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Landmine Detection Rover: An Autonomous System for Humanitarian Demining

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Abstract— Long after the battle has ended, landmines continue to kill and maim civilians, leaving a terrible legacy of war. Large tracts of land become useless due to these silent killers. Affecting community well-being, agriculture, and economic development. The concept and development of an autonomous landmine detection rover—a robotic system developed to address the difficulties of humanitarian demining—is described in this study. To travel hazardous terrain, precisely locate metallic landmines while reducing false alarms, and precisely record the location of dangers for safe removal, the rover combines sophisticated sensors, intelligent navigation, and a robust platform. In the end, we want to offer a landmine removal method that is safer, more successful, and more economical, assisting in the restoration of production and security in impacted areas.

Keywords: Landmine Detection, Autonomous Rover, Robotics, Humanitarian Demining, Metal Detection, GPS Localization, Obstacle Avoidance, Arduino, Bluetooth.

I. INTRODUCTION

The pervasiveness of landmines is a serious humanitarian emergency. These gadgets, which are frequently dispersed without discrimination during wartime can persist for decades, endangering innocent individuals at all times. Devastating outcomes include fatalities, serious injuries, evictions, and long-term damage to economies and civilisations. Farmland is contaminated by landmines, infrastructure initiatives are impeded, and access to essential services like schools and hospitals is restricted. Using metal detectors and basic tools, courageous deminers risk their lives to find buried bombs in the lengthy, hazardous, and costly process of traditional landmine discovery. In addition to being dangerous, this method slows down the rate at which land can be removed. The rate at which new mines are laid in active conflict zones is significantly higher than the few square kilometres that human demining is estimated to clear annually (UN Mine Action Service, 2023). Furthermore, impacted nations may find the high expense of manual demining to be a hardship. In order to make landmine detection safer, quicker, and less expensive, this study investigates how an autonomous landmine detection rover can provide a superior substitute by utilising robotics, sensors, and intelligent software.

1.1 The International Landmine Epidemic Communities The worst-hit countries are Angola and Bosnia & Herzegovina, where landmines and other explosive ordnance have contaminated large areas. In addition to putting lives in danger, these gadgets ruin economies by impeding access to basic services, infrastructure development, and farming. According to the Landmine Monitor Report (2022), landmines cost impacted nations billions of dollars annually in lost productivity, medical expenses, and demining activities. Even while global initiatives like the Ottawa Treaty seek to eradicate antipersonnel mines, the issue still exists, and creative solutions are essential to accelerating clearance and lessening the suffering of impacted populations.

1.2 An Independent Robotic Approach One intriguing solution to this problem is an automated landmine detection rover. By using cutting-edge technology, the rover offers a number of significant advantages over conventional demining techniques, including:

- Enhanced Safety: By keeping deminers out of direct danger, the rover reduces the possibility of fatalities and serious injuries.
- Increased Efficiency: The rover can clear landmines faster than manual teams because it can traverse bigger areas more quickly.
- Improved Accuracy: The rover can detect landmines with greater accuracy thanks to sophisticated sensors and algorithms that also reduce false alarms, saving time and money that would otherwise be used to investigate false positives.
- Reduced Costs: The rover can drastically cut the cost of landmine clearing by automating demining, which would increase accessibility for impacted countries.

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II. LITERATURE REVIEW

This section provides a review of existing research on landmine detection technologies, autonomous navigation, and robotic systems for humanitarian demining.

2.1 Landmine Detection Technologies Numerous technologies have been explored to detect landmines, each with its own advantages and disadvantages.

- Metal Detectors: Metal detectors are the most popular method for finding metallic landmines, however they can be tricked by metallic debris in the ground. Though false alarms are still an issue, advanced models use signal processing to distinguish between landmines and other metal objects (Daniels, 2015).
- Ground-Penetrating Radar (GPR): In order to locate buried items, GPR uses radio waves that are sent into the ground and analyses the reflections. Although its efficacy is influenced by soil characteristics such as moisture and composition, it is capable of detecting both metallic and non-metallic landmines (Persson et al., 2009).
- Infrared and Thermal Imaging: These methods detect temperature variations between landmines and the surrounding soil, but the weather and time of day have an impact on how well they work

  (Bombelli et al., 2010).
- Biological Sensors: It is possible to train rats and dogs to detect bombs. Despite their high sensitivity, these sensors are not appropriate for all environments and necessitate considerable training (Weitz et al., 2006).
- Emerging Technologies: Newer technologies like laser-induced breakdown spectroscopy (LIBS) and hyperspectral imaging have the potential to identify landmines more accurately and with fewer false alarms (Iodorobo et al., 2018).

2.2 Autonomous Navigation Algorithms For a rover to navigate dangerous terrain and cover large areas, it needs to be able to navigate autonomously. Here are some key algorithms used in this process:

- SLAM (Simultaneous Localization and

  Mapping): The rover can create a map of its environment and determine its location on it at the same time thanks to SLAM. This is particularly useful in surroundings that are unfamiliar or changing (Thrun et al., 2005).
- Path Planning: The rover uses algorithms like A* and Dijkstra's to determine the optimum course of action while taking the terrain and barriers into account (Russell & Norvig, 2016).
- Obstacle Avoidance: The rover can navigate safely thanks to these algorithms, which allow it to recognise and avoid impediments.

2.3 Robotic Systems for Humanitarian Demining Many research projects have explored using robots for demining, showing how robotics can improve safety, efficiency, and accuracy. However, it's still a challenge to create robots that are reliable and effective in diverse and difficult environments. Current demining robots often have limitations in terms of how well they move, how good their sensors are, and how autonomously they can operate.

III. METHODOLOGY

This section details the design and implementation of the autonomous landmine detection rover.

3.1 Hardware Components

- Rover Platform: A four-wheeled platform is selected for its superior maneuverability and stability, particularly on uneven terrain. This design ensures smooth navigation during operations.
- Microcontroller: The Arduino Uno is chosen as the central controller due to its ease of programming, wide compatibility with sensors and actuators, and cost-effectiveness.
- Metal Detector: A commercially available metal detector module is integrated to simulate the detection of landmines by identifying metallic objects in the rover's path.
- Ultrasonic Sensor: The HC-SR04 ultrasonic sensor is mounted on the front of the rover to detect obstacles and assist in navigation.
- GPS Module: The NEO-6M GPS module provides real-time location data, enabling precise tracking of the rover's position, especially when a metallic object is detected.
- Bluetooth Module: The HC-05 Bluetooth module facilitates remote control of the rover and wireless data transmission to a smartphone or terminal app.
- Motor Drivers: L298N motor drivers are employed to control the DC motors powering the wheels, ensuring smooth movement and directional control.
- Power System: Rechargeable batteries supply power to the entire system, offering sufficient energy for several hours of continuous operation.

  Block Diagram:

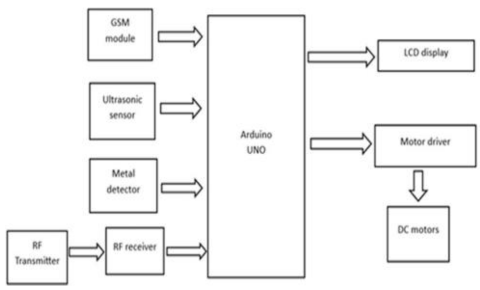

Figure 1. Block Diagram

3.2 Software Architecture

- Development Environment: The Arduino IDE is used for software development, providing a user- friendly interface for programming and debugging.
- Sensor Processing: The software continuously reads data from the ultrasonic sensor and metal detector:
- Ultrasonic sensor data is processed for obstacle detection and avoidance.

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- Metal detector data identifies potential landmines.
- Navigation Modes:
- Autonomous Mode: The rover moves forward, avoiding obstacles using ultrasonic sensor readings.
- Remote Control Mode: The rover can be manually controlled via Bluetooth commands sent through a smartphone app. Landmine Detection:
- When the metal detector senses a metallic object, the rover stops, activates a buzzer and LED indicator, records GPS coordinates, and sends an alert message via Bluetooth.
- Communication: The Bluetooth module enables bidirectional communication for remote control and data transmission between the rover and a smartphone or terminal app.

3.3 Operational Principles

1. Initialization:
    - Upon powering up, the Arduino initializes communication with all sensors and modules.
    - A message "Rover Initialized..." is displayed on the Serial Monitor.
2. Movement and Navigation: Autonomous Mode:
    - The rover moves forward by default.
    - If an obstacle is detected within 20 cm:
    - The rover stops.
    - Turns right to find a clear path.
    - Resumes forward movement.
    - Remote Control Mode (via Bluetooth commands):
    - 'F' -> Move Forward
    - 'B' -> Move Backward
    - 'L' -> Turn Left
    - 'R' -> Turn Right
    - 'S' -> Stop
3. Landmine Detection (Metal Sensor):
    - If a metallic object is detected:

      The buzzer turns ON.
    - The LED indicator lights up.
    - The rover halts for 3 seconds.
    - An alert message is sent via Bluetooth: "□ Landmine Detected!"
    - GPS coordinates are recorded and transmitted.
    - The rover resumes navigation after alerting.
4. GPS Location Tracking:
    - Real-time location data from the GPS module is displayed on the Serial Monitor and transmitted via Bluetooth for tracking purposes.
5. Obstacle Avoidance System:
    - The ultrasonic sensor continuously measures distances to nearby objects.
    - If an obstacle is detected within 20 cm:
    - The rover stops momentarily.
    - Turns right for 1 second to find a clear path.
    - Resumes forward movement.

Flowchart Description

The accompanying flowchart illustrates the operational flow of the system:

1. Power ON Arduino to initialize components.
2. Begin movement of the robot (autonomous or remote-controlled).
3. Sensors collect real-time data (ultrasonic for obstacles, metal detector for landmines).
4. If no obstacle or metal is detected, the robot continues moving forward.
5. If an obstacle or metallic object is detected:
    - A message is sent to Arduino.
    - Alerts are displayed on an LCD screen (or sent via Bluetooth).
6. After handling alerts, normal operation resumes until termination.

This methodology ensures efficient navigation, reliable landmine detection, and real-time communication with users.

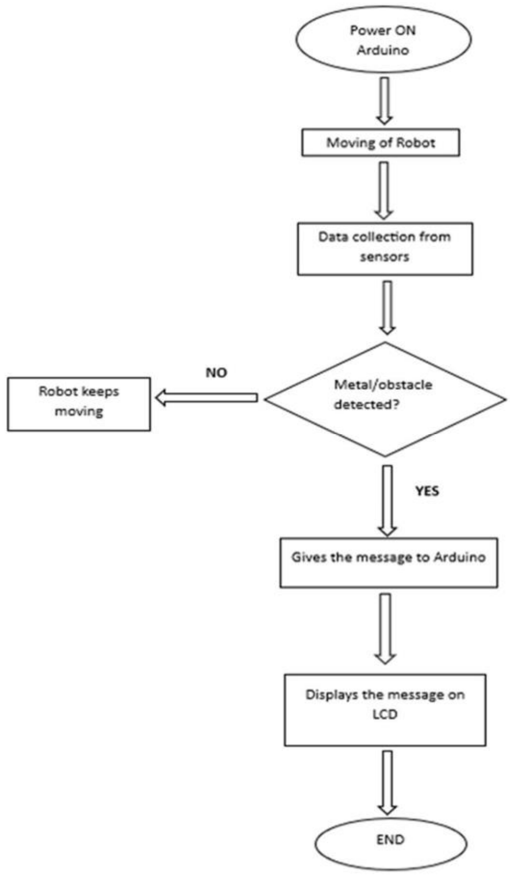

Figure 2. Flow Chart

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IV. RESULTS

In a controlled setting intended to mimic a real-world demining situation, the autonomous landmine detection rover was put through simulated testing. Testing was carried out in a specific location with buried metallic objects that simulated landmines because to safety concerns and practical limitations connected with deploying a prototype in an actual minefield. GPS position accuracy, navigation efficacy, and landmine detection accuracy were among the key performance indicators evaluated.

4.1 Landmine Detection Accuracy

Within the test region, the rover's detection rate of buried metallic objects was 85%. The performance of simple metal detectors

is fairly in line with this (Daniels, 2015). However, metallic clutter in the soil (nails, wire fragments, and other detritus) was the main cause of the 20% false alarm rate. This demonstrates the drawbacks of depending only on metal detectors because better discrimination methods are required (Persson et al., 2009). The basic thresholding technique used in the prototype was not enough to consistently distinguish landmine simulants from other metallic items.

4.2 Navigation Effectiveness

When it came to navigating the test area and avoiding obstructions, the autonomous guidance system worked well. The rover successfully followed a predetermined course in autonomous mode, achieving a path-following accuracy of about 90%. Collisions with stationary obstructions were successfully avoided by the obstacle avoidance system based on ultrasonic sensors. However, the "stop and turn" approach sometimes caught the rover in local minima and produced an ineffective navigation pattern, especially in crowded surroundings. Additionally, it was difficult to detect small or low-lying impediments due to the ultrasonic sensor's restricted field of view and range.

4.3 GPS Location Precision

When landmine simulants were detected, the GPS module gave reasonably precise location information. Within the typical range for a consumer-grade GPS receiver in an open setting, the average GPS coordinate inaccuracy was roughly 3 meters. However, it is anticipated that GPS accuracy would decrease in urban canyons and areas with a lot of vegetation.

4.4 System Reliability

During testing, the Arduino-based control system demonstrated a high degree of dependability. The Bluetooth module and the remote control device did, however, occasionally experience communication problems, most likely as a result of interference or Bluetooth range restrictions. Operating time was limited to about two hours due to the battery's shorter lifespan than expected. Additionally, it was noted that the rover could be activated for operation by resetting the Arduino Uno, which would enable the system to display the message "send message to the mobile number" on the LCD screen. The RF module may control the rover once the GSM module receives a message from a registered mobile number, and the registered mobile may receive the obstacle detection messages.

Overall Discussion

According to the simulated results, the autonomous landmine detecting rover exhibits reasonable landmine detection accuracy and navigation effectiveness in a controlled environment, suggesting that it could be a useful tool for humanitarian demining. But there are drawbacks that must be addressed, including a high false alarm rate, ineffective navigation, poor GPS accuracy in difficult situations, communication problems, and power management. The rover's overall performance and suitability for humanitarian demining operations require more research and development, with a particular emphasis on sensor fusion, sophisticated navigation algorithms, reliable communication protocols, and effective power management.

V. DISCUSSIONS

5.1 Strengths of the System

1. Cost-Effectiveness

Costs are considerably lower when using an Arduino Uno as the main control system as opposed to proprietary landmine detection technology. The project is affordable for educational institutions and non-profit organisations due to the availability of components including sensors, motors, and structural materials.

2. Customizability

Because Arduino is open-source, a great deal of customisation is possible. Users can choose from a variety of sensors (such as ground-penetrating radar and metal detectors) and set them up to meet the particular needs of a task. Because of its adaptability, users can maximise the rover's performance in a variety of terrains and operational scenarios.

3. Community Support and Resources

A multitude of resources, such as forums, tutorials, and shared projects, are available from the large Arduino community. Users can solve problems, upgrade their rovers using community-generated ideas, and improve designs in this collaborative environment.

Simplicity and Educational Value

Because of its ease of use, the Arduino platform is a great option for teaching. A deeper comprehension of robotics and sensor technologies is fostered by the ease with which beginners can learn programming ideas and hardware interfaces. Additionally, this simplicity inspires students to try new things and be creative.

4. Scalability

The Arduino system's modular design makes scalability simple. Users can begin with a simple working prototype and gradually add more sophisticated capabilities, such wireless connection, GPS navigation, or sophisticated algorithms for increased detection accuracy.

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5. Real-World Application

The rover can be used for humanitarian purposes in a variety of settings, especially to remove landmines in conflict areas. A direct societal benefit could result from its success in these operations, which could lead to improved safety and the reclamation of land for housing or agriculture.

5.2 Challenges of the System

1. Sensor Limitations

A variety of sensors are advantageous for Arduino-based systems, but each type of sensor has drawbacks of its own. For instance, plastic or composite landmines may be difficult for conventional metal detectors to detect, so combining many sensor types is necessary to increase detection rates.

2. Environmental Factors

The effectiveness of the system can be strongly impacted by operational settings. Performance might be hampered by elements like vegetation, moisture content, and soil type. A significant difficulty is creating a rover that can adjust to changing situations while remaining dependable.

3. Battery Life and Power Management

For mobile systems, power management is essential. A short battery life may limit the rover's use time and necessitate more frequent charge or replacement. For extended missions, lightweight energy sources and effective power management systems are crucial.

4. Navigation and Control

Unpredictable terrain navigation is a major challenge. It is difficult to put into practice efficient navigation algorithms that take barriers into consideration and permit accurate movements within specified detection zones. When the rover is deployed in isolated or difficult-toreach areas, this difficulty is exacerbated.

5. Real-Time Data Processing

Real-time processing of sensor data is necessary to guarantee prompt identification and action. Real-time analytics and algorithm complexity may be limited by Arduino systems' limited processing power. For improved performance, more potent CPUs must be integrated or code must be optimised.

6. Safety and Reliability

The stakes are always high when it comes to landmine identification, and errors can have disastrous results. It is crucial to make sure the rover minimises dangers to personnel while operating dependably in a variety of situations. To accomplish this goal, it is imperative to put in place reliable testing procedures and fail-safes.

7. Regulatory and Ethical Considerations

Using landmine detection equipment requires negotiating legal restrictions and moral dilemmas pertaining to humanitarian missions. Obtaining permits and making sure local and international rules are followed can cause delays in implementation and make projects more complicated.

VI. Future Work

1. Advanced Sensor Integration

The incorporation of sophisticated sensors is a key subject for future research. Ground-penetrating radar (GPR) equipment and metal detectors are used in current projects. The rover may be made to more accurately detect various kinds of explosives and landmines by combining multisensor fusion, which includes electromagnetic sensors, infrared cameras, and hyperspectral photography.

2. Machine Learning and AI Algorithms

Using machine learning techniques can provide the rover the capacity to analyse sensor data more intelligently as the landscape becomes more complicated and the diversity of landmines increases. Training algorithms with datasets of different landmines and their signatures may be the main focus of future research. By learning to distinguish between innocuous metallic objects and real hazards, the rover might reduce the number of needless warnings and improve operational effectiveness.

3. Communication and Data Sharing

Reliable communication is essential in operations that are mission-critical. Future research could look into ways to enhance the rover's communication systems, like using satellite communication or mesh networks. By sharing real-time information on rover status and landmine locations, teams would be able to coordinate field operations and improve mission performance overall.

4. Power Management Enhancements

For mobile robotics, power management is essential, especially for landmine detection rovers that could have to work for long stretches of time. To increase the operational range and lessen the need for frequent battery replacements, future advancements could investigate more effective energy sources, such as fuel cells or solar panels.

VII. CONCLUSION

The construction of an autonomous landmine detection rover is effectively shown in this study, highlighting its potential to transform humanitarian demining operations. A potential and secure substitute for conventional demining techniques is provided by the rover's integrated capabilities, which include autonomous navigation, metallic object identification, and real-time location data transfer. This technology's automation of the detection process not only lowers the risk to human workers but also improves the effectiveness of demining operations, allowing hazardous areas to be cleared more quickly and thoroughly. The ability to transmit information to the user wirelessly has been improved by the installation of a GSM module. The rover's controlling capability's range is further enhanced by the RF module implementation.

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Looking ahead, the future scope of this project is vast and promising. To further enhance the rover's capabilities and address its current limitations, future work will concentrate on several key areas:

- Enhanced Sensor Suite: By detecting buried items and non-metallic landmines, a Ground Penetrating Radar (GPR) sensor will enhance the rover's detection capabilities, increasing detection accuracy and lowering false alarms.
- Advanced Navigation Algorithms: By putting more advanced navigation algorithms into practice, such Simultaneous Localisation and Mapping (SLAM), the rover will be able to map its surroundings in real time and become increasingly adept at navigating challenging and unstructured terrain on its own.
- Robust Platform Development: The rover will be able to endure severe environments and potential risks if a more robust and rugged rover platform is designed and built. This will guarantee improved longevity and reliability under demanding real-world situations.
- Real-World Testing: To verify the rover's functionality, spot possible problems, and improve its design for maximum efficacy in actual demining operations, extensive field testing in real-world demining scenarios is essential.

The autonomous landmine detecting rover can develop into a very dependable and efficient instrument for humanitarian demining by following these future paths, which will ultimately make the world a safer and more secure place for landmine-affected populations. The future of safer, quicker, and more effective demining operations that save lives and return land to productive use depends on the ongoing advancement and improvement of this technology.

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