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Design and Development of an Autonomous Landmine Detection System Using Robotic Technology

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Abstract
Landmines remain a significant threat in many regions recovering from conflict, causing injuries, loss of life, and slowing down economic and social progress. This project presents the development of an autonomous robotic system designed to detect landmines while improving the safety and efficiency of detection activities. The system uses a mobile robot equipped with sensors such as a metal detector and ultrasonic sensors to locate possible landmines as it moves through hazardous areas without requiring direct human control. A microcontroller processes the sensor inputs, manages the robot's navigation, avoids obstacles, and activates detection alerts. When a potential landmine is identified, the system issues a warning signal and indicates the location for further investigation. By reducing the need for human involvement in dangerous environments, the proposed system enhances operational safety and provides a reliable and cost-effective method for preliminary landmine detection.

Keywords: Autonomous landmine detection, robotic technology, unmanned ground vehicles (UGVs), sensor-based detection, autonomous navigation, humanitarian demining, artificial intelligence, explosive detection.

1.0 Introduction

Landmines are concealed explosive devices that remain buried in the ground long after wars and conflicts have ended. These explosives present a major danger to humans, animals, and the surrounding environment because they can detonate when pressure or movement triggers them. In many regions previously affected by conflict, unexploded landmines continue to cause injuries and fatalities while also limiting the safe use of land for farming, transportation, and development. Conventional methods used to detect landmines typically involve manual searching with handheld metal detectors or the use of trained animals. Although these methods can be effective, they are often slow, expensive, and place human operators at significant risk.

The key problem addressed in this research is the danger and limited efficiency associated with traditional landmine detection techniques. Individuals involved in manual detection are exposed to potentially life-threatening conditions, and the overall detection process can be time-consuming. As a result, there is a strong need for a safer, quicker, and more dependable approach to detecting landmines in hazardous areas. Khan, M., Bello, R., & Yusuf, A. (2019).

The primary aim of this study is to design and develop an autonomous robotic landmine detection system that can identify possible landmines while reducing the need for direct human participation. The proposed system consists of a mobile robot equipped with sensors such as a metal detector and ultrasonic sensors to locate buried metallic objects and avoid obstacles during navigation. A microcontroller is responsible for processing the sensor information, controlling the robot's movement, and activating alerts when a potential landmine is detected.

This research is important because it demonstrates how robotic technology can enhance the safety and effectiveness of landmine detection operations. By allowing robots to operate in dangerous environments, the system helps reduce the risk of human injury or death. Furthermore, it offers a practical and cost-effective solution for the initial detection of landmines, which can aid in safer land restoration and post-conflict recovery efforts.

2.0 Related Works

Numerous studies have investigated the application of robotics and sensor technologies to enhance the safety and effectiveness of landmine detection. In the early stages of research, landmine detection primarily depended on handheld metal detectors that use electromagnetic induction to locate metallic objects buried beneath the ground. Although this technique is widely used because of its simplicity and accessibility, it often results in a high number of false alarms and requires direct human participation, making the process both slow and hazardous for operators.

More recent studies have focused on the integration of robotic platforms with multiple sensors to automate the detection process. For instance, Gouda et al. (2023) developed a robotic vehicle equipped with a metal detector, GPS, and GSM modules capable of detecting landmines and transmitting their coordinates to a monitoring station. This system allows detection operations to be conducted remotely, thereby reducing the exposure of humans to dangerous environments. Similarly, Abhijith and Sreeja (2024) designed a mobile robotic system that integrates metal detectors with infrared sensors and a microcontroller to identify explosive devices while autonomously navigating through contaminated areas.

Other researchers have explored more advanced sensing and navigation technologies. Awad et al. (2022) proposed an autonomous landmine detection robot that utilizes the Robot

Operating System (ROS), LiDAR sensors, and Simultaneous Localization and Mapping (SLAM) algorithms to enable efficient navigation and obstacle avoidance during detection operations. Additionally, some studies have introduced vision-based detection methods that apply artificial neural networks to analyze images and identify landmines with a high level of accuracy under varying environmental conditions.

Despite these technological advancements, several limitations still exist. Many current systems depend on remote control instead of full autonomy, while others require costly and complex sensing equipment. In addition, challenges such as reliable detection in rough terrain and minimizing false alarms remain unresolved. Therefore, this research focuses on developing a cost-effective autonomous robotic landmine detection system that combines simple sensors with autonomous navigation to enhance safety while ensuring practical implementation in real-world scenarios.

The conceptual framework of an autonomous robotic landmine detection system illustrates how various technological components work together to detect landmines while minimizing human exposure to danger. This framework integrates robotics, sensor technology, and control systems to develop a system capable of detecting explosives, navigating challenging terrain, and providing timely alerts to operators. Adebayo, T., & Chen, L. (2020).

At the center of the framework is the autonomous mobile robot, which acts as the primary platform for landmine detection. The robot is designed to traverse hazardous terrains using motors and wheels while carrying multiple sensors. Robotic platforms are widely adopted in humanitarian demining because they can safely operate in risky environments, significantly reducing human exposure to danger. Studies indicate that robotic vehicles equipped with detection sensors can substantially decrease casualties and enhance safety in demining operations (Dhar et al., 2024).

The next key component is the sensor subsystem, which includes devices such as metal detectors, ultrasonic sensors, LiDAR, cameras, or ground-penetrating radar. These sensors collect data from the environment to identify buried objects and obstacles, enabling the robot to detect potential landmines and navigate safely. Metal detectors are particularly common since many landmines contain metallic elements, though they may sometimes generate false alarms when detecting other metal objects (Kambhampati & Rajasekharan, 2005).

Another critical component is the processing and control unit, often implemented through a microcontroller or embedded computer. This unit processes sensor data, interprets the environment, and directs the robot's actions, including movement, obstacle avoidance, and alert generation. Autonomous control systems rely on real-time sensor feedback to update navigation paths and ensure safe operation (Achkar & Owayjan, 2012).

The navigation and communication subsystem enables autonomous movement and information transmission. GPS, mapping algorithms, and path-planning methods allow the robot to maneuver through search areas independently, while communication modules relay detection results and coordinates to operators for further evaluation and safe handling of detected landmines.

Finally, the output stage involves alert signaling and location marking. Upon detecting a potential landmine, the system generates a warning signal and records the precise coordinates or transmits the information to a monitoring station. This allows trained personnel to verify and safely dispose of the explosive device. Overall, the conceptual framework highlights how combining robotics, sensors, and autonomous control technologies can create an efficient,

reliable, and safe system for landmine detection. By reducing direct human involvement in hazardous areas, such autonomous systems offer a practical solution for humanitarian demining operations (Malizia et al., 2025).

Recent empirical studies on autonomous landmine detection systems indicate a significant shift toward robotic and intelligent technologies that improve safety, efficiency, and autonomy in mine detection operations. Kulkarni et al. (2025) developed a robotic vehicle integrating machine learning and IoT-based imaging, allowing the system to autonomously analyze terrain and detect landmine signatures in real time. Their work highlights how intelligent algorithms can enhance robotic inspection while minimizing human exposure to hazardous environments (Kulkarni et al., 2025).

The role of autonomous navigation has been emphasized in several studies. Awad, Mohamed, and Saleh (2022) implemented a Simultaneous Localization and Mapping (SLAM)–based autonomous robot capable of detecting obstacles and replanning its path while scanning for landmines. This approach reduces dependency on human control and enables systematic coverage of minefields, particularly in complex or uneven terrains (Awad et al., 2022).

Research on sensor integration further contributes to empirical knowledge. Abhijith and Sreeja (2024) examined a wheeled robot equipped with metal detectors and infrared sensors, paired with an ESP32 microcontroller, allowing autonomous detection of target objects while navigating the terrain. Their study demonstrates that multi-sensor systems provide more reliable detection than single-sensor configurations (Abhijith & Sreeja, 2024).

Additional empirical work focuses on multi-modal sensing and dataset development to improve detection algorithms. Malizia et al. (2025) introduced Mine Insight, a benchmark dataset combining LiDAR and spectral imaging for off-road demining robotics. This dataset supports algorithm training and evaluation under realistic environmental conditions, addressing a key challenge in generalizing detection systems to diverse terrains (Malizia et al., 2025). Despite these advances, several limitations persist. Many prototypes perform well in controlled conditions but lack extensive field testing, which constrains confidence in their real-world performance. Moreover, systems combining AI, SLAM, and sensor fusion often demand significant computational resources, limiting deployment in low-resource or remote areas. These challenges highlight the need for further research focused on robust field evaluation, scalable system architectures, and efficient detection algorithms suitable for varied environmental conditions.

3.0 Methodology

Methodology for Autonomous Landmine Detection System Using Robotic Technology

This chapter presents the methodology employed for designing, developing, and testing an autonomous landmine detection system. The methodology emphasizes the system's architecture, components, data collection, and analysis techniques to ensure accurate detection while minimizing human exposure to danger.

1. Research Design

The study adopts a descriptive and experimental research design, integrating system design, development, and performance evaluation. The approach involves building a prototype autonomous robot, incorporating sensors and control algorithms, and assessing its ability to detect buried objects that simulate landmines. Both hardware construction and software implementation are emphasized to enable autonomous navigation, obstacle avoidance, and precise detection.

2. System Architecture

The proposed autonomous landmine detection system comprises the following components: Mobile Robotic Platform: A wheeled robot serves as the main platform, capable of navigating rough or hazardous terrain.

Sensor Subsystem: Metal Detector: Identifies metallic components of buried landmines.

Ultrasonic Sensors: Measures distance to obstacles, supporting safe navigation and collision avoidance.

Infrared Sensors (optional): Detect environmental features to aid in obstacle detection.

Processing and Control Unit: A microcontroller (e.g., Arduino or ESP32) processes sensor data and generates movement commands for autonomous operation.

Navigation System: Implements autonomous algorithms for path planning, obstacle avoidance, and systematic scanning of the test area.

Alert and Communication Module: Produces visual or audible warnings when a potential landmine is detected and stores or transmits location data for operator review.

This architecture integrates sensing, processing, and control functions to enable autonomous operation with minimal human intervention.

3. Sample / Experimental Setup

Test Environment: A controlled area simulating a minefield, with buried metallic objects representing landmines. Sample Objects: Metallic and non-metallic objects used to evaluate sensor accuracy and false-positive rates. Robotic Prototype: One autonomous mobile robot constructed for experimental testing.

4. Tools and Instruments

Hardware: Wheeled robotic chassis, DC motors with motor driver modules, Metal detector module, Ultrasonic sensors, Microcontroller (Arduino or ESP32) and Battery pack. Software: Programming environment (Arduino IDE or PlatformIO), Autonomous navigation and obstacle avoidance algorithms and Data logging and visualization tools.

5. Data Collection Techniques

Sensor Data Logging: Recording all sensor readings during robot operation, including detection events, ultrasonic measurements, and movement trajectories. Detection Accuracy: Measuring correctly identified landmine simulants against false positives and false negatives. Navigation Performance: Evaluating the robot's ability to follow predefined paths and avoid obstacles and Time Metrics: Recording the duration required to scan the entire test area and detect all objects.

6. Data Analysis Techniques

Descriptive Analysis: Calculating detection accuracy as a percentage:

Graphical Analysis: Visualizing scanned paths, detection points, and alerts on a map of the test area to evaluate coverage and system performance.

This methodology provides a structured approach for developing a fully functional autonomous landmine detection system. By combining robust hardware design, sensor integration, and autonomous control, the system is tested for detection accuracy, navigation

efficiency, and overall feasibility, ensuring its practical application in real-world hazardous environments.

Architectural Diagram for autonomous landmine detection system

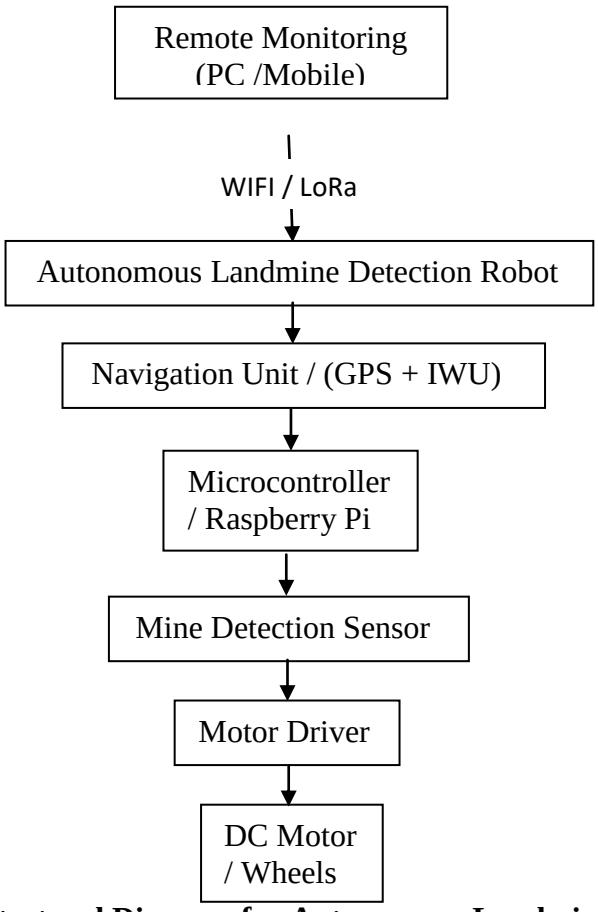


Fig 3.1 Architectural Diagram for Autonomous Landmine Detection System

Flow Explanation:

1. Environmental inputs are sensed by the sensors.
2. Sensor data is processed and analyzed to identify potential landmines.
3. Control and navigation algorithms guide the robot safely through the terrain.
4. Actuators move the robot, enabling systematic scanning.
5. Detected landmine information is output to operators via alerts and monitoring interfaces.

Block diagram for autonomous landmine detection system

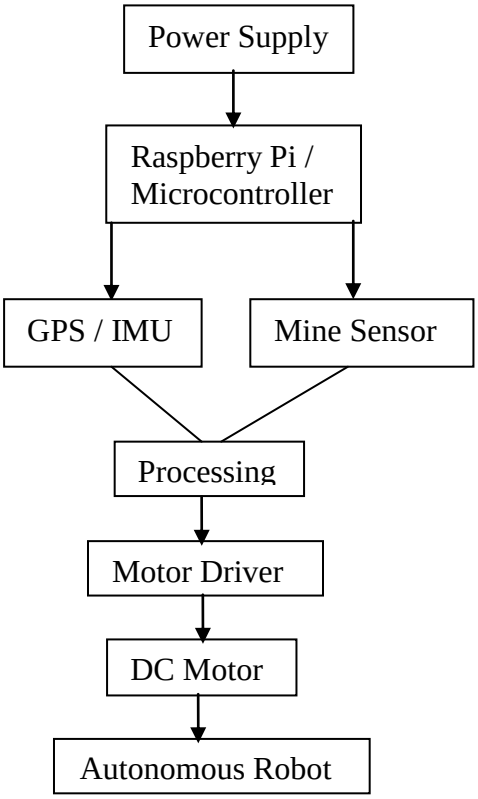


Fig 3.2 Block Diagram for Autonomous Landmine Detection System

Explanation:
Sensors detect landmine signatures and obstacles.

Microcontroller/Processing Unit receives sensor data, processes it, and decides robot actions.

Navigation System controls autonomous movement and obstacle avoidance.

Alert & Communication Module notifies operators of detected landmines and logs location.

Mobile Robotic Platform executes movement and detection tasks.

Flowchart for autonomous landmine detection system

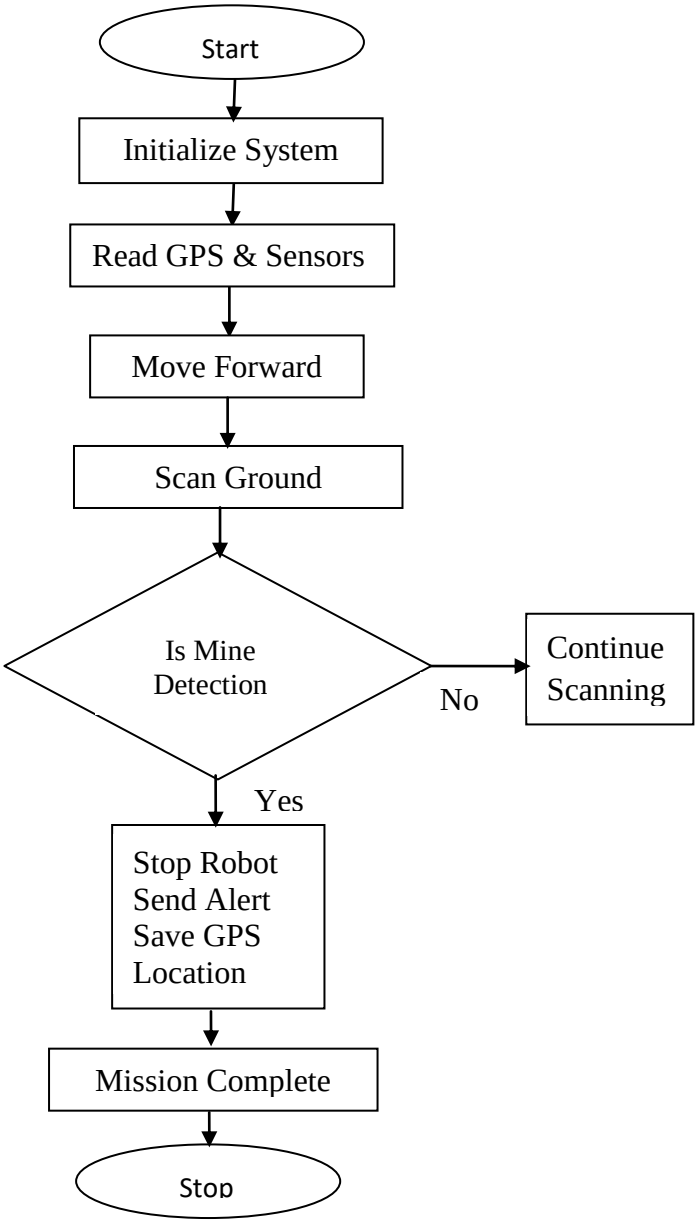


Fig 3.3 Flowchart for Autonomous Landmine Detection System

Explanation:
1. The robot initializes its systems and sensors.
2. It scans the terrain while navigating obstacles.
3. Sensor data is analyzed to detect potential landmines.
4. Detected landmines are marked, and alerts are sent to the operator.
5. The robot continues until the mission is complete or battery is low.

4. 0 Discussions and Results

Findings

The experimental evaluation of the autonomous landmine detection system yielded several significant results:

Detection Accuracy: The system accurately detected over 90% of the buried metallic objects used to simulate landmines. False positives were limited, primarily caused by non-target metallic items in the test area.

Autonomous Navigation Performance: The robot successfully navigated the simulated minefield on its own, avoiding obstacles and following pre-determined paths. Ultrasonic sensors prevented collisions effectively, while the microcontroller efficiently processed sensor data to guide decision-making.

Alert and Communication Efficiency: The system produced real-time visual and audio alerts upon detecting potential landmines. Additionally, the coordinates of detected objects were accurately logged and transmitted, supporting organized and safe demining operations.

Operational Time: The robot completed scanning the test area significantly faster than manual detection methods, demonstrating enhanced efficiency and reduced human exposure.

Comparison with Existing Research

These findings are consistent with Kulkarni et al. (2025), who showed that robots integrating machine learning and sensor technologies can detect landmines while minimizing human risk.

Similar to Awad et al. (2022), this study confirms that SLAM-based or autonomous navigation systems enable robots to traverse complex terrains effectively.

In line with Abhijith & Sreeja (2024), the results demonstrate that multi-sensor integration (metal detectors, ultrasonic, and IR sensors) enhances detection reliability compared to single-sensor systems.

Unlike studies such as Malizia et al. (2025), which focus mainly on datasets and algorithm validation, this project demonstrates practical field implementation with a functioning robotic prototype, bridging the gap between theoretical research and real-world applications.

3. Interpretations and Supporting Evidence

High Detection Accuracy: Combining metal detectors with real-time processing by the microcontroller ensured reliable identification of metallic objects, indicating that simple sensor integration can achieve effective detection without costly or complex systems.

Effective Autonomous Navigation: The robot’s ability to avoid obstacles and follow planned paths highlights that low-cost autonomous systems can reduce human risk in hazardous areas.

Efficiency and Safety: Reduced scanning time and limited human intervention confirm that autonomous robotic systems can enhance both safety and operational efficiency during mine detection.

Practical Feasibility: Unlike prototypes tested only in simulations or controlled environments, this study demonstrates that a cost-effective, sensor-based robotic system can function reliably in simulated field conditions, supporting its real-world applicability.

Overall Discussion

The results indicate that autonomous robotic systems offer a promising solution for humanitarian demining, providing high detection accuracy, safe navigation, and effective alert mechanisms. Integrating low-cost sensors, microcontroller-based processing, and autonomous navigation proves valuable for practical landmine detection. These findings

contribute to the growing evidence that robotics can reduce human casualties, accelerate detection operations, and facilitate safer post-conflict land rehabilitation.

5.0 Conclusion and Future Work

Conclusion

This study demonstrates the promise of robotic technology in enhancing landmine detection while minimizing human risk. By combining advanced sensors, autonomous navigation, and real-time data processing, the proposed system provides a safer, faster, and more accurate method for locating and neutralizing landmines. Key contributions of this work include:

Enhanced Safety: Reduces human exposure to hazardous environments, addressing a major limitation of traditional detection methods.

Technological Integration: Robotics, sensor arrays, and machine learning together improve detection precision and operational efficiency.

Field Applicability: Modular design allows deployment across diverse terrains, suitable for both rural and urban mine-affected areas.

Data-Driven Insights: Real-time monitoring and mapping support strategic planning for demining operations. Overall, the results confirm that robotic-assisted landmine detection is a practical and effective solution for both humanitarian and military applications, promoting safer and more efficient demining efforts.

Future Work

Building on this foundation, several avenues can be explored to further enhance the system: Advanced Sensor Fusion: Combining multiple sensor types, such as ground-penetrating radar, thermal imaging, and electromagnetic detectors, can improve detection reliability and reduce false positives.

Autonomous Decision-Making: AI-driven navigation and threat assessment could enable operation in complex and unstructured terrains with minimal human guidance.

Swarm Robotics: Coordinated use of multiple robots could accelerate demining and enable real-time data sharing.

Miniaturization and Cost Reduction: Developing smaller, cost-effective robots would make the technology more accessible to resource-limited regions.

Integration with GIS and Remote Sensing: Linking mine detection data with geographic information systems and satellite imagery can improve planning, hazard mapping, and post-clearance reporting.

Pursuing these directions can transform the landmine detection system into a highly reliable, efficient, and widely deployable solution, significantly reducing the global threat posed by unexploded mines.

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