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Landmine Detection Robotic Vehicle using ARM Cortex (STM32)

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Abstract: *The "Landmine Detection Robotic Vehicle with GPS Positioning Using STM32" paper is designed to enhance safety and efficiency in landmine detection through advanced robotics. The system utilizes an STM32F103C8T6 microcontroller to orchestrate various components aimed at detecting and locating landmines. A metal detector sensor is employed to identify metallic objects, with the system programmed to send alerts via GSM if a mine is detected, including the precise GPS coordinates of the location. The robotic vehicle is powered by DC motors, which are controlled through a motor driver module and Bluetooth interface, allowing for directional movement (forward, backward, right, and left). The setup includes buzzers for sound alerts to indicate detection or operational status, and a robot chassis with wheels for mobility. The integration of these components ensures a robust and efficient landmine detection system, combining real-time detection with precise location tracking to improve safety and operational effectiveness in hazardous environment.*

1. INTRODUCTION

1.1.1 Overview of Landmine Detection Systems

Landmines continue to be a major global concern, particularly in post-war zones, where unexploded mines pose severe risks to civilians and military personnel. These landmines remain active for decades, causing thousands of deaths and injuries every year. Conventional landmine detection techniques, such as manual detection using metal detectors and trained sniffer dogs, are not only inefficient but also expose human and animal lives to extreme danger. To address these challenges, robotic landmine detection systems have emerged as a viable alternative. By integrating autonomous movement, sensor technology, GPS tracking, and wireless communication, these systems enhance detection accuracy, minimize human risk, and speed up demining operations. The development of an STM32-based robotic vehicle for landmine detection is a step toward a safer and more reliable solution.

1.1.2 Importance of Automated Landmine Detection

Landmine detection is a time-sensitive and high-risk operation. The deployment of automated robotic systems is essential for:

- Improving safety: Reducing human and animal exposure to hazardous areas.
- Enhancing efficiency: Robots can scan large areas faster compared to manual methods.
- Increasing detection accuracy: Reducing false positives using smart sensor integration.
- Remote operation capability: Allowing operators to monitor and control the robot wirelessly from a safe distance.
- Cost-effectiveness: Providing an affordable and scalable solution compared to expensive AI-based or radar-based detection methods.

1.1.3 Role of Robotics in Hazardous Environments

Robotics plays a critical role in modern demining operations by:

- Enabling autonomous navigation in high-risk areas where human access is unsafe.
- Utilizing advanced sensors such as metal detectors and ground-penetrating radar (GPR) to detect landmines.
- Integrating GPS tracking to mark detected landmine locations on a digital map.

- Providing real-time monitoring through a camera module for operator-assisted confirmation.
- Improving operational flexibility, allowing both manual remote control and AI- assisted decision-making.

Robots significantly reduce the time, cost, and danger associated with traditional landmine clearance, making them an indispensable tool in humanitarian and military operations.

1.1.4 Objectives of the Project
The primary objective of this project is to develop an autonomous robotic vehicle using an STM32 microcontroller to detect landmines safely and efficiently. The key goals include:

- Designing and implementing an STM32-based robotic platform for landmine detection.
- Integrating a metal detector sensor to identify buried metallic landmines.
- Incorporating GPS tracking to log the exact coordinates of detected landmines.
- Enabling wireless communication using a Bluetooth module (HC-05) for real- time data transmission.
- Adding an ESP32-CAM module to provide a live video feed for remote monitoring.
- Using an L298N motor driver to control the movement of the robotic vehicle across different terrains.
- Enhancing battery efficiency for extended field operations.
- Minimizing false positives through sensor calibration and software optimization.
- Providing an affordable, scalable, and reliable alternative to existing landmine detection methods.

1.1.5 Scope of the Project
This project serves as a foundation for future advancements in robotic landmine detection, with potential improvements including:

- Integration of AI algorithms for more precise landmine detection.
- Deployment of ground-penetrating radar (GPR) for non-metallic mine detection.
- Solar-powered operation to enhance battery life and field endurance.
- Long-range wireless communication using LoRa or 5G connections.

2. LITERATURE SURVEY

This paper reviews various advances in landmine detection and robotic navigation, focusing on sensor integration, intelligent control systems, and new algorithms. It uses Microsoft Kinect for bomb disposal robots, ground penetrating radar (GPR), and holographic subsurface radar (HSR) for buried mine detection in conjunction with tripwire sensors. Challenges such as limited payload capacity, terrain constraints, and sensory overload are discussed. Emerging solutions include deep learning for underwater detection, transfer learning for object recognition, and GPS-based path tracking using SAWOA and Boracic algorithms. The research emphasizes the need for advanced image processing, robust path planning, and improved decision making in hazardous environments.

3. PROJECT OVERVIEW AND SYSTEM ARCHITECTURE

3.1 Overview of the Project
Landmine detection requires high accuracy, efficiency, and safety to prevent casualties in war-affected regions. This project presents an autonomous landmine detection robotic vehicle integrating metal detection, GPS tracking, wireless communication, and real-time video surveillance.

Key Features of the System

- STM32 microcontroller-based control system for processing sensor data and controlling the robot.
- Metal detector module for identifying buried metallic landmines.
- GPS module (NEO-6M) for location tracking and precise minefield mapping.
- Bluetooth (HC-05) communication module for remote monitoring and control.
- ESP32-CAM module for live video feed and real-time object verification.
- L298N motor driver for smooth movement and terrain adaptability.
- Buzzer alert system to notify the operator upon landmine detection.

- Rechargeable Li-Po battery for extended field operation.

3.2 Block Diagram of the System

A block diagram of the robotic system provides an overview of the functional components and their interconnections.

Main Blocks in the System

- Microcontroller (STM32F103C8T6): Central processing unit managing all operations.
- Metal Detector Sensor: Scans for underground metallic objects.
- GPS Module (NEO-6M): Captures the robot’s location and transmits data.
- Bluetooth Module (HC-05): Enables wireless data transmission to the operator.
- ESP32-CAM Module: Streams live video for remote monitoring.
- Motor Driver (L298N): Controls the movement of the robotic vehicle.
- Power Supply (Li-Po Battery): Provides power to the system.
- Buzzer & LED Alert System: Signals landmine detection to nearby personnel.

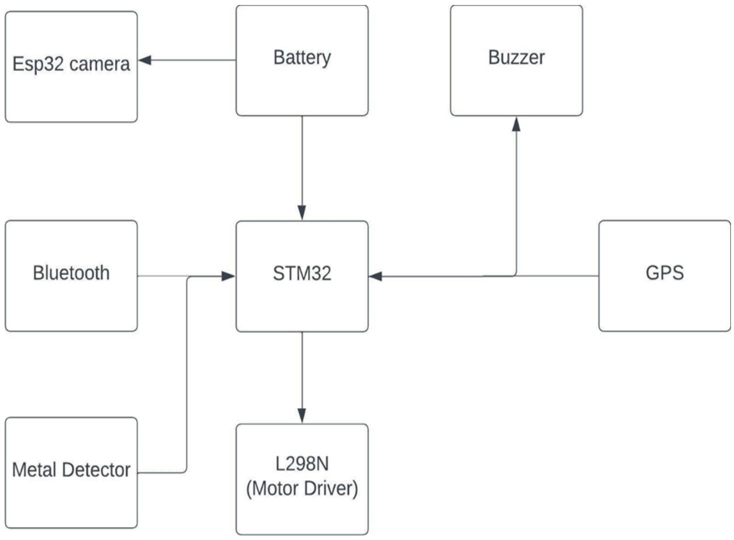


FIGURE 1. Block Diagram of the System

4. HARDWARE DESCRIPTION

4.1 Overview

The hardware implementation of the landmine detection robotic vehicle involves the integration of various electronic components, sensors, and actuators to enable real-time landmine detection, GPS tracking, wireless communication, and remote monitoring. The system is built around an STM32 microcontroller, which acts as the central processing unit, interfacing with the metal detector, GPS module, Bluetooth module, ESP32-CAM, motor driver, and power supply. The design ensures efficient energy consumption, robust sensor integration, and reliable mobility for rough terrains.

4.2 Power Supply System

The power supply system is a critical component of the landmine detection robotic vehicle, ensuring that all electronic modules and motors receive stable voltage and current for reliable operation. The system is designed to provide efficient energy distribution, voltage regulation, and protection against power fluctuations to maximize battery life and overall system performance.

Battery Selection

The robotic vehicle is powered by a 12V Li-Po (Lithium Polymer) rechargeable battery, chosen for its high energy density, lightweight properties, and stable voltage output. Li-Po batteries provide consistent power delivery to motors and electronic components, ensuring uninterrupted operation in the field. The battery capacity (measured in mAh) determines the runtime of the system, with a 2000mAh–5000mAh battery typically used for extended operation.

Voltage Regulation

Different components in the system require different operating voltages. To prevent overvoltage or undervoltage issues, voltage regulators are used to step down the battery voltage to required levels. The voltage regulation system consists of:

- LM2596 DC-DC Buck Converter: Steps down 12V to 5V for components such as the metal detector, Bluetooth module, and ESP32-CAM.
- LM1117 Voltage Regulator: Converts 5V to 3.3V for low-power components such as the STM32 microcontroller and GPS module.L298N Motor Driver Voltage Input: Motors receive direct 12V power from the battery for optimal torque and speed.

Power Distribution

To ensure proper power delivery to all modules, the power supply system is structured as follows:
STM32 Microcontroller: Receives 3.3V from the LM1117 regulator.

- Metal Detector Module: Operates on 5V, powered by the buck converter.
- GPS Module (NEO-6M): Requires 3.3V, provided through the STM32 power rail.
- HC-05 Bluetooth Module: Operates on 3.3V for logic signals, but 5V for power, regulated by the buck converter.
- ESP32-CAM Module: Requires 5V for proper Wi-Fi operation and video streaming.
- L298N Motor Driver & DC Motors: Receives 12V directly from the battery for full power delivery to the motors

4.3 STM32 Microcontroller Setup

FIGURE 2. STM32 Microcontroller

The STM32F103C8T6 microcontroller is the central processing unit of the landmine detection robotic vehicle, responsible for handling sensor inputs, processing data, controlling motors, and managing wireless communication. It is based on the ARM Cortex-M3 architecture, offering low power consumption, real-time processing capabilities, and multiple communication interfaces for seamless integration with external modules.

Features of STM32F103C8T6

- Core: ARM Cortex-M3, 32-bit, 72 MHz clock spee
- Flash Memory: 64 KB (for program storage)
- SRAM: 20 KB (for runtime data storage)
- GPIO Pins: 37 configurable I/O pins
- Communication Interfaces: UART, I2C, SPI for sensor and module interfacing
- PWM Support: Controls motor speed and direction
- Low Power Modes: Reduces energy consumption for battery-powered operation

Microcontroller Role in the System

- The STM32 microcontroller is responsible for managing all essential functions of the robotic vehicle, including:
- Reading sensor inputs from the metal detector to detect landmines
- Processing GPS data to log real-time location tracking
- Controlling the L298N motor driver to navigate the robot
- Communicating with the HC-05 Bluetooth module for wireless monitoring
- Interfacing with the ESP32-CAM module for live video streaming
- Activating the buzzer and LED alerts when a landmine is detected

Pin Configuration and Interfacing

The STM32 microcontroller interacts with multiple components via dedicated GPIO pins. The main connections include:

- Metal Detector: Connected to a digital input pin, detecting HIGH/LOW signals when metal is found
- GPS Module (NEO-6M): Uses UART for receiving real-time coordinates
- HC-05 Bluetooth Module: Uses UART for sending detection alerts and GPS data
- ESP32-CAM: Uses UART for triggering image capture and data transmission
- L298N Motor Driver: Uses PWM pins to control motor speed and direction
- Buzzer and LED Alert System: Controlled via GPIO pins to signal landmine detection

4.4 Metal Detector Integration

FIGURE 3. Metal Detector

The metal detection module, connected to an STM32 microcontroller, uses electromagnetic induction to identify buried metal objects. When the metal disrupts the coil's field, the sensor emits a low signal. The STM32 detects this change, activates an alert, and records the GPS location for accurate mine detection and tracking.

4.5 GPS Module (NEO-6M) for Location Tracking

FIGURE 4. GPS Module (NEO-6M)

The NEO-6M GPS module plays a key role in enabling accurate real-time location tracking in the mine detection robot vehicle. It captures latitude and longitude data, which the STM32 microcontroller processes and records when a mine is detected. This location is then transmitted via Bluetooth for remote monitoring. The GPS module receives signals from multiple satellites and generates NMEA sentences containing location details. Through UART communication at 9600 bps, the STM32, using the TinyGPS++ library, extracts the corresponding coordinates. For optimal performance, the module uses a ceramic antenna and is placed in open areas to avoid interference. It provides an accuracy of 2-3 meters and includes power saving features such as low-power modes and selective activation. Challenges such as signal loss and drift are mitigated through assisted GPS, filtering, and warm-up periods. This integration ensures accurate mapping of landmines, greatly improving safety and efficiency in mine clearance operations'

4.6 HC-05 Bluetooth Module for Wireless Control

FIGURE 5. HC-05 Bluetooth Module

The HC-05 Bluetooth module is a key component in the mine detection robot vehicle, enabling real-time wireless communication between the STM32 microcontroller and a remote operator. It helps transmit key information such as metal detection alerts, GPS coordinates, and battery level. In addition, it supports manual control, allowing operators to remotely guide the robot. Operating via the UART protocol at a default baud rate of 9600 bps, the module enables two-way communication - sending data from the STM32 to a connected mobile device or PC and receiving control commands from the operator. The module connects as a slave device, waits for a pairing request, after which it efficiently transmits data within a range of 10 meters. To ensure safe operation, voltage level converters are used when interfacing with the STM32, especially when the logic levels differ. Power efficiency is maintained by putting the HC-05 into sleep mode during idle and dynamically turning it on during active operations. Despite its limited range, the HC-05 provides reliable short-range communications in open areas. Future enhancements include the use of LoRa or Wi-Fi for extended range. The module’s simple interface, energy efficiency, and ease of integration make it ideal for real-time monitoring and control in mine clearance applications.

4.7 ESP32-CAM for Video Surveillance

FIGURE 6. ESP32-CAM

The ESP32-CAM module enhances a landmine detection robot vehicle and provides real-time video surveillance, enabling remote operators to visually assess threats and navigate to hazardous areas. Equipped with an OV2640 2MP camera and built-in Wi-Fi, the ESP32-CAM streams video independently without the need for external microcontrollers or displays. It provides a web server that streams live footage that can be accessed via any browser, eliminating the need for additional software. The module supports both access point and station modes, providing flexible connectivity options. In landmine detection, the STM32 can enable the ESP32-CAM to send footage for operator verification. This approach reduces system complexity and offloads video processing tasks. The ESP32-CAM operates at 5V and draws 180–300mA during streaming. To save power, it can enter sleep mode or be powered on in a mode selected by the STM32. Challenges such as limited night vision and Wi-Fi range can be addressed using IR LEDs and external antennas. The ESP32-CAM's unique functionality, real-time video capability, and efficient power management make it an ideal solution for field-based surveillance in demining operations.

4.8 L298N Motor Driver for Motion Control

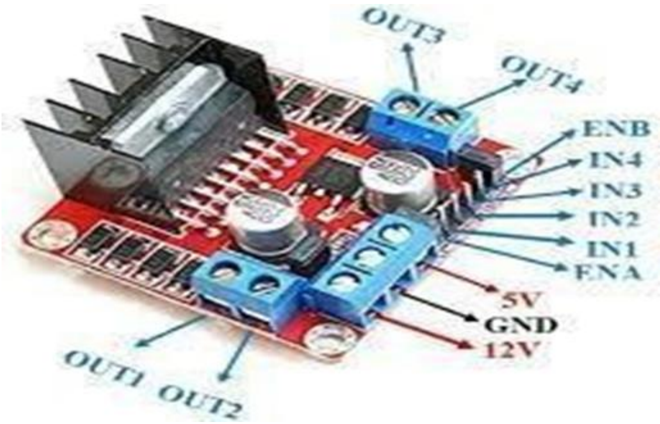


FIGURE 7. L298N Motor Driver

The L298N motor driver is crucial in the landmine detection robot vehicle to manage the speed and direction of the two DC motors and enable smooth and precise navigation. It acts as a bridge between the STM32 microcontroller and the motors, using dual H-bridge circuits to allow independent motor control. The direction is set via digital signals, while the speed is controlled via PWM signals from the STM32. The L298N, which operates on 12V power and 5V logic, supports up to 2A per motor. Heat sinks improve thermal performance, and PWM control ensures energy-efficient operation. Gradual speed changes help prevent jerky motion during direction changes.

4.9 Buzzer for Alert System

FIGURE 8. Buzzer

In a mine detection robot vehicle, a buzzer serves as a key warning mechanism, providing immediate audible warnings when a metal object is detected. Controlled by an STM32 microcontroller, the buzzer is activated upon receiving a signal from the metal detector, alerting the operator and nearby personnel to a potential mine. Operating on electromagnetic or piezoelectric principles, it produces sound by vibrating a diaphragm in response to an electrical signal. The STM32 interfaces with the buzzer via a GPIO pin, using a high-frequency signal to activate it. The Pulse Width Modulation (PWM) system enables the creation of different sound patterns, from landmine detection to battery warnings, such as continuous, pulsating, or short beeps, depending on the situation. By activating the buzzer only when needed, power efficiency is maintained by using PWM to reduce current. Challenges such as false alarms and audibility in noisy areas are addressed through signal filtering and frequency adjustment, ensuring reliability in field conditions.

4.10 Robot Chassis with Wheels

FIGURE 9. Robot Chassis with Wheels

The robotic chassis forms the structural backbone of the mine detection vehicle, supporting all electronic components, sensors, and motors, while ensuring durability and mobility in harsh environments. Crafted from lightweight materials such as aluminium alloy or ABS plastic, it balances strength and portability. A four-wheel differential drive system enables smooth forward, backward, and turning movements controlled by two independent DC motors. Shock-absorbing mounts protect the electronics from vibrations, and strategically placed battery and sensor modules ensure optimal weight distribution. Rubber or all-terrain wheels provide traction on a variety of surfaces. The modular design supports future upgrades such as tank tracks or additional sensors for improved field performance.

5. SOFTWARE DESCRIPTION

5.1 Software Requirements

The software implementation of the landmine detection robot uses Arduino IDE and STM32CubeIDE for programming and debugging. Libraries like TinyGPS++ and Bluetooth Serial manage GPS data and wireless communication. The ESP32-CAM enables live video streaming, while UART-based serial monitoring supports real-time data logging, debugging, and system performance verification.

5.2 Arduino IDE for STM32 and ESP32 Programming

The Arduino IDE was chosen to program the STM32 and ESP32-CAM due to its simplicity, library support, and hardware compatibility. The code is limited to managing motor control, metal detection, GPS tracking, and wireless communication. Initialization sets up the GPIO pins, serial interfaces, and PWM. The metal detection algorithm activates alerts and logs GPS data. GPS tracking uses the TinyGPS++ library to parse coordinates and transmit them via Bluetooth. UART communication connects the STM32 to the GPS, HC-05, and ESP32-CAM modules. The ESP32-CAM handles video streaming over Wi-Fi. This structured approach ensures efficient control, real-time monitoring, and reliable data transmission in field operations.

5.3 Configuring Input and Output Pins

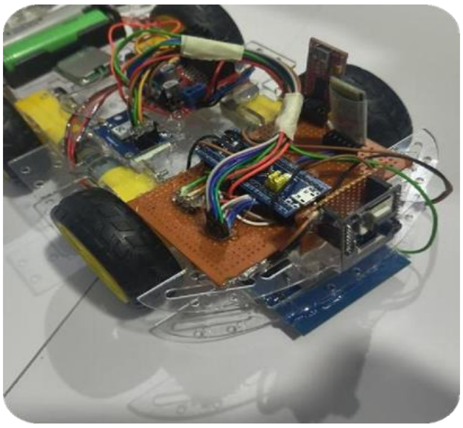
Proper pin configuration is essential for the correct operation of the robotic vehicle. The following table shows the hardware pin assignments:

TABLE 1. Configuring Input and Output Pins

Component	STM32 Pin	Mode	Function
Metal Detector	PA0	Input	Reads metal detection signal
GPS (NEO-6M) Module	PB6, PB7	UART	Receives GPS data
Bluetooth Module (HC-05)	PA9, PA10	UART	Sends alerts and GPS coordinates
Motor Driver (L298N)	PA1, PA2, PA3, PA4	PWM	Speed and Controls motor direction s
ESP 32 CAM	UART2 (PA9, PA10)	UART	Streams live video
Buzzer	PA5	Output	Sounds alert when landmine is detected
Robot Chassis with Wheels	N/A	Output	Able to move vehicle

6. RESULTS

Results of Landmine Detection System: The landmine detection robotic vehicle was tested in various environments to evaluate its metal detection accuracy, GPS tracking reliability, wireless communication stability, and real-time monitoring capabilities. The system successfully detected metallic objects buried at different depths, logged GPS coordinates accurately, and transmitted data wirelessly to a remote device.



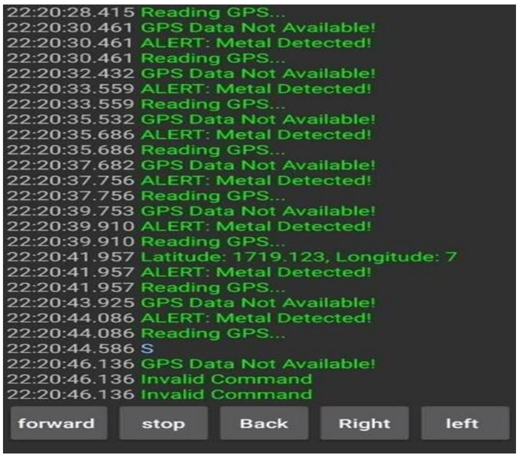


FIGURE 10 & 11. Results of Landmine Detection

The mine detection robot vehicle demonstrated strong performance in key areas. Metal detection was accurate to a depth of 10 cm, with immediate buzzer and LED alerts. The GPS module provided accurate location tracking within 2-3 meters, enabling accurate hazard mapping. Wireless communication using Bluetooth and Wi-Fi allowed for effective data transfer and real-time video streaming. A differential drive enabled stable navigation in a variety of terrains, while PWM improved power consumption. Live video feeds supported object verification, improving detection reliability. The system’s low-cost design, combined with real-time monitoring, remote operation, and automatic alerts, makes it well-suited for deployment in resource-constrained, mine-affected zones.

TABLE 2. Challenges & Limitations

Issue	Observation	Proposed Solution
Metal Detection False Positives	Small metallic debris triggered unnecessary alerts	Implement AI- based signal filtering
Limited Bluetooth Range	Connection dropped beyond 10 meters	Use LoRa or Wi-Fi for extended communication
GPS Accuracy Variability	Slight errors in tracking due to interference	Use GPS GLONASS dual positioning
Battery Drain Issues	Continuous video streaming consumed high power	Implement sleep mode for ESP32-CAM
Uneven Terrain Challenge	The robot struggled on soft surfaces	Use larger wheels and adaptive suspension

7. ADVANTAGES, DISADVANTAGES AND APPLICATIONS

Advantages

- High Sensitivity: The use of ARM Cortex (STM32) allows precise signal processing, enhancing the sensitivity of sensors to detect metallic and non-metallic mines.
- Automation: The robotic vehicle can operate autonomously, minimizing human intervention in dangerous areas.
- Real-time Monitoring: Integration of wireless communication systems enables real-time data transmission for remote monitoring.
- Compact and Cost-effective: ARM Cortex-based controllers are efficient, lightweight, and cost-effective, making the system affordable.
- Versatility: The system can be adapted to different terrains and detection scenarios.
- Safety: Reduces the risk to human life by eliminating the need for manual mine detection.

Disadvantages

- Environmental Limitations: Performance can be affected by environmental factors such as soil composition, humidity, or temperature.
- Power Dependency: Continuous operation requires a reliable power source, which may not always be feasible in remote locations.
- Sensor Limitations: Depending on the technology used, the sensors may struggle with deeply buried or non-metallic mines.
- Complexity in Design: Advanced features like GPS, wireless modules, and precise sensors increase the system's complexity
- High Initial Cost: While cost-effective in the long run, the initial investment in development and deployment may be high.
- Limited Detection Speed: Scanning large areas can be time-consuming.

Applications

- Military Operations: Used for clearing landmines in war-affected areasto ensure troop and civilian safety.
- Humanitarian Demining: Deployed by organizations working to remove mines in post conflict regions to restore safe living conditions.
- Agricultural Recovery: Helps clear landmines from agricultural lands to enable farming and rural development.
- Disaster Response: Useful in detecting buried explosives in disaster-hit regions for safe recovery and reconstruction.

8. CONCLUSION

Landmine detection robots have the potential to revolutionize the way we detect and clear landmines, which continue to pose a serious threat to civilians in many parts of the world. With advances in robotics and AI technologies, these machines are becoming increasingly sophisticated and effective at detecting landmines. However, there are still challenges that need to be addressed to make these robots more widely available and effective. One of the key challenges is ensuring that the robots can operate in a range of different environments and terrains, including those that are difficult to access or have limited visibility. In conclusion, the logistic regression model is a promising approach for underwater mine detection. In this study, we applied a logistic regression model to the analysis of underwater mine data, and our results demonstrate its effectiveness in detecting and classifying mines. Our study shows that the logistic regression model can accurately classify mines based on their features, such as size, shape, and acoustic signature. We also found that feature selection is crucial in improving the accuracy of the logistic regression model. Future research in underwater mine analysis using a logistic regression model should focus on addressing these challenges. More efforts should be devoted to collecting high- quality labeled data to train and validate the model. Additionally, more robust feature selection and extraction techniques should be explored to improve the accuracy and efficiency of the model

9. FUTURE SCOPE

The mine detection robot vehicle has shown effective performance in metal detection, GPS tracking, wireless communication, and real-time monitoring. However, to improve its practical application in real-world scenarios, several improvements have been proposed. A key area is metal detection accuracy, in which AI-based signal filtering can help distinguish between real mines and harmless metal debris, which can significantly reduce false alarms. Integrating multi-sensor fusion, such as ground-penetrating radar (GPR), can expand detection capabilities to include non-metallic mines. Adjustable sensitivity settings also provide adaptability to different soil conditions. Solar panels can be added for constant power to support extended missions, as well as energy-efficient motor control and sleep modes to preserve battery life. The communication range can be improved by replacing Bluetooth with LoRa or 4G modules. For advanced applications, voice control can be introduced with speech recognition and autonomous navigation using GPS waypoints and LiDAR or ultrasonic sensors. A hybrid control system combining manual and autonomous modes, along with a mobile app interface, will provide flexible and user-friendly operation. Beyond mine detection, the system also has potential in other areas such as disaster relief, pipeline and utility location, and military surveillance - where adding night vision to the ESP32-CAM will support operations in low-light conditions. These upgrades will significantly increase the versatility and impact of the system.

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