with a wide range of sensors: a Stereo camera sensor, Lidar Instrumentation, GPS localization, Radio telemetry, along with tri-layered computing architecture for Autonomous or Ground-station controlled mission deployment. **User is to set a destination** on the *AGV Control Station* and AGV will proceed with the mission to navigate autonomously to the destination. Administrators can access the *AGV Control Station* and observe system vitals (e.g. Battery Information, Mission details, and thermals) along with Sensory raw data collected during mission and will have the Autonomous path planner on debug mode where Administrator access will allow watching classifications (Bounding boxes/Segmentation), prediction score, and above all overall system performance.

2.2 EXTERNAL INPUTS & OUTPUTS

The AGV System takes a series of Inputs from a wide range of sensors staring from Camera, IMU (Inertial Measurement Units), Global Positioning System (GPS) and Lidars and binds this data to predict where is is from it's destination and how to get to the destination in the most efficient manner and by avoiding obstacles. The Table 2 shows the Data Inputs and Outputs from the AGV in brief detail.

Data	I/O Class	Source	Description
GPS Coordinate Vector	Input	GPS Module	Location of vehicle expressed in coordinate vector from the GPS Module onboard
Motor speed [4]	Input	ESS (Electronic Speed Sensors)	Speed attained by all Wheels on the AGV during mission for instances where speed regulation is essential
Image (RGB)	Input/Output	Camera Sensor	Image data recorded by the camera sensor in RGB color channels
XYZ Depth map	Input	LIDAR Sensory	Depth Map of coordinates in X, Y, and Z from the LIDAR sensor
Point Cloud Map	Input/Output	Stereo Camera Sensor	RGB Image data represented with their respective pixel coordinate in XYZ using onboard sensory for depth representation of image data.
Motor Drive (PWM)	Output	Motor Control Unit	PWM Signal output to drive the motor controller and the motor for mobility
AGV Neural Network Response	Output	Primary Computing Unit	Output of Processed Image data, Point cloud data and Lidar Data by the AI/ML machine compute units with bounding boxes and or image process outputs
Motor State Command	Output	Primary Computing Unit	Command by the Primary Computing unit issued over the communication bus to activate motors to go at a specific direction

Table 2: Data Flow form AGV

2.3 PRODUCT INTERFACES

We currently do not have all our interfaces planned but we do know that mission planner, OpenVNC and OpenSSH will be some interfaces we will be working on.

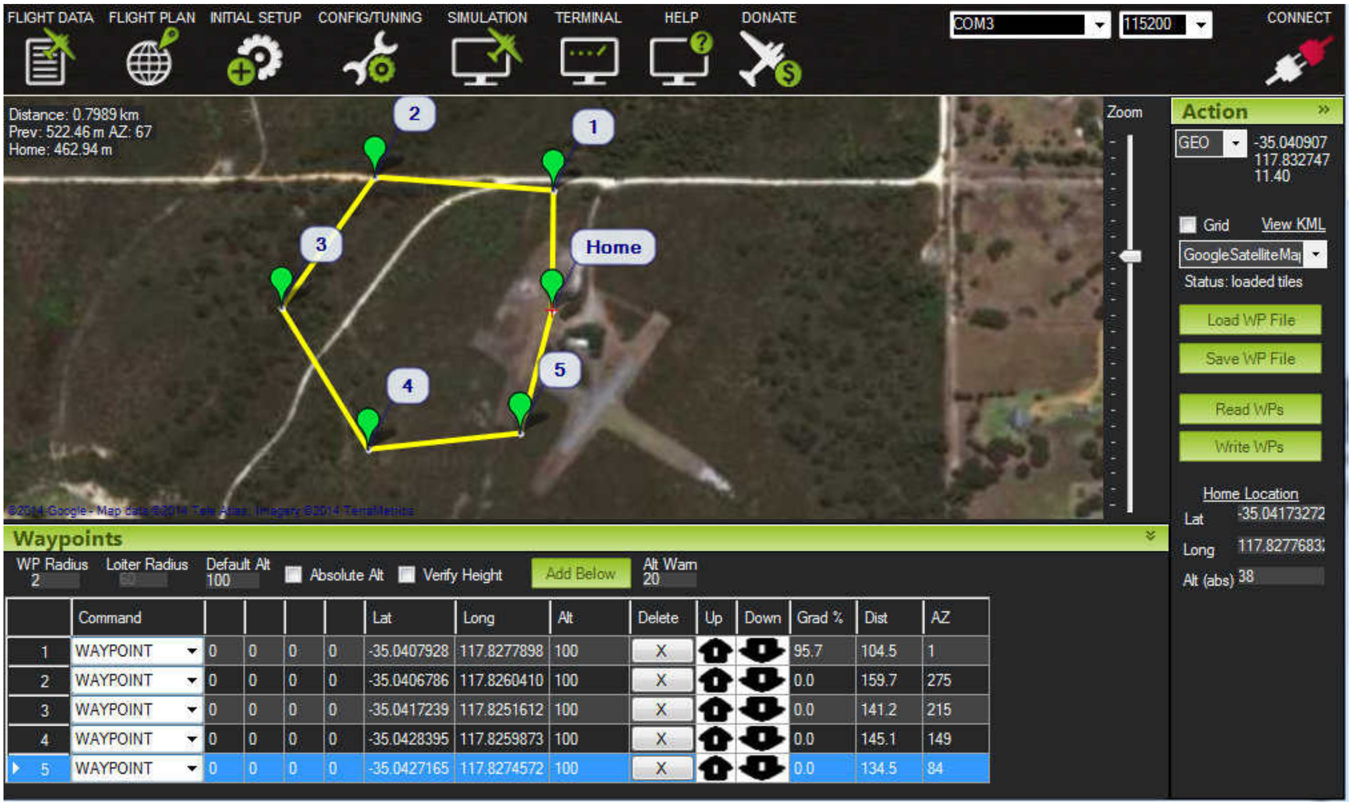

Figure 1: Mission Planner Interface

3 Customer Requirements

The autonomous vehicle we are building has requirements set by the customer and the Intelligent Ground Vehicle Competition. The vehicle must follow certain dimensions for it to compete. It also should be able to carry a payload of 20 pounds. The vehicle should also move at speeds within the bound of the competition rules. The vehicle should also have a mechanical and wireless emergency stop mechanism. The vehicle should be able to have lane following, obstacle avoidance, and waypoint navigation. The vehicle should be modular, so it must be able to be taken apart and reassembled with ease. The vehicle will also have a vision system to recognize the environment it is in. The vehicle will also be able to move omnidirectionally by usage of mecanum or omni wheels. And lastly we need to allow for unit testing of each individual component.

3.1 Vehicle Dimensions

3.1.1 Description

The vehicle dimensions must follow the rules set by the IGVC competition. The dimension constraint for the length a minimum of 3 ft and a max of 7 ft. For the dimension of width a min of 2 ft and a max of 4 ft. The height of the vehicle must not exceed 6 ft.

3.1.2 Source

Intelligent Ground Vehicle Competition Rules

3.1.3 Standards

N/A

3.1.4 Priority

Critical

3.2 Payload

3.2.1 Description

The vehicle must be able to have a payload securely mounted on the vehicle and carry it to a specific location. The payload is 18 inches long, 8 inches wide, 8 inches high, and will weight 20 pounds

3.2.2 Source

Intelligent Ground Vehicle Competition Rules

3.2.3 Standards

N/A

3.2.4 Priority

Critical

3.3 Vehicle Velocity

3.3.1 Description

The vehicle must have a velocity with a minimum of 1 mph and a maximum 5 mph. If the vehicle fails to either move at 1 mph or goes above the max, the vehicle will be disqualified.

3.3.2 Source

Intelligent Ground Vehicle Competition Rules

3.3.3 Standards

N/A

3.3.4 Priority

Critical

3.4 Emergency Stops

3.4.1 Description

The vehicle will have 2 different ways to stop in case of an emergency. It will have physical emergency button that must be a push to stop, red, and one inch in diameter. It will also have a wireless emergency stop button that must be effective for a minimum distance of 100 ft.

3.4.2 Source

Intelligent Ground Vehicle Competition Rules

3.4.3 Standards

N/A

3.4.4 Priority

Critical

3.5 Safety Light

3.5.1 Description

The vehicle must have an easily viewed light that indicates when the vehicle is powered on or off. When the vehicle enters autonomous mode the light must blink and once it is out of autonomous mode the light should go back to solid.

3.5.2 Source

Intelligent Ground Vehicle Competition Rules

3.5.3 Standards

N/A

3.5.4 Priority

Critical

3.6 Lane Following

3.6.1 Description

The vehicle must have a way to detect and follow lanes for it to qualify for the competition. The lanes will be taped on asphalt pavement with continuous lanes or dash white lines that are approximately 3 inches wide. The vehicle will need to follow and detect these lanes to prevent violating traffic violations provided by the Intelligent Ground Vehicle Competition rules.

3.6.2 Source

Intelligent Ground Vehicle Competition Rules

3.6.3 Standards

N/A

3.6.4 Priority

Critical

3.7 Lane Following

3.7.1 Description

The vehicle must have a way to detect and follow lanes for it to qualify for the competition. The lanes will be taped on asphalt pavement with continuous lanes or dash white lines that are approximately 3 inches wide. The vehicle will need to follow and detect these lanes to prevent violating traffic violations provided by the Intelligent Ground Vehicle Competition rules.

3.7.2 Source

Intelligent Ground Vehicle Competition Rules

3.7.3 Standards

N/A

3.7.4 Priority

Critical

3.8 Vision System

3.8.1 Description

The vehicle will have a camera that will send image data to a deep learning model for the obstacle detection portion of the vehicle. This detector should be able to identify various colors of construction barrels found on roadways and highways, natural obstacles such as trees or shrubs and man made obstacles such as light posts or street signs. It should also be able to detect simulated potholes that will be white circles 2 feet in diameter along the course trial.

3.8.2 Source

Intelligent Ground Vehicle Competition Rules

3.8.3 Standards

N/A

3.8.4 Priority

Critical

3.9 Modular Vehicle

3.9.1 Description

The vehicle has to be modular. Last year team competition had a lot of trouble with the transportation of the vehicle so our sponsor requires us to make the vehicle modular for ease of transportation. By making the vehicle modular shipping costs can be avoided by simply being taken on an airplane in pieces and then reassembled at the competition locale.

3.9.2 Source

The source of this requirement is our customer Dr. Christopher McMurrough.

3.9.3 Constraints

The manufacture of the parts may pose a problem. We are looking at different approaches but for now 3D printing the parts for the vehicle is our first solution. We would try to avoid creating the pieces by hand but if it necessary then that will be done.

3.9.4 Standards

N/A

3.9.5 Priority

Critical

3.10 Omni-directional Vehicle

3.10.1 Description

The vehicle should have mecanum or omni wheels for it be able to move in any direction at any point. This makes the vehicle more versatile for obstacle avoidance.

3.10.2 Source

Sponsor Dr. Christopher McMurrough

3.10.3 Constraints

Inexperience of our team to deal with designing a system that can utilize that. That said we have great resources to rely on.

3.10.4 Standards

N/A

3.10.5 Priority

Critical

3.11 Path Tracing Algorithm

3.11.1 Description

The vehicle will be able to make autonomous decisions on the direction it needs to travel based on the information given by the LiDAR and the camera for obstacle avoidance.

3.11.2 Source

Intelligent Ground Vehicle Competition Rules

3.11.3 Constraints

N/A

3.11.4 Standards

N/A

3.11.5 Priority

Future

4 Packaging Requirements

This section details the packaging requirements for the AGV hardware and delivery method of the software.

4.1 Modular Delivery of Vehicle

4.1.1 Description

The AGV will be shipped in several modules and is primarily constructed of lightweight materials, such as aluminium and PLA plastic. This is done to keep costs low during delivery and transport. The e-stop remote will be shipped along with the rest of the vehicle.

4.1.2 Source

IGVC Sponsor Dr. McMurrough

4.1.3 Constraints

The boxes containing the AGV should be fragile and have padding inside them in case of roughness upon delivery. The total weight of the AGV should be reasonable enough to be shipped through USPS or FedEx

4.1.4 Standards

N/A

4.1.5 Priority

Critical

4.2 Delivery of Software

4.2.1 Description

Software for the AGV will be delivered on a USB drive. The software will include a Makefile for compilation.

4.2.2 Source

AGV Sponsor (Dr. McMurrough)

4.2.3 Constraints

We need to make sure the OS in which the software will run is Linux as all our development is done through Linux.

4.2.4 Standards

N/A

4.2.5 Priority

Critical

5 Performance Requirements

The performance requirements for the Intelligent Ground Vehicle (IGV) in the IGCV competition are designed to ensure safe and competitive operation. These requirements encompass carrying a payload, maintaining a controlled speed, precise navigation, and timely completion of the course. Adhering to these performance criteria allows the IGV to operate effectively and demonstrate its capabilities within the competition environment.

5.1 Navigation Accuracy

5.1.1 Description

To compete effectively, the robot must meet specific speed criteria. It should be capable of moving forward at a minimum speed of 1 mph, ensuring a baseline level of performance. However, the robot must not exceed a speed of 5 mph while moving forward. Additionally, when moving in reverse, the robot's speed should not surpass 2 mph, ensuring controlled and safe movement. The speed range must keep the speed requirements within the bounds of 1 mph $< x <$ 5 mph.

5.1.2 Source

Intelligent Ground Vehicle Competition Policy

5.1.3 Constraints

Must keep speed requirements of 1 mph $< x <$ 5 mph.

5.1.4 Standards

N/A

5.1.5 Priority

Critical

5.2 Classification Speed

5.2.1 Description

The vehicle will have to do image classification in real time. We expect that we can classify at the very least 5 frames per second. This would give the vehicle and advantage when having to make decision on path changes as it will be able to adjust with enough time. We can also make correlation between an object detected at each fram and know the current relative speed at which we are approaching the object

5.2.2 Source

Self

5.2.3 Constraints

5.2.4 Standards

N/A

5.2.5 Priority

High

5.3 Object Perception

5.3.1 Description

Besides having to quickly classify the objects we have to also map the distance to the vehicle by using the LiDAR in our vehicle. Though the process is fast we still would like for this to be adequate for the previously described classification speed requirement.

5.3.2 Source

Self

5.3.3 Constraints

5.3.4 Standards

N/A

5.3.5 Priority

High

6 Safety Requirements

The AGV is designed to keep user safety in mind however it is to be noted that the AGV contains Lead-Acid or Lithium Polymer batteries which have certain safety policies that need to be complied with. Furthermore, some vital safety regulations the AGV complies with are mentioned below and have been expanded below.

6.1 Laboratory equipment lockout/tagout (LOTO) procedures

6.1.1 Description

Any fabrication equipment provided used in the development of the project shall be used in accordance with OSHA standard LOTO procedures. Locks and tags are installed on all equipment items that present use hazards, and ONLY the course instructor or designated teaching assistants may remove a lock. All locks will be immediately replaced once the equipment is no longer in use.

6.1.2 Source

CSE Senior Design Laboratory policy

6.1.3 Constraints

Equipment usage, due to lock removal policies, will be limited to the availability of the course instructor and designed teaching assistants.

6.1.4 Standards

Occupational Safety and Health Standards 1910.147 - The control of hazardous energy (lockout/tagout).

6.1.5 Priority

Critical

6.2 National Electric Code (NEC) wiring compliance

6.2.1 Description

Any electrical wiring must be completed in compliance with all requirements specified in the National Electric Code. This includes wire runs, insulation, grounding, enclosures, over-current protection, and all other specifications.

6.2.2 Source

CSE Senior Design laboratory policy

6.2.3 Constraints

High voltage power sources, as defined in NFPA 70, will be avoided as much as possible in order to minimize potential hazards.

6.2.4 Standards

NFPA 70

6.2.5 Priority

Critical

6.3 RIA robotic manipulator safety standards

6.3.1 Description

Robotic manipulators, if used, will either be housed in a compliant lockout cell with all required safety interlocks, or certified as a "collaborative" unit from the manufacturer.

6.3.2 Source

CSE Senior Design laboratory policy

6.3.3 Constraints

Collaborative robotic manipulators will be preferred over non-collaborative units in order to minimize potential hazards. Sourcing and use of any required safety interlock mechanisms will be the responsibility of the engineering team.

6.3.4 Standards

ANSI/RIA R15.06-2012 American National Standard for Industrial Robots and Robot Systems, RIA TR15.606-2016 Collaborative Robots

6.3.5 Priority

Critical

7 Security Requirements

Our project does not pertain to any information security risk so we can avoid this part. No user will have to input their personal information in order to run our vehicle. They would need the vehicle's physical computer for it to be used. One possible security risk could be someone remoting into the vehicle computer to change the vehicle's current path but the risk of that is

7.1 Deny access to remote hijack control of the AGV

7.1.1 Description

A malicious actor could try to remote into our vehicle but this is a very low-risk requirement so it can be ignored since RDF-900X Binding already will ensure that our controller pair will be registered to provide instructions. Similarly, other wireless connections can be intercepted such as Wi-Fi connections from the device which are already protected by WPA2 Protocols.

7.1.2 Source

RFD-900X Manufacturer Data sheet X8R Radio receiver Bind-mode on Data sheet WPA2 Protocol Packet protection

7.1.3 Constraints

0Day Exploits from the hardware manufacturer's end

7.1.4 Standards

N/A

7.1.5 Priority

Low

8 Maintenance & Support Requirements

This section will explain how to maintain the robot from the setup guide as well as the written report on how the system works.

8.1 Written IGCV Report

8.1.1 Description

The IGCV competition requires a written 15 page minimum report that documents all aspects of the robot. This document explains all the hardware and software incorporated into the robot. Future changes after the competition can be consulted via the report.

8.1.2 Source

Intelligent Ground Vehicle Competition Policy

8.1.3 Constraints

Report must be 15 pages. Must follow the required format provided by the IGCV.

8.1.4 Standards

IGCV

8.1.5 Priority

Low

8.2 Start Guide

8.2.1 Description

A detailed document that will contain information for future teams on how to setup robot and get it running as well as what portion of the codes they should be working on and what shouldnt be altered.

8.2.2 Source

Team

8.2.3 Constraints

Guide should contain a start guide on how to setup robot for basic use.

8.2.4 Standards

NA

8.2.5 Priority

Low

9 Other Requirements

This section describes the other requirements for the IGVC. Most of the requirements for this vehicle have covered by the rules of the competition while the some of the software requirements come from the sponsor and what we find to be the most compatible with the rest of the systems that will be implemented.

9.1 ROS Requirement

9.1.1 Description

This framework for robot software development provides the same services as a regular operating system such as hardware abstraction and low-level device control.

9.1.2 Source

IGVC sponsor (Dr.McMurrough)

9.1.3 Constraints

Compatibility with our day-to-day computers

9.1.4 Standards

List of applicable standards

9.1.5 Priority

High

9.2 3D Printing Requirement

9.2.1 Description

Some components of the vehicle will be 3D printed outdoor use filament that could withstand the terrain of the competition.Items like the shell of the vehicle and small components that will make it possible to disassemble the vehicle to make easier for transportation)

9.2.2 Source

IGVC sponsor (Dr.McMurrough)

9.2.3 Constraints

Being able to buy outside filament and access to the 3D printing lab

9.2.4 Standards

List of applicable standards

9.2.5 Priority

Medium

9.3 Robotic map planner Requirement

9.3.1 Description

The vehicle will be given or build a mapped representation of its surrounding with the use of machine learning path planning like deep neural networks in order for the robot to learn and modify its movements according to the feedback from its surroundings as it makes its way through the obstacle course.

9.3.2 Source

IGVC sponsor (Dr.McMurrough)

9.3.3 Constraints

Compatibility with the software and hardware systems that we will be utilizing because the previous team used a tree algorithm for path planning.

9.3.4 Standards

List of applicable standards

9.3.5 Priority

High

9.4 GPS Requirement

9.4.1 Description

The vehicle will be equipt with a GPS system that will let it identify its position and navigate through the course with obstacles set out in the competition .

9.4.2 Source

IGVC rule set

9.4.3 Constraints

Compatability of LIDAR with the shell of the vehicle

9.4.4 Standards

List of applicable standards

9.4.5 Priority

High

10 Future Items

Only one item is listed as a future item because it is out of scope of our teams side of the project. If we were to complete all the previous requirements with enough time we can add this requirement to the high priority requirement. This requirement is the responsibility of the team that will take over the project once we finish Senior Design 2.

10.1 Path Tracing Algorithm

10.1.1 Description

The vehicle will be able to make autonomous decisions on the direction it needs to travel based on the information given by the LiDAR and the camera for obstacle avoidance.

10.1.2 Source

Intelligent Ground Vehicle Competition Rules

10.1.3 Constraints

N/A

10.1.4 Standards

N/A

10.1.5 Priority

Future

REFERENCES