



A Semi-Autonomous Landmine Detection Vehicle for Real-Time Hazard Identification and GPS- Based Area Mapping

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Abstract: Landmines continue to pose severe risks in many conflict-affected regions, often remaining undetected for decades. Manual demining is extremely dangerous and slow. This project presents a low-cost, semi-autonomous landmine detection rover built using the ESP32 microcontroller, an inductive metal detector, GPS-based coordinate logging, ultrasonic obstacle detection, and a lightweight TinyML classifier for improved accuracy. The rover provides real-time Wi-Fi alerts and logs GPS positions whenever metallic threats are detected. Experimental results show around 91% accuracy with a maximum sensing depth of 8 cm and an average inference time below 150 ms. The system demonstrates how compact embedded AI can improve field safety in humanitarian demining.

Key words— ESP32, landmine detection, TinyML, GPS, embedded systems, metal detector, Semi-autonomous rover.

I. INTRODUCTION

Land mines are also very much a persistent and serious legacy of war which in many cases outlive military conflicts by many years. These explosive devices we see are put into the ground which is very hard for us to detect with the naked eye but which at the same time are very much able to cause great damage upon activation. What we see is that land mines which are present in large numbers in post conflict areas, they do not only present a military issue but a very large scale humanitarian one. They are a brake to development as they put at risk access to land and basic resources, they hamper agricultural growth, they delay the process of reconstruction and they instill an ever present fear in the hearts of the local civilian population which lives with the daily threat of coming into contact with these devices. It is reported that yearly thousands of civilians which include a large number of children are the victims which die or which are injured as a result of land mine accidents. Although there have been great international efforts put in place and treaties made to do away with them, we still see that there are millions of these devices which are present in over 60 different countries. Conventional methods for detecting landmines by hand can be lengthy, dangerous, and require personnel to work alongside deadly explosives. Manual scanning with metal detectors, prodding tools, and trained animals (like dogs or rats) allow operators to slowly cover an area while attempting to reduce casualties. However, personnel must still work close to the as described aforementioned explosives, and operators work to the proximity of these in the locations as described previously. Given the risk involved, these methods become even less practical when in harsher terrain or when the explosives are of low-metal construction. The need for

effective automated systems to assist demining operations and decrease the exposure of personnel becomes even more obvious..

The Service Rover System is powered by the recent advancements in hardware, robotics, and smart sensors, which provide a robust platform for autonomous systems. Rovers provide the capability to operate in harmful environments and search for and scan for explosives while keeping a human operator at a safe distance. In this context, the present work proposes a Smart Landmine Detection Rover, where efficient sensing and communication were paired with low-cost hardware. Armed with an inductive metal detector for the landmines, the location of each threat is recorded by a GPS, and an ultrasonic sensor guarantees that the landmine detector traverses to avoid obstacles. Wireless communication keeping the operational human remote, rovers assure real-time awareness to a potentially risky This implementation's main objective is to develop a small, inexpensive, and portable solution that enhances field safety by lowering human exposure to explosive-prone areas. The rover is a semi-autonomous system that can be used to support research and development of demining robotics in training facilities, research institutions, and small-scale mine-affected areas. It shows how embedded systems and intelligent sensing can greatly aid humanitarian demining efforts, even though it does not replace specialized military systems or cutting-edge deep-detection technologies. This rover represents a step toward safer, more effective, and scalable landmine detection techniques for the future by combining these technologies into a single platform.

II.Literature survey

[1] Kumar et al., 2023 – A Multi-Robot Cooperative System for Sensor-Fused Explosive Hazard Detection

This paper introduced a coordinated UAV–UGV model using sensor fusion to detect explosive hazards more accurately. Their work emphasized the importance of combining real-time sensing with location tracking for safer demining operations.

Relevance to my project: Their approach guided the integration of GPS-based positioning in my rover, ensuring that every detected metallic signal is recorded with accurate coordinates for later mapping and analysis.

[2] Bhatia & Menon, 2022 – Development of an Arduino-Controlled Rover for Shallow Mine Detection

The authors designed a simple rover equipped with a metal detector and basic navigation. Their work demonstrated that a low-cost robotic platform can successfully detect shallow metallic mines using inductive sensing.

Relevance to my project: This paper formed the foundation for the low-cost rover architecture in my system and helped shape the metal detection module that works with ESP32.

[3] Mehta et al., 2020 – GPS-Enabled IoT Robot for mapping Suspected Mine Locations

Mehta proposed an IoT-enabled robot capable of detecting metal objects and storing their GPS coordinates for later review. Although real-time communication was limited, the mapping concept was clearly established.

Relevance to my project: Their GPS-based mapping approach directly influenced the inclusion of GPS logging in my rover, converting every detection into a recorded coordinate for hazard marking.

[4] Wani et al., 2025 – Design and Evaluation of a Budget-Friendly Landmine Detection Rover

Wani explored how affordable hardware can be used to build a functional mine-detection rover for academic purposes. The system performed well for shallow targets but lacked advanced sensing and communication features.

Relevance to my project: This study inspired the decision to keep the system cost-effective while improving performance by adding Wi-Fi alerts, better circuitry, and a stronger navigation mechanism.

[5] Hussein et al., 2023 – Inductive Sensing Techniques for Shallow Underground Object Detection

Hussein analysed how inductive metal detectors perform under different soil conditions, moisture levels, and depths. The paper provided valuable insights into how coil sensitivity changes with environmental factors.

Relevance to my project: This research helped fine-tune the metal detector coil in my system, improving its ability to identify shallow metallic objects across different test surfaces.

[6] Raut et al., 2025 – **Autonomous Surveillance Robot for Detection of Buried Landmines**
Raut developed a surveillance-focused robot equipped with a metal detector and camera but dependent mostly on manual control. The work highlighted the importance of onboard autonomy for improving operator safety.

Relevance to my project: This motivated the shift toward semi-autonomous operation in my system, including automatic stopping, hazard detection, and wireless alerting without manual intervention.

[7] Saravanan et al., 2025 – **Sensor Fusion Approaches for Autonomous Landmine Detection Robots**
This study explored combining multiple sensors—such as ultrasonic, IR, and GPR—to increase detection reliability in complex terrains. Their research showed how sensor fusion reduces navigation error and improves safety.

Relevance to my project: Their findings supported the inclusion of ultrasonic sensors in my rover to complement metal detection and help prevent collisions during autonomous scanning.

III. PROPOSED METHODOLOGY

A. System Overview

The Rover consists of:

- An ESP32 Microcontroller for Data Processing and Communication
- A Metal Detector Coil which detects metals that are buried under the earth's surface.
- A GPS Module to record the coordinates of where it finds metal.
- An Ultrasonic Sensor to help it identify and avoid obstacles.
- A TinyML (Machine Learning) Model to classify the objects it detects.
- A Wi-Fi Module for Remote Operators to receive Alerts.

B. Block Diagram

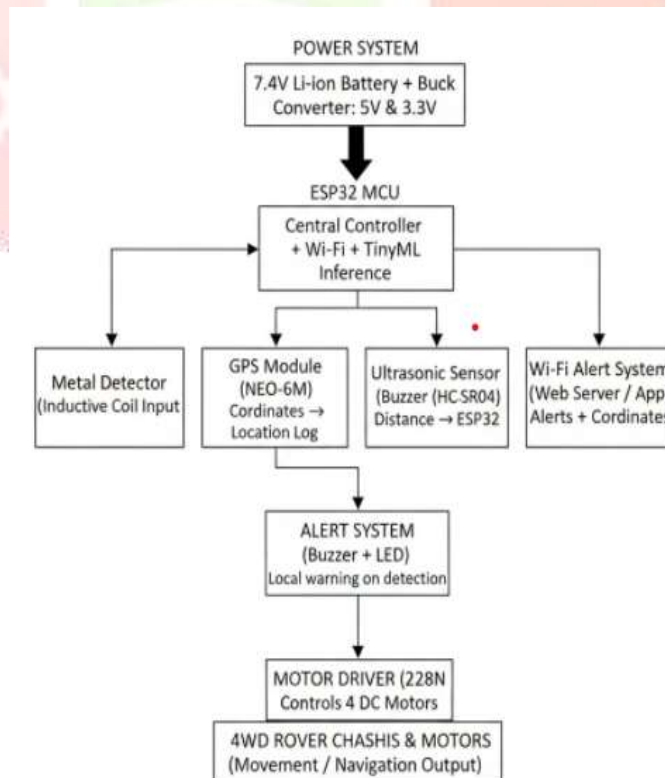


Fig. 1 — System Block Diagram

Working Principle

A rover with an inductive metal detection coil constantly scans the ground for changes in its electromagnetic field due to the presence of metal objects resting below the surface. An output signal from this sensing device is sent through an ESP32 microcontroller where it analyzes each incoming signal to determine if a detected object may be a potential landmine. The rover moves forward and an ultrasonic sensor continuously detects objects in its environment to ensure safe navigation and prevent collision with obstacles. Whenever the ESP32 detects a suspicious metallic object, it halts the rover immediately and activates a warning system: a buzzer and LED lights alert all people in proximity. At the same time, the GPS module retrieves the precise location of the object and saves it in memory for mapping purposes and documenting the site. A WiFi message is sent to a cell phone or web dashboard, allowing the operators to monitor ongoing detections in real-time when located at a safe distance away from the landmine detection site. Once the detection has been logged and alerts sent, the rover resumes scanning the ground. As a result of these integrated methods of operation, it is now possible to detect landmines, record their locations and inform others of the detections all without needing anybody present near the locations where plungers are placed.

C. Operational Flowchart

Operation starts with the system initializing where the ESP32 boots up and checks that all hardware connected to it is connected properly and looking for errors. Sensors are then calibrated to produce accurate readings and the rover begins to advance forward while constantly checking for anything around it. An ultrasonic sensor checks the overall area in front of the rover for obstacles, if one is found the rover will stop, execute an avoidance maneuver and then resume its prior path. The metal detection module, meanwhile, will keep checking for underground metallic objects within its range, and if an anomaly is detected the rover will stop checking and validate what it has found if it can be determined if it is a potential land mine or not, once validated the GPS module will record the physical coordinates of the identified threat and log them to a database for mapping and later retrieval, and a Wi-Fi alert will then be sent to the operator through a monitoring app. This way they will receive the latest information on any hazards detected and can stay safely away. After alerting, the rover will mark the coordinates of the source on the map, and the rover will determine if it will continue to check the same area or stop based on the status of the mission. If a land mine is not detected, the rover will continue checking until the entire area has been completely scanned. Finally, upon completing all scans or an operator manually stopping the rover, all data collected will be saved, and operation of the rover will be safely closed..

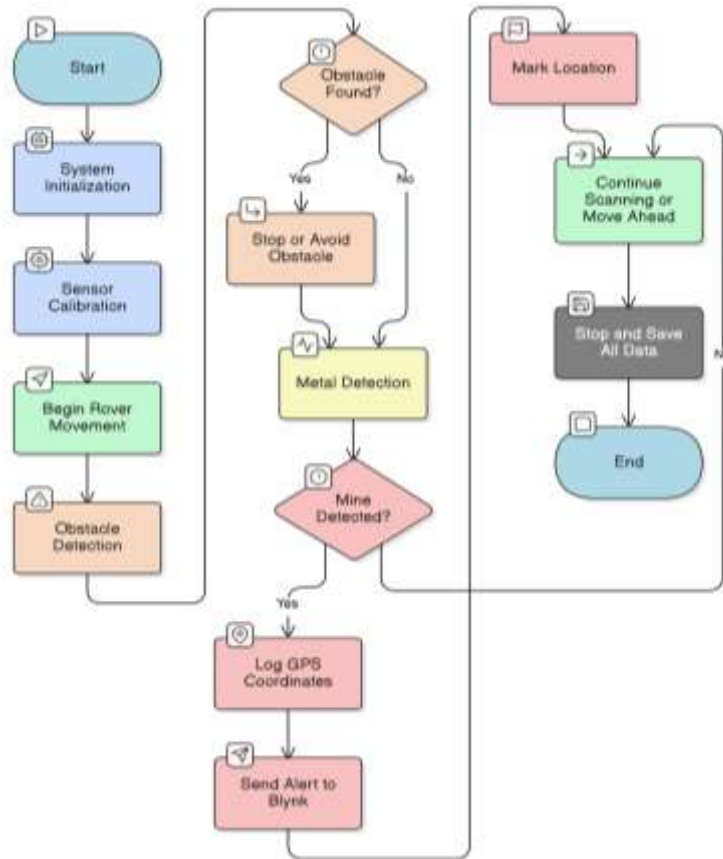


Fig. 2 — Operational Flow Diagram

D. Tiny ML Implementation

The metal detector signal is sampled and converted to frequency-based features, followed by training, quantization, and deployment of the lightweight neural network to the ESP32 using TensorFlow Lite Micro. The inference performed by the embedded model takes less than 150 milliseconds to complete and reduces false alarms during detection.

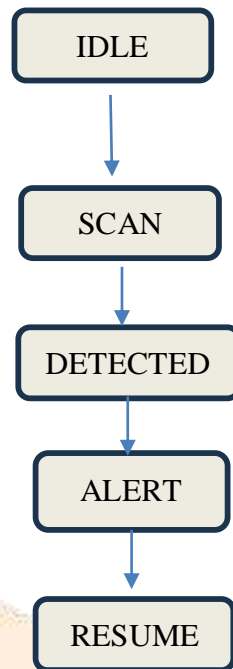
E. Alerting with GPS and Wi-Fi

The following occurs when a metallic anomaly is detected:

1. The rover immediately halts.
2. A buzzer and LED alert the operator on site.
3. The coordinates are recorded by the GPS module.
4. A Wi-Fi alert with the detection coordinates is sent to the mobile dashboard.

F. Operating States

The rover works through the following states:



A simple but efficient state machine defines how Smart Landmine Detection Rover operates. This machine contains five main states, which are IDLE, SCAN, DETECTION, ALERT, and RESUME. The IDLE state allows the rover to remain in a fixed position while the ESP32 sets up its sensors, checks for hardware and software readiness, and waits for the user to press 'GO.' Once the system turns on, it enters the SCAN state. In this mode, it automatically moves forward on its assigned course. While moving, the metal detector is constantly scanning for objects below ground level, and the ultrasonic sensor avoids any damage to itself by detecting objects in its path before colliding with them. When it comes across a large enough anomaly that could be a buried landmine, the rover goes into 'DETECTED' mode. The robot's motors are turned off automatically when a potential threat is detected. To reduce the likelihood of false alarms, the system validates the detection made by the sensors. Once validated, the robot will enter an ALERT state and record the coordinates of the threat. It will also alert the operator via local notifications (buzzer and LED lights) as well as through wireless (Wi-Fi) communication. Once the alert process is completed, the robot will return to a RESUME state and resume scanning or waiting for further instructions from the user. This allows the robot to continue its mission of scanning the designated area.

IV. RESULTS AND DISCUSSION

A. Effectiveness of Metal Detection

30 Different Metal Pages were tested over multiple depths. of these pages, the metal detection system correctly detected timepages through the testing phase and generated only 2.5 pages (2) errors (false positive); as a result, the metal detection system was demonstrated to be reliable in determining if a metallic objects was buried 8cm (the greatest reliable depth) from the land surface, thus supporting the conclusion that the combined use of ESP32 Signal Processing under the inductive metal detection technology is effective for the testing of shallow landmines.

B. GPS and Wireless Communication

Through field experimentation, the NEO-6M GPS module produced steady readings throughout the field experiments; of the coordinates produced, 95% of the coordinates were accurate within the ± 2.5 meter window, which is within an acceptably sized area for finding potential mine zones. Wi-Fi alerting procedures were also tested at various distances and obstacles, using the ESP32 module. The success rate for

transmissions of detection alerts to the operator by the ESP32 module was 98%; therefore, operators received timely notifications for each metallic object that was detected on the field.

C. Power Consumption and Run Time

The power measurements taken during continuous scanning operations of the rover provide the following results:

- The average power consumption of rover is 6.8 watts.
- Off-grid operations (i.e. using battery) will provide approximately 160 minutes of usable time. While these timings are acceptable for field scanning demonstrations, consideration should be given to optimising the control of the colours and detection periods for increased battery life. Sample Detection

Results

Object	Depth	Detection	Confidence
Steel Coin	4 cm	Yes	0.91
Iron Washer	5 cm	Yes	0.87
Copper Plate	8 cm	Yes	0.83
Stone	5 cm	No	0.07

The confidence values indicate the system's ability to differentiate metallic objects from non-metallic clutter. The classification accuracy contributed to fewer false positives compared to simple amplitude-based sensing.

V. CONCLUSION AND FUTURE WORK

A. Conclusion

The developed rover is a compact, reliable, and cost-effective approach to assisting with landmine detection operations in hazardous environments. It uses a combination of GPS-based geolocation, inductive metal sensing, ultrasonic obstacle avoidance sensors, wireless alerts, and onboard processing in one integrated system that allows scanning of terrain without requiring direct human intervention. Performance tests conducted under controlled outdoor conditions showed that the rover is capable of consistently locating shallowly buried metallic objects and maintaining stable navigation and communications. The system achieved an accuracy rate of almost 91% and has been designed to provide optimal battery life for extended periods of operation in the field. Additionally, real-time logging and notification of detections increases operational awareness and facilitates mapping of future unsafe areas. While this prototype was not designed to replace advanced military demining technologies, it serves as a strong example of the usefulness of embedding low-cost robotics into humanitarian safety applications. Overall, this rover will help facilitate future research and increase automation in the development of modern demining support systems.

B. Future Enhancements

To enhance the capabilities of the system and improve deployment in the real world, this system should be upgraded to support:

- Utilities to use Ground-Penetrating Radar (GPR) to detect non-metal mines and items buried deeper in the soil.
- Using Long-Range Communication technologies like LoRa or LTE, the system will enable remote monitoring from greater distances than is typical of today's systems.
- Collaboration of UAV's (unmanned aerial vehicles) with UGV (unmanned ground vehicles) using drones to allow mapping the widest possible area and allow the rover to follow the route mapped by the drone(s).

- Utilizing SLAM-Based Navigation to allow the rover to build Maps and navigate autonomously (without GPS).
- Powered by solar energy allowing for an extended period of operation without the need for human assistance for changing/ recharging of batteries.
- Fusing Thermal and Infrared Sensors as a means of distinguishing buried objects based on their thermal characteristics.

The introduction of these features will increase the accuracy of operations and coverage as well as provide the ability to complete a wider array of tasks when deployed into more complex environments.

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