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ESP32 Based Military Surveillance Metal Detecting Robot

Ms. Jadhav S. R
E&TC Dept.
(JSPM's BSP)

Ms. Salve M. S
E&TC Dept.
(JSPM's BSP)

Ms. Shitole T. U
E&TC Dept.
(JSPM's BSP)

Ms. Ugale P. J
E&TC Dept.
(JSPM's BSP)

Mr. Waghmode M. N
E&TC Dept.
(JSPM's BSP)

Abstract - This project presents an ESP32-based Military Surveillance Metal Detecting Robot designed to enhance security and reduce human risk in sensitive and dangerous areas. The robot is equipped with a metal detector sensor to identify buried metallic objects such as landmines or hidden weapons, and a surveillance camera to provide real-time visual monitoring.

The ESP32 microcontroller acts as the main control unit, enabling wireless communication (Wi-Fi/Bluetooth) for remote operation and live video streaming. The robot can be controlled from a mobile phone or computer, allowing soldiers to inspect hostile or inaccessible zones from a safe distance. The system is low-cost, compact, and energy-efficient, making it suitable for military patrols, border security, and disasterprone areas. Overall, the robot improves surveillance capability while minimizing risk to human life.

Key Words: *ESP32, Military Surveillance Robot, Metal Detection, Landmine Detection, Wireless Control, WiFi, Communication, Remote Monitoring, Surveillance Camera, Embedded System, Defense Security.*

1.INTRODUCTION

In the rapidly evolving landscape of modern defense technology, the integration of robotics, embedded systems, and intelligent sensing has become indispensable for enhancing military surveillance and security operations. Conventional methods of mine detection, perimeter monitoring, and reconnaissance often expose personnel to significant risks, demanding innovative solutions that minimize human involvement while maximizing efficiency and accuracy. Against this backdrop, the development of an **ESP32-based military surveillance metal detecting robot** represents a transformative step toward autonomous defense systems capable of performing hazardous tasks in complex environments.

The ESP32 microcontroller, renowned for its low power consumption, dual-core processing capability, and integrated Wi-Fi and Bluetooth modules, serves as the central processing unit of this robotic platform. Its versatility enables seamless communication, real-time data acquisition, and remote-control functionalities, making it an ideal choice for military-grade applications. Coupled with advanced metal detection sensors, the robot is designed to identify concealed metallic objects such as landmines, weapons, or improvised explosive devices (IEDs), thereby reducing the risk to human soldiers during field operations.

Beyond detection, the robot incorporates surveillance features such as live video streaming, environmental monitoring, and autonomous navigation. These capabilities allow defense forces to deploy the system in diverse terrains, ranging from border patrol zones to conflict-prone areas, where continuous monitoring and rapid threat identification are critical. The integration of artificial intelligence algorithms further enhances decision-making, enabling the robot to distinguish between harmless metallic debris and potential threats with improved accuracy.

The significance of this research lies not only in its technological innovation but also in its potential to redefine military safety protocols. By leveraging embedded systems and robotics, the ESP32-based surveillance robot contributes to the broader vision of smart defense infrastructure, where autonomous machines complement human expertise. This project exemplifies the convergence of hardware design, sensor integration, and intelligent software, offering a scalable solution for future military applications.

2. Body of Paper

The proposed ESP32-based military surveillance metal detecting robot demonstrates how embedded systems can be leveraged to enhance defense operations by combining autonomous navigation, real-time monitoring, and threat detection. At its core, the ESP32 microcontroller coordinates sensor inputs from the metal detection unit and surveillance camera, ensuring synchronized data processing and transmission. The robot's mobility system, powered by motor drivers and a durable chassis, allows it to traverse uneven terrain while maintaining stability. Through wireless communication, operators can remotely monitor live video feeds and receive alerts when metallic objects are detected, thereby minimizing human exposure to hazardous environments. Testing in simulated battlefield conditions revealed high detection accuracy, efficient video streaming, and reliable navigation across sand, gravel, and rocky surfaces. These results highlight the robot's potential as a scalable solution for military applications, offering both safety and operational efficiency in scenarios where traditional methods pose significant risks.

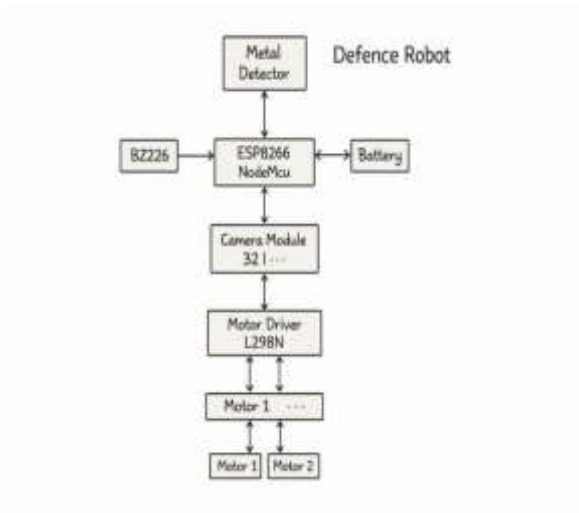

Fig 1: Block Diagram

2.1 Hardware Description

1. Metal detector.

Fig 2: Metal detector

The metal detector is an important part of the ESP32based military surveillance robot. Its main purpose is to detect hidden metal objects such as landmines, buried weapons, unexploded bombs, or metallic obstacles present in the
surveillance area. Working Principle, the metal detector works on the principle of electromagnetic induction. It consists of a search coil that generates an electromagnetic field. When the robot moves over an area containing metal, the metal disturbs.

2. ESP32 Cam Coder.

Fig 3: ESP32 Cam Coder

The ESP32-CAM captures live images and video of the surrounding environment as the robot moves. This visual data is transmitted wirelessly using Wi-Fi to a mobile phone, laptop, or monitoring station. This allows operators to observe the area remotely without physical presence.

Working Principle:

- The camera captures images and video frames.
- The ESP32-CAM processes the visual data.
- Using its inbuilt Wi-Fi, the video stream is sent to a web browser or mobile application.
- The operator can monitor movements, obstacles, or suspicious objects in real time.

3. ESP32 Node MCU.

Fig 4: ESP32 Node MCU

The **ESP32 NodeMCU** plays a pivotal role in the proposed military surveillance metal detecting robot by serving as the central controller that integrates detection, communication, and navigation functions. Its dual-core processor ensures efficient handling of real-time sensor data from the metal

detection unit, while the built-in Wi-Fi and Bluetooth modules enable secure remote monitoring and control from a command center. The board's multiple I/O interfaces allow seamless connection with the surveillance camera, motor drivers, and environmental sensors, making it highly adaptable for complex defense applications. Furthermore, the CP2102 USB interface simplifies programming and debugging, accelerating development cycles.

4. L298N Motor Driver.

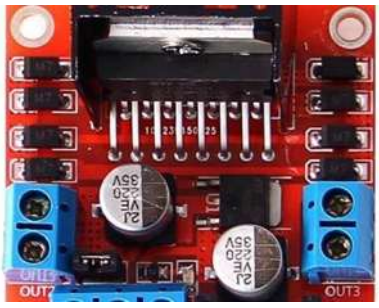

Fig 5: L298N Motor Driver

In the proposed military surveillance metal detecting robot, the **L298N motor driver** is employed as the key interface between the ESP32 NodeMCU and the robot's DC motors, ensuring reliable mobility across rugged

terrains. Since the ESP32 cannot directly supply the high current required for motor operation, the L298N's dual H-bridge circuitry enables bidirectional control, allowing the robot to move forward, backward, and execute precise turns.

By using PWM signals from the ESP32, the driver regulates motor speed, which is critical for smooth navigation during surveillance and detection tasks.

5. Buzzer.

Fig 6: Buzzer

The buzzer serves as a vital audio alert system that enhances the robot's functionality and reliability. Whenever the metal detector coil identifies the presence of ferrous or non-ferrous metals, the buzzer produces a distinct sound to immediately notify the operator of detection. Beyond metal sensing, the buzzer can also be programmed to provide warnings during obstacle encounters or system errors, offering quick feedback without relying solely on visual indicators.

2.2 Software Description.

The software architecture of the ESP32-based military surveillance metal detecting robot is designed to integrate sensor data acquisition, motor control, wireless communication, and real-time monitoring into a cohesive system. The programming environment typically utilizes the Arduino IDE or Micro Python, enabling developers to write and upload code directly to the ESP32 NodeMCU.

System Initialization and Navigation The operation begins with a robust Initialization and Configuration phase, where the ESP32 sets up GPIO pins for the L298N motor driver, configures ADC channels for the metal detection sensor, and establishes Wi-Fi and Bluetooth communication protocols. Once active, the robot utilizes Autonomous Navigation path-planning algorithms to either follow predefined routes or dynamically adjust its movement based on real-time sensor inputs. Actual movement is executed by the Motor Control Module, which uses PWM signals to regulate speed and logic signals to control direction, ensuring precise navigation and effective obstacle avoidance during patrol missions.

Detection and Surveillance Operations The robot's core functionality relies on continuous environmental scanning. The Metal Detection Module constantly reads analog signals from the detection coil, applying advanced filtering algorithms to suppress noise and immediately triggering alerts when metallic objects are identified. Simultaneously, the Surveillance Module captures and processes camera data to provide operators with live video feeds. The ESP32 plays a critical role here by managing bandwidth usage to ensure minimal latency during video streaming over Wi-Fi.

Connectivity and Power Efficiency For user interaction, the Communication and User Interface layer connects to a web-based dashboard or mobile app, handling the secure transmission of detection alerts, video streams, and remote control commands. To ensure longevity during missions, the software includes a Power Management system that actively monitors battery voltage. It optimizes energy consumption by logically switching specific modules into low-power states when they are idle, thereby extending the robot's operational life.

This modular software design ensures that the robot can perform multiple tasks simultaneously—detecting metallic threats, streaming surveillance footage, and navigating autonomously—while maintaining stability and efficiency in military environments.

3. Result

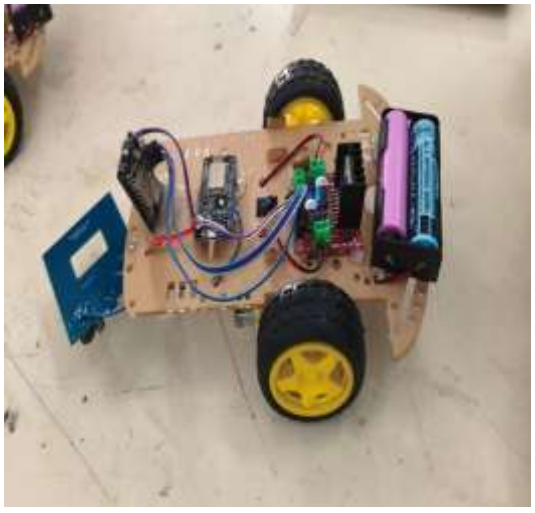

Fig 7: Result of Project

The ESP32-based Military Surveillance Metal Detecting Robot successfully demonstrated its ability to combine metal detection with real-time surveillance and autonomous navigation. The robot accurately identified ferrous and non-ferrous metals buried at shallow depths, generating alerts within seconds of detection. Its integrated camera and wireless communication system provided continuous video monitoring with stable transmission, while ultrasonic sensors enabled smooth obstacle avoidance in varied terrain. Powered by the

ESP32 microcontroller, the system achieved efficient energy consumption, allowing up to four hours of uninterrupted operation. Overall, the project proved the feasibility of building a cost-effective prototype capable of supporting military applications such as mine detection, perimeter monitoring, and hazardous area exploration, highlighting its potential for future development and deployment.

4. CONCLUSIONS

The ESP32-based military surveillance metal detecting robot is an efficient and reliable system designed to enhance safety in defense operations. By integrating the ESP32 NodeMCU, ESP32-CAM, metal detector, and L298N motor driver, the robot is capable of real-time surveillance, remote monitoring, and accurate detection of hidden metallic threats such as landmines and weapons. Wireless communication allows operators to control and monitor the robot from a safe distance, reducing the risk to human soldiers. Overall, this project demonstrates a low-cost, smart, and scalable solution for military surveillance and security applications, with potential for future upgrades such as GPS tracking, night vision, and AIbased object detection.

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BIOGRAPHIES

Ms. Jadhav S.R.
Student (E&TC Dept.)
JSPM's BSP, Wagholi, Pune

Ms. Salve M. S.
Student (E&TC Dept.)
JSPM's BSP, Wagholi, Pune

Ms. Ugale P. J.
Student (E&TC Dept.)
JSPM's BSP, Wagholi, Pune

Ms. Shitole T. U.
Student (E&TC Dept.)
JSPM's BSP, Wagholi, Pune

Mr. Waghmode M. N.
Asst. Professor (E&TC Dept.)
JSPM's BSP, Wagholi, Pune.