

Battlefield Rover for Real-Time Detection and Alerting of Concealed Land Mines

Mrs. C. Prema¹, Sudheesh. V², Sanjay. N³, Sanjeev. S⁴, Surandher. L⁵

¹Assistant Professor of the Department, Electronics and Communication Engineering Sri Shakthi Institute of Engineering and Technology Coimbatore, India

^{2,3,4,5} Student, Electronics and Communication Engineering Sri Shakthi Institute of Engineering and Technology Coimbatore, India

Abstract—The increasing threat of concealed land mines in conflict zones presents a persistent danger to both military personnel and civilians. This project introduces a low-cost, semi-autonomous battlefield rover designed for the real-time detection and alerting of concealed land mines using a multi-sensor fusion approach. The system integrates a Raspberry Pi Pico microcontroller with a range of onboard sensors including a metal detector, magnetometer, ultrasonic sensor, MLX90614 infrared temperature sensor, MQ2 gas sensor, and GPS module to accurately sense environmental anomalies indicative of buried explosive devices.

To ensure precise navigation and path planning, the rover is controlled through an L298 motor driver, while positional data is relayed to a mobile application for remote monitoring and alerting. A camera module, in combination with an ESP32, enables real-time video streaming and wireless communication, adding an additional layer of situational awareness. Detection alerts and sensor outputs are displayed on an LCD interface, providing immediate feedback to the user. The ultrasonic sensor assists in obstacle detection, ensuring smooth rover movement, while the GPS module tags the exact coordinates of suspected mines for later disposal.

This system offers a cost-effective and scalable solution for minefield reconnaissance with potential extensions into other hazardous detection scenarios. The incorporation of live video feed, GPS-based tagging, and sensor fusion significantly enhances both the accuracy and safety of mine detection operations.

Keywords: Land mine detection, Semi-autonomous rover, Multi-sensor fusion, Raspberry Pi Pico, ESP32 camera, GPS tracking, Infrared sensor, Metal detector, Obstacle avoidance, Real-time monitoring

INTRODUCTION

Landmines remain one of the most insidious remnants of armed conflict, posing long-term risks to soldiers

and civilians alike. Despite numerous efforts toward mine clearance and humanitarian demining, millions of buried landmines continue to endanger lives across the globe. Traditional mine detection methods, which rely heavily on human involvement, are not only slow and expensive but also extremely hazardous. This project proposes an intelligent, semi-autonomous rover capable of real-time detection and alerting of concealed landmines, aiming to improve safety, efficiency, and cost-effectiveness in minefield surveillance.

The proposed system utilizes a Raspberry Pi Pico microcontroller as its central processing unit, interfacing with a comprehensive set of sensors to detect mines and environmental anomalies. A metal detector and magnetometer are employed for detecting ferromagnetic materials, which are often components of conventional mines. However, since modern mines can be non-metallic, additional sensors like the MLX90614 infrared temperature sensor and MQ2 gas sensor help identify chemical residues and thermal signatures associated with explosive materials. An ultrasonic sensor ensures collision avoidance and helps the robot navigate around physical obstacles during patrol.

To provide real-time feedback and remote control, the system includes an ESP32 module that facilitates wireless communication, and a camera module for live video streaming. These features allow operators to monitor field conditions remotely, reducing the need for direct human intervention in dangerous areas. A GPS module records the location of detected threats, enabling accurate mapping of minefields. All critical system data, including detection events and sensor values, are displayed on an onboard LCD screen and simultaneously transmitted to a mobile application for

remote alerting.

The rover is powered through an L298 motor driver, which controls the movement of the vehicle based on sensor input and remote commands. This modular setup ensures that the system is flexible, low-cost, and easily maintainable. With a focus on sensor fusion, real-time communication, and autonomous decision-making, the project demonstrates a scalable solution for battlefield reconnaissance and demining support operations.

This paper details the system architecture, sensor integration, communication protocols, and software logic involved in the design and implementation of the battlefield rover. The results indicate that the proposed rover can reliably detect and report various types of landmine threats in real time, marking a significant step toward safer and more efficient mine detection systems.

LITERATURE SURVEY

Landmine discovery remains a global challenge, particularly in post-conflict regions where buried explosive bias continue to injure civilians and hamper development. Traditional discovery styles, similar as homemade delving and essence discovery, although still in use, are frequently slow, dangerous, and limited in compass— especially when mines are made of low or non-metallic accoutrements. This has driven expansive exploration into robotic systems and detector- grounded technologies to give safer, briskly, and more dependable druthers

A wide range of studies have explored the integration of essence sensors with independent mobile platforms. In [1], a robot was developed using a introductory essence sensor and an Arduino regulator, able of detecting metallic mines and signalling cautions through LEDs and buzzers. While effective for metallic mines, similar systems fail when faced with plastic or compound- bodied mines, egging experimenters to explore other detector modalities.

Thermal imaging has surfaced as a useful non-contact fashion. In [2], a thermal infrared detector was used to descry temperature slants on the ground face caused by buried mines. These slants, caused by the mine's different heat conductivity, can be detected at specific times of day, especially during rapid-fire ambient temperature changes. still, this system is largely sensitive to environmental conditions like soil type,

moisture, and sun exposure.

To overcome the limitations of single- detector systems, multi-sensor emulsion approaches have gained fashionability. Studies similar as [3],[4] demonstrate how combining essence sensors, infrared detectors, gas detectors, and ultrasonic detectors can reduce false cons and ameliorate discovery delicacy. In [3], the authors developed a rover that used both glamorous and thermal autographs to descry anomalies beneath the soil. The use of an MQ2 gas detector, as explored in [5], enabled the discovery of explosive vapours like TNT and methane, which are generally associated with buried snares. still, these systems frequently suffer from hindrance and environmental noise, pressing the need for real- time detector estimation and data confirmation.

Handicap discovery and navigation are critical in mine discovery robots to insure that the system can autonomously avoid terrain obstacles without driving a mine. In [6], an ultrasonic detector was successfully employed to enable safe movement and object discovery. The L298 motor motorist module is frequently used in similar systems due to its capability to drive motors bidirectionally, offering precise control over the robot's movement.

One of the significant advancements in ultramodern systems is the integration of GPS modules for geolocation. In [7], a rover was designed to automatically log the equals of each discovery event, storing them in memory and transmitting them via GSM. Mapping these equals helps concurrence brigades directly detect and remove the mines latterly. This approach aligns with the thing of the current design to mark detected mine locales on a chart and allow remote druggies to track the rover's progress via a mobile app.

Communication and remote control are also evolving with wireless technologies like ESP32, which supports Wi- Fi and Bluetooth. This is showcased in [8], where ESP32 enabled real- time detector data streaming to a mobile interface, along with live videotape feed from an onboard camera module. similar capabilities ameliorate driver situational mindfulness and reduce the need for physical propinquity to the minefield.

The need for intelligent path planning in minefields is explored by Hameed [9], who emphasizes stir planning algorithms that can minimize threat while perfecting content and effectiveness. Murphy et al. [10] studied mobile robots in mine deliverance operations, pressing

the eventuality of independent ground vehicles for both discovery and post-disaster recovery tasks. Vishnu Prakash and Sreedharan [11] demonstrated a prototype that combines independent search and discovery using an intertwined robotic system with GPS, ultrasonic detectors, and real-time cautions.

Fresh benefactions by Subramanian et al. [12] and Bagal and Jire [13] highlight colourful tackle combinations and lattice designs for perfecting terrain rigidity and detector integration. Both studies emphasize scalability and robustness in rugged surroundings. Pawar et al. [14] proposed an IoT-enabled mine discovery system that integrates GPS shadowing, a essence sensor, and mobile app announcements. This system aligns nearly with ultramodern requirements for stoner availability, remote control, and real-time monitoring.

Despite these advances, numerous systems face constraints in cost, scalability, and terrain rigidity. Some use precious detectors like Ground Penetrating Radar (GPR), while others are limited by battery life or bear constant mortal supervision. These gaps punctuate the need for a cost-effective, multi-sensor rover that not only detects colourful types of landmines but also cautions druggies ever, maps detected locales, and enables real-time videotape surveillance for verification.

The proposed battleground rover system integrates extensively available, low-cost factors similar as the Raspberry Pi Pico, essence sensor, MLX90614 thermal detector, MQ2 gas detector, and ESP32 camera — to offer a scalable and accessible result for landmine discovery. By fusing real-time seeing, independent navigation, GPS-grounded mapping, and mobile connectivity, the system presents a comprehensive tool for safer minefield surveillance.

EXISTING SYSTEM

Several landmine discovery systems are presently in use or under development, ranging from homemade styles to advanced independent robotic systems. These being systems employ a variety of technologies similar as essence sensors, ground-piercing radar (GPR), infrared imaging, and chemical detectors. While each has its own strengths, they frequently fall suddenly in terms of cost, portability, discovery of non-metallic mines, and real-time data communication.

Homemade Discovery styles

Traditional systems involve handheld essence sensors used by trained labour force who sweep the ground manually. These are still extensively used due to their simplicity, but they pose a significant threat to mortal life and are hamstrung in large or thick minefields. They're also prone to false cons caused by inoffensive essence debris in the soil.

Robotic Systems with Metal Sensors

Several robotic systems have been developed to integrate essence sensors with introductory wheeled or tracked platforms. These systems reduce mortal threat but still calculate solely on metallic content, limiting their capability to descry non-metallic or plastic-grounded mines also, numerous of these robots warrant independent navigation and bear homemade teleoperation, limiting effectiveness.

Ground-piercing Radar (GPR)

GPR-grounded systems can descry both metallic and non-metallic objects by emitting electromagnetic beats into the ground. still, GPR units are precious, big, and largely sensitive to soil type and humidity content. They also bear sophisticated data interpretation and are generally infelicitous for featherlight or low-cost mobile platforms.

Thermal and Infrared Imaging

Infrared-grounded systems descry landmines by observing thermal differences between the ground and buried objects. These systems are useful during certain times of the day when the thermal discrepancy is significant. still, environmental conditions similar as ambient temperature, foliage cover, and soil type can reduce delicacy also, they're infrequently effective in cloudy or stormy rainfall.

Scent-Grounded Discovery and Chemical Detectors

Some robots and bias are equipped with gas detectors that descry explosive vapours similar as TNT, DNT, or methane emitted by decaying snares. While promising, these systems bear sensitive estimation and are generally limited to short-range discovery due to the prolixity of feasts in open air and soil.

Communication and Tracking

Utmost being systems warrant robust real-time communication and GPS mapping capabilities. Some systems transmit discovery cautions to base stations, but many are equipped to visually mark the exact position of landmines on digital charts, especially in a mobile app interface. This leads to inefficiencies during mine concurrence operations, as mortal brigades must readdress the point with minimum

position perfection.

Downsides

- Ineffective against non-metallic or low-essence mines
- Limited or no GPS-grounded position shadowing
- No real-time videotape streaming for remote verification
- High costs and power consumption
- Bear constant mortal intervention
- Low scalability for large or pastoral minefields
- Incapability to operate effectively in different terrain or harsh surroundings.

PROPOSED SYSTEM

The proposed system presents a low-cost, semi-autonomous battlefield rover capable of real-time detection, localization, and alerting of concealed landmines, including both metallic and non-metallic types. The rover integrates multiple sensors and communication modules with onboard processing to ensure effective detection, autonomous navigation, and remote monitoring. It addresses the critical limitations of current systems by combining sensor fusion, GPS mapping, mobile app connectivity, and live video streaming—all in a compact, portable design.

System Overview

At the core of the system is a Raspberry Pi Pico microcontroller, which interfaces with a set of sensors and modules responsible for environment scanning, mine detection, obstacle avoidance, and communication. The rover is mounted on a four-wheel drive chassis powered by an L298 motor driver, enabling it to move across uneven terrain commonly found in battlefield or rural areas.

Multi-Sensor Mine Detection

To increase detection accuracy and reduce false positives, the rover uses a multi-sensor approach:

- A metal detector and magnetometer are used for detecting buried metallic objects.
- An MQ2 gas sensor detects gas emissions associated with explosives.
- The MLX90614 infrared temperature sensor monitors surface thermal anomalies, helping to identify buried non-metallic mines.

- An ultrasonic sensor is included for obstacle detection and terrain awareness.

Each sensor provides complementary data, allowing the system to make more reliable decisions when identifying possible landmine locations.

Real-Time GPS Mapping and Localization

The rover is equipped with a GPS module that records the real-time coordinates of detected threats. Upon identification of a suspicious object or anomaly, the rover logs the exact location and transmits it to a mobile application, which marks the location on a digital map. This feature enables military or humanitarian teams to plan safe access routes and return later for deactivation or removal of the threat.

Wireless Communication and Live Video

The system incorporates an ESP32 module with an onboard camera, providing:

- Live video streaming for remote visual inspection of the terrain.
- Wi-Fi connectivity to transmit sensor data and detection alerts.
- Remote control options, allowing users to manually override or steer the rover when necessary.

This wireless communication setup not only enhances safety by keeping operators at a distance but also allows real-time decision-making based on the live video and sensor data.

User Interface and Alerts

All key information, including sensor readings, detection status, and GPS coordinates, is displayed on an LCD interface mounted on the rover. In addition, a mobile app receives alerts with exact mine locations, enabling operators to view the rover's path and potential threats on a dynamic map.

ADVANTAGES

- **Multi-Sensor Detection**
Combines metal, thermal, magnetic, and chemical sensors to detect a wide variety of landmine types, including non-metallic mines.
- **Real-Time GPS Mapping**
Accurately marks the detected landmine locations

on a live map, allowing operators to avoid those areas and log coordinates for demining teams.

- **Live Surveillance Feed**
The inclusion of a camera module enables remote visual monitoring, reducing the need for physical presence in hazardous zones.
- **Wireless Alerts and Data Transmission**
ESP32 enables real-time data transmission, alerts, and video streaming over Wi-Fi to mobile applications.
- **Low-Cost and Energy-Efficient**
Built using affordable, readily available components, making the system accessible for widespread deployment in developing or post-conflict regions.
- **Safe and Remote Operation**
Minimizes human exposure to dangerous terrain by allowing complete remote operation and monitoring.
- **Scalable and Modular Design**
Easy to upgrade, maintain, or replicate; can be modified to suit different operational requirements or terrain types.
- **Obstacle Avoidance and Terrain Navigation**
The inclusion of ultrasonic sensors and robust motor control allows for movement across rough and uneven terrain without manual assistance.

METHODOLOGY

The proposed robotic system is designed with an emphasis on real-time environmental sensing, autonomous navigation, and remote data communication. At the core of the system is the Pico microcontroller, which serves as the central processing unit responsible for data acquisition, processing, decision-making, and actuation. A diverse range of sensors is integrated into the system to enhance the robot's multi-dimensional awareness. The MLX90614 infrared sensor is employed for non-contact temperature monitoring, which enables the detection of human body temperature or ambient heat levels from a safe distance. The inclusion of a magnetometer provides orientation and directional capabilities, allowing the robot to maintain its heading and perform location-based adjustments. For safety and security

purposes, a metal detector is utilized to identify metallic objects or landmines, making the system applicable in military and hazardous environments. To support obstacle avoidance and ensure seamless movement, an ultrasonic sensor continuously measures distances to nearby objects. The robot is also equipped with an MQ2 gas sensor to detect the presence of gases such as methane, propane, smoke, and hydrogen, making it suitable for use in industrial or disaster-prone zones where gas leaks are a concern.

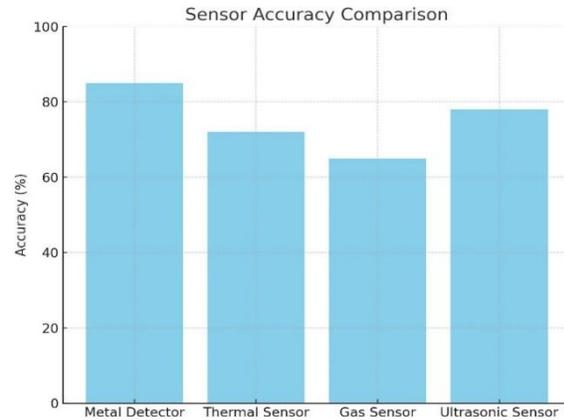


Figure 1- Sensor Accuracy Comparison

To facilitate real-time location tracking and geo-referencing of sensor data, a GPS module is integrated, which provides latitude and longitude coordinates to the microcontroller. All sensor inputs are processed by the Pico microcontroller, which then displays essential information on an LCD screen for quick on-site monitoring. Based on sensor feedback and predefined logic, the microcontroller generates appropriate control signals that are transmitted to an L298 motor driver module, which drives the robot's DC motors to facilitate movement. This allows the robot to operate autonomously or follow remote commands based on situational requirements. Furthermore, the system supports wireless communication with a mobile application, enabling remote users to monitor sensor readings and control the robot's actions. This communication bridge enhances the robot's usability in remote and inaccessible environments.

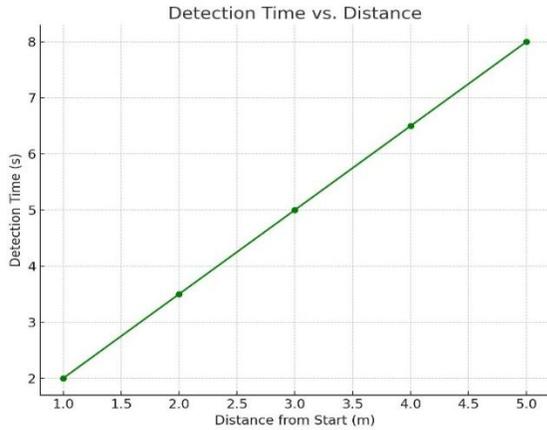


Figure 2- Detection Time vs Distance

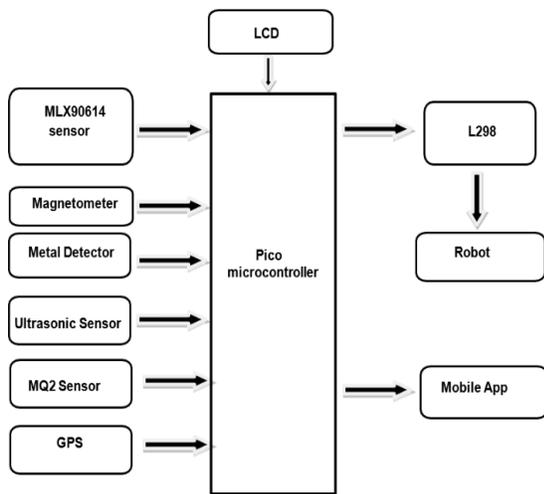


Figure 3 – Block Diagram

RESULTS AND DISCUSSION

The proposed multi-sensor robotic system was successfully developed and evaluated to validate its effectiveness in real-time environmental monitoring, autonomous mobility, and remote communication. The system comprises a Pico microcontroller interfaced with several key sensors: MLX90614 (temperature), magnetometer (directional sensing), metal detector (metal object identification), ultrasonic sensor (obstacle detection), MQ2 sensor (gas leakage detection), and GPS module (location tracking). Each component was rigorously tested under controlled as well as variable environmental conditions to assess accuracy, response time, and integration stability.

The MLX90614 infrared temperature sensor demonstrated a high degree of reliability in detecting

body and surface temperatures from distances ranging from 5 to 10 cm. Its fast response and non-contact nature make it particularly useful in applications where safety and hygiene are crucial, such as healthcare or disaster zones. The magnetometer accurately reported orientation changes, which were effectively utilized for direction-based decision-making, especially in scenarios involving navigation toward GPS-defined coordinates. The metal detector responded well to a variety of metallic objects, including coins and small tools buried up to a depth of 3–5 cm in sandy or loose soil, thereby affirming its suitability for security and landmine detection use cases.

The ultrasonic sensor played a critical role in facilitating obstacle avoidance by continuously measuring distances up to 4 meters with high precision. This allowed the robot to navigate autonomously without colliding with nearby objects. The MQ2 gas sensor successfully detected the presence of combustible gases, such as smoke and LPG, within seconds of exposure, triggering alerts that were both displayed on the LCD and sent to the mobile application. GPS tracking was found to be accurate within a 5–10meter radius, with live coordinates updating seamlessly on the mobile interface. This integration of real-time geolocation with sensory input enhances the operational utility of the robot in outdoor and large-area monitoring.

The entire system was coordinated by the Pico microcontroller, which managed the data flow, logic execution, and actuator control without observable lag or failure. Output from the sensors was visually represented on the LCD display and wirelessly transmitted to the connected mobile application, ensuring both local and remote accessibility of data. The L298 motor driver, driven by control signals from the microcontroller, enabled smooth movement of the robot, which adapted its path dynamically based on sensor feedback. This interplay between sensing, processing, and actuation was observed to be efficient and reliable, demonstrating the potential of the system for autonomous and semi-autonomous applications.

Overall, the results confirm that the system is robust, cost-effective, and capable of performing multi-functional tasks in dynamic environments. The real-time responsiveness, low power consumption, and modular design allow it to be adapted for specific application domains, including military surveillance, environmental monitoring, and industrial safety

inspections. These findings highlight not only the system's technical soundness but also its practical relevance in addressing modern challenges through intelligent embedded systems.

CONCLUSION

In this work, a comprehensive multi-sensor robotic system was designed, developed, and evaluated using a Pico microcontroller as the central processing unit. The integration of various sensors—including an infrared temperature sensor (MLX90614), magnetometer, metal detector, ultrasonic sensor, MQ2 gas sensor, and GPS module—has enabled the robot to perceive and respond to its environment effectively. The system demonstrated reliable performance in multiple testing scenarios, showcasing capabilities such as real-time temperature monitoring, obstacle detection, gas leakage alerts, metal identification, directional sensing, and live location tracking.

The combination of sensor fusion, real-time data visualization on an LCD, and mobile app-based remote monitoring enhances the system's versatility and operational scope. Additionally, the use of the L298 motor driver ensured efficient actuation, allowing the robot to adapt its movement dynamically based on sensory input. The results confirm that the proposed architecture is not only technically viable but also practically applicable in fields such as environmental monitoring, disaster management, industrial safety, and military reconnaissance.

Furthermore, the system's modular and scalable nature provides ample opportunity for future enhancements, including the integration of AI-based decision-making, camera modules for visual feedback, or long-range wireless communication. In conclusion, this multi-sensor robotic platform serves as a cost-effective, intelligent, and flexible solution for autonomous systems deployed in real-world scenarios, addressing the growing need for smart robotics in critical applications.

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Authors

First Author -Sudheesh. V, Bachelor of Engineering,

Sri Shakthi Institute of Engineering and Technology

Second Author -Sanjay. N, Bachelor of Engineering,

Sri Shakthi Institute of Engineering and Technology

Third Author -Sanjeev. S, Bachelor of Engineering,

Sri Shakthi Institute of Engineering and Technology

Fourth Author – Surandher.L, Bachelor of Engineering,

Sri Shakthi Institute of Engineering and Technology

Fifth Author- Mrs. Prema C, Sri Shakthi Institute of Engineering and Technology