**Project Proposal**

**Project Name: Autonomous Ground Vehicle for Real-Time Detection and Classification of Adversaries**

**Project Team Members: Alessia Tripaldelli, Rachel Swan, George Pozek, Sebastian Calixtro, Matthew Berkowitz, Joel Steuber, Cameron Sauvageau, Andrea Gamble, Peter Nguyen**

**Problem Statement:**

In modern autonomous vehicle systems, detecting and classifying objects is important for navigating safely and effectively, especially in potentially hazardous situations. Our Senior Design Project aims to develop an Autonomous Ground Vehicle (AGV) capable of detecting and identifying small rovers within its ground operational environment. The vehicle’s job is to distinguish between "enemy" rovers, which may be a threat, and "friendly" rovers, which should be identified as non-threatening. The primary goal of the project is to reduce potential security threats, which could happen in case of operational inefficiencies in detecting adversaries. This capability is important in military and security operations, where confusion between friendly and enemy entities could lead to mission failure and safety risks. Today, there is a lack of detection systems that provide the accuracy required to identify entities in challenging environments. Therefore, our primary objective is to develop a reliable system that will not classify entities improperly, will map out the location of all the friendly and enemy entities in relation to the AGV, and relay this information to a ground station.

A literature review revealed that it is really important for AGVs to use the right sensors, communication protocols, and frameworks for detecting and classifying entities. For instance, to make the system communicate efficiently, previous research has shown that communication systems like ‘Profinet’ provide reliable wireless data transmission between AGVs and external systems, making it a possible candidate for the implementation of our project (Nesti, 2023). Considering sensors, research shows that both radar and LiDAR have their advantages since radar offers good range and performance in bad weather conditions, whereas LiDAR provides a high-resolution 3D mapping of the AGVs' environment. This makes radar more suitable for military applications that require precision and reliability, and LiDAR for environments that require real-time object detection and classification. However, as radar is complex and susceptible to interference, LiDAR is a better fit for our project because it provides more security (Vargas, 2021). Moreover, recent research has shown promising developments in optimizing bandwidth using LiDAR, which makes it more suitable for our scope (Mahboob, 2023), and (Müller, 2023). Given this previous research, our project will integrate the best options to accomplish the goal in the most effective way, enhancing the AGV's ability to move in complex environments and providing security.

**Stakeholders:**

**Primary stakeholders:** Our primary stakeholder is the product owner, Dr. T, and therefore Embry-Riddle Aeronautical University. Military institutions could benefit from this project too, using it to identify and neutralize threats in the field. Also, defense contractors would greatly benefit from this project as well because they would then be able to develop their own models and manufacture it to assist in military operations.

**Secondary stakeholders:** Civilians in warring areas as this could help militaries clear out bombing zones. Drone developers would benefit from this as well since their drones would be less likely to be confused for enemy drones. Finally, the US government would benefit from this as well since they wouldn’t have to spend as much funding on making new drones to replace those that are broken.

**Proposed Solution:**

The goal of this project is to design and develop an Autonomous Ground Vehicle (AGV) capable of detecting and classifying autonomous vehicles, referred to as “rovers," either as an "enemy" or "friendly" rover based on data provided by various sensors. The scope of the project is going to include the development of an AGV equipped with real-time detection and classification of small rovers, integration of communication protocols to transmit data between the AGV and external systems, implementation of algorithms to classify enemy rovers, rigorous testing of the AGV to evaluate its capabilities and performance. The scope of the project will not include autonomous attack mechanisms, full-scale development of hardware, and deployment in active military operations. This project will be performed by three subteams: communication, hardware, and software. Each team will be responsible for developing a specific component of the AGV, making sure to integrate and collaborate with each of the other teams. The paragraphs below will analyze and describe each team’s objectives and proposed solutions in more depth.

**Communication Team**

The goal of the communication team is to develop a reliable and efficient data transmission system that allows interaction between the Autonomous Ground Vehicle and external systems. This system will provide real-time transmission of data and information regarding object detection and classification. The goal is to develop a system that can support fast, reliable, and secure data transfer between the vehicle’s sensors and the ground station. The project will use raspberry pi 5 to transmit real-time data using wifi. The system will ensure low-latency and minimize signal interference.

The ground station will use a raspberry pi 5 to communicate with the raspberry pi on the robot. It will provide graphical interfaces and can be customized with object detection, mapping, and rover identification. Moreover, the ground station will allow the user to send commands to the AGV and adjust it in real time. Communication will happen via Wi-Fi. Finally, it will save all the data related to object detection and classification for later analysis.

**Hardware Team**

The hardware team is responsible for developing the physical Autonomous Ground Vehicle, ensuring that components such as the chassis, motors, control units, communications systems, and power systems, are all securely connected to each other, satisfy voltage and power constraints, and are properly wired and grounded. The hardware team is also responsible for assisting in the development of the external ground station from which the AGV will communicate, following the same requirements previously listed.

The AGV will use four independently-controlled motors for movement, and will utilize both pivot and differential steering to control tight or longer turns, respectively. Aluminum structure framework will be used for the chassis. The AGV will also have the capabilities to be controlled both manually, which will provide support for functionality testing, and autonomously, provided by the Software Team. Electrical components will be connected through insulated cables.

Additionally, the Hardware Team will conduct physical testing of the AGV to ensure the capabilities developed and implemented are functional, and satisfy the requirements and scope of the project. In the event that all requirements are met for the hardware team, and the scope remains unchanged, improvements will be made to the physical structure to increase its strength and integrity. Further, more rigorous testing will also be conducted to ensure its reliability in the event that any future development or application of this AGV will be plausible.

**Software Team**

The purpose of the software team is to develop programs to receive the raw input data, convert it into data that can be used to determine the location and whether it is friend or adversary, then decide what to do, which could be a change in its speed, direction, etc.

To implement sensor data, CloudCompare will be used to transform raw LiDAR data into reliable data structures for classification. There will be classifications for buildings, ground, and vegetation. Functionalities including noise filtering, data conversion, and batch processing will be utilized in the project. This system operates in a C++ programming environment. A Raspberry Pi will be used to send and receive information to/from the ground station via peer-to-peer (P2P) communication.

To manage the robotic systems, including obstacle avoidance, algorithms will be developed to control the motors using a second Raspberry Pi in C++. The main responsibilities of motor control will be sending select signals to turn each wheel on or off for robot navigation. The data collected from LiDAR will be processed via CloudCompare as a format compatible with an image processing tool (e.g. OpenCV). Developed algorithms will be used to read and publish the results of the QR code reading. The developed algorithms will use the results for robot navigation and communication procedures. All software listed will be free and open source. Additionally, motor control algorithms will be developed via Linux.

The project will follow a two-semester development cycle:

**Semester 1:** The focus during the first semester will be on system architecture, sensor selection, and initial development of the vehicle.

1. **Communication Team:**

* Research and selection of communication protocols, such as wifi relay, for data exchange between the AGV and external systems
* Research and test of potential wireless communication challenges, such as interference
* Implementation of the ground station
* Implementation of a basic version of the communication between the AGV and the ground station
* Use of simulated environments to evaluate data transfer reliability and speed
* Real-time communication for data exchange
* Update documentation

1. **Hardware Team:**

* Inspect current condition and capabilities of the robot
* Research frame materials to improve the structure of the robot
* Research different types of hardware/sensors to include on the robot
* Develop movement capabilities
* Develop a “wishlist” of capabilities and additions to include on the robot
* Evaluate power constraints
* Document work done on the robot
* Integrate components from Software Team and Communication Team and provide feedback with respect to possible hardware constraints

1. **Software Team:**

* Develop and algorithms for robot and obstacle avoidance
* Utilize P2P communication algorithms to connect with ground station
* Test robot motor controls and obstacle avoidance
* Develop algorithms for various motor movements in certain situations
* Develop preliminary software analysis documentation
* Develop preliminary requirements

**Semester 2:** The second semester will focus on finalizing the system, including testing and performance optimization.

1. **Communication Team**

* Optimization of communication for real-time detection and classification (low latency)
* Testing on the communication system using real-world data
* Integration of the communication system with the navigation and object detection systems to test that everything works between teams
* Finalization of communication modules to interact with software and hardware components
* Final Documentation

1. **Hardware Team:**

* Finalize construction of AGV, to include integration of all communication and software components
* Finalize construction of ground station
* Optimize AGV through rigorous physical tests, to include collisions, vibrations, and movement on different natural terrains
* Finalize documentation of work done
* Clean up the appearance of the robot

1. **Software Team:**

* Research and utilize CloudCompare APIs to integrate LiDAR data conversion into suitable data structures
* Test CloudCompare data processing for noise, data conversion, and batch processing to integrate more effective data reading
* Implement image processing tool for integrating QR code reading
* Write and test algorithms that determine whether an identified object is friend or enemy
* Test and refine motor movement algorithms for certain situations
* Implement and test motor algorithms for unprecedented events
* Finalize requirements and software documentation

**Proposed Project Budget:**

The proposed project budget is …

Rpi 5 LoRa hat: 35$

<https://www.amazon.com/SX1262-LoRa-HAT-Transmission-Communication/dp/B07W83FCCZ>

2 Batteries: 86$

<https://www.amazon.com/Talentcell-LF8011-Rechargeable-Phosphate-Batteries/dp/B0CNLKKL9C/ref=sr_1_5?crid=1XGH3AB0OAAKW&dib=eyJ2IjoiMSJ9.8jZxKXrzefpmPEME6T2kWCOS8NTXOLfEKS14ssX_BV1G6h5cbC8eWrWC0ADsayoiHBpV8BJRYHIL8oIhP8Ii4xMbbeTqWfFDhCjSpn17RXQpF4foGMbQ9tnIQwhG7Xi50-884UYxqog1wllM0DBZPdYfa9uISP7gFbYdnp--h60o4ZKLKD_aksrnHimF9VVnb_nSYaqOlTEAeLAYfgGYHDcjtL8xQPawyO4eosuWRu4HGhjUrZc9IR59OGr605nMUjW-G9CuoYZS1nbWZ33Emr8KoGnGiHsS8v2dA2w3wf4.thR2d1sizt8vdnPf0oVgjKLEJH0307qnHwFAG00vusM&dib_tag=se&keywords=battery+24v&qid=1727204346&sprefix=battery+24v%2Caps%2C115&sr=8-5>

3x Radar: 450$

<https://www.ti.com/tool/IWR6843AOPEVM>

2x Raspberry Pi 5: 160$

<https://www.sparkfun.com/products/23551?src=raspberrypi>

**References:**

Stój, J., Kampen, A.-L., Cupek, R., Smołka, I., & Drewniak, M. (2023). Industrial Shared Wireless Communication Systems—Use Case of Autonomous Guided Vehicles with Collaborative Robot. Sensors (14248220), 23(1), 158. <https://doi.org/10.3390/s23010158>

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=>

Mahboob, H., Yasin, J. N., Jokinen, S., Mohammad-Hashem Haghbayan, Plosila, J., & Muhammad, M. Y. (2023). DCP-SLAM: Distributed Collaborative Partial Swarm SLAM for Efficient Navigation of Autonomous Robots. Sensors, 23(2), 1025. <https://doi.org/10.3390/s23021025>

Liu, Y., Sun, R., Zhang, X., Li, L., & Shi, G. (2021). An autonomous positioning method for fire robots with multi-source sensors. Wireless Networks. <https://doi.org/10.1007/s11276-021-02566-6>

Vargas, J., Alsweiss, S., Toker, O., Razdan, R., & Santos, J. (2021). An overview of autonomous vehicles sensors and their vulnerability to weather conditions. Sensors, 21(16), 5397. <https://doi.org/10.3390/s21165397>

Nesti, T., Boddana, S., Yaman, B., & Bosch Center for Artificial Intelligence. (2021). Ultra-Sonic Sensor based Object Detection for Autonomous Vehicles. In *CVPR Workshop* [Conference-proceeding]. <https://openaccess.thecvf.com/content/CVPR2023W/WAD/papers/Nesti_Ultra-Sonic_Sensor_Based_Object_Detection_for_Autonomous_Vehicles_CVPRW_2023_paper.pdf>

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>

Fink, J., Ribeiro, A., & Kumar, V. (2012b). Robust control for mobility and wireless communication in Cyber–Physical Systems with application to robot teams. Proceedings of the IEEE, 100(1), 164–178. https://doi.org/10.1109/jproc.2011.2161427

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

Yang, Y., Huang, T., Wang, T., Yang, W., Chen, H., Li, B., & Wen, C. (2024). Sampling-efficient path planning and improved actor-critic-based obstacle avoidance for Autonomous Robots. Science China Information Sciences, 67(5). https://doi.org/10.1007/s11432-022-3904-9