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Design and Implementation of an IoT-Based Intelligent Security Robot

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Abstract: *This report presents the the iot based security robot. The proposed system integrates a lightweight, rugged mobile platform with multi-modal sensors (RGB camera, thermal camera, LiDAR, IMU) and a dexterous manipulator to perform remote reconnaissance, object detection, and safe neutralization or removal of suspicious ordnance. A hybrid control architecture combines operator telepresence for high- risk manipulations with autonomous capabilities for navigation, target tracking, and obstacle avoidance. Sensor fusion and deep-learning based perception enable real-time detection and classification of threats, while path-planning and behavior modules ensure robust operation in cluttered and GPS-denied environments. Emphasis is placed on human-robot interaction, secure wireless communications, and fail-safe mechanical and software layers to minimize risk to operators. Prototype development and field trials demonstrate the platform's effectiveness in simulated urban and rural scenarios, showing improved situational awareness, reduced time- to-intervention, and enhanced operator safety compared to conventional methods. The system is intended as a modular, upgradable solution for military and homeland-security agencies requiring rapid, reliable, and safe robotic support for surveillance and explosive ordnance disposal missions.*

Keywords: Military robot; surveillance; explosive ordnance disposal (EOD); sensor fusion; autonomous navigation; teleoperation; machine learning; human–robot interaction

I. INTRODUCTION

The design and development of a smart military robot for surveillance and explosive handling represents a significant advancement in the modernization of defense technology by integrating robotics, embedded systems, and Internet of Things (IoT) technologies to enhance safety, intelligence, and operational efficiency in military missions [1][2]. In modern warfare, soldiers are frequently exposed to highly dangerous environments such as war zones, insurgency-affected regions, and areas contaminated with explosives or hazardous chemicals. These conditions pose serious threats to human life, creating a critical need for intelligent robotic systems capable of operating in such environments with minimal human involvement [3].

To reduce the risks faced by military personnel, autonomous and remotely operated robotic platforms have become an essential innovation in contemporary defense systems. Military robots are increasingly used for surveillance, reconnaissance, explosive detection, and hazardous material handling, enabling missions to be carried out with greater precision and reduced casualties [4]. The proposed system introduces a multi-functional robotic platform equipped with advanced sensors, cameras, and wireless communication modules to perform real-time surveillance, threat detection, and explosive-handling tasks efficiently.

At the core of the system, the ESP32 microcontroller functions as the central processing unit, coordinating sensor inputs, motor control, and communication between the robot and remote monitoring stations. The ESP32 is widely adopted in IoT-based robotic applications due to its low power consumption, high processing capability, and built-in Wi-Fi support, making it suitable for real-time military surveillance systems [5]. Through IoT connectivity, the robot continuously transmits live sensor data, video feeds, and alert notifications, enabling defense personnel to monitor high- risk zones remotely and respond proactively to detected threats [6].

The ESP32-CAM module further enhances the system by providing high-quality live video streaming, which is crucial for surveillance in inaccessible or hazardous areas such as minefields, chemical zones, and active conflict regions. Visual feedback combined with real-time sensor data significantly improves situational awareness and supports informed tactical decision-making [7]. This integration reduces the need for direct human presence in dangerous missions, thereby enhancing soldier safety and mission effectiveness.

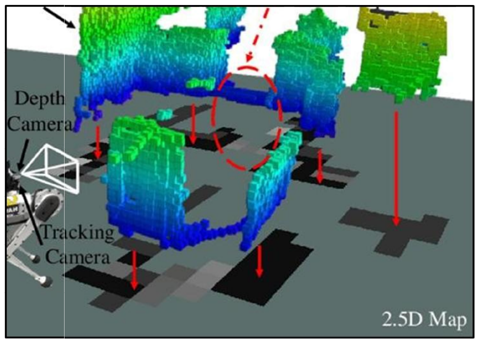

Fig 1: Robot’s Sensor Suite

The robot is equipped with a comprehensive sensor suite that includes a GPS module for real-time location tracking, metal detectors for identifying hidden explosives or unexploded ordnance, and gas/smoke sensors for detecting toxic or flammable substances. These sensors enable early threat detection and environmental assessment, allowing military personnel to take preventive actions before entering hazardous areas [8][9]. The robot’s mechanical design emphasizes mobility and adaptability, utilizing a four-wheel- drive mechanism powered by DC motors and controlled through a motor driver interfaced with the ESP32. This configuration ensures stable navigation across uneven terrains such as sand, rocks, and debris-filled landscapes [10].

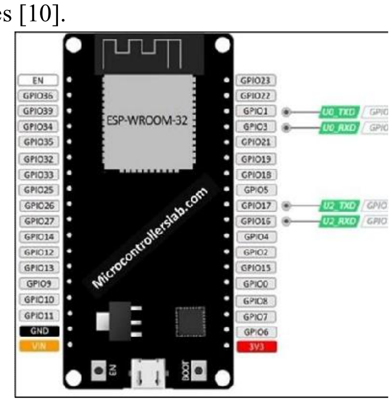

Fig 2: ESP 32 diagram

The development process follows a systematic approach involving hardware integration, software development, and rigorous testing to ensure reliability and safety. Modular firmware architecture allows independent handling of motor control, telemetry, and video streaming, improving fault tolerance and system robustness [11]. Remote monitoring interfaces provide live video, location tracking, and real-time alerts, enabling effective mission planning and control. Future enhancements include the integration of robotic manipulators for explosive handling, autonomous navigation with obstacle avoidance, secure encrypted communication, and advanced sensor fusion techniques [12].

Overall, the proposed smart military robot aims to provide a reliable, intelligent, and scalable solution for high- risk defense operations. By combining IoT-enabled communication, intelligent sensing, and robust mechanical design, the

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system contributes to safer, smarter, and more efficient military operations while significantly reducing human exposure to danger [13].

II. PROBLEM STATEMENT

Modern military operations frequently take place in environments that are extremely hazardous to human life, including active war zones, terrorist-affected regions, border surveillance areas, minefields, and locations contaminated with explosives, toxic gases, or smoke. Soldiers deployed in such conditions face constant threats from hidden explosives, unexploded ordnance, chemical hazards, and hostile surveillance, which significantly increases the risk of injury or loss of life. Traditional methods of reconnaissance, surveillance, and explosive handling rely heavily on human involvement, exposing personnel to unpredictable and life- threatening situations.

Existing military surveillance and bomb disposal techniques often suffer from several limitations, such as restricted situational awareness, delayed threat detection, limited real-time communication, and dependence on manual inspection. Many conventional systems lack integrated sensing and real-time video feedback, making it difficult for operators to accurately assess threats from a safe distance. Additionally, human-operated explosive handling procedures require soldiers or technicians to physically approach dangerous objects, increasing the likelihood of fatal accidents.

Although some robotic systems are currently used in defense applications, they are often expensive, complex, and not easily adaptable for multi-purpose missions. Many available solutions do not provide seamless integration of surveillance, environmental sensing, location tracking, and wireless communication within a single compact platform. Furthermore, the absence of IoT-based connectivity in traditional robotic systems limits real-time data sharing, remote monitoring, and centralized command control, reducing operational efficiency during critical missions.

There is therefore a critical need for a cost-effective, intelligent, and reliable robotic system capable of performing real-time surveillance, detecting explosives and hazardous substances, and operating in dangerous environments without direct human intervention. Such a system must support remote monitoring, live video streaming, accurate sensor feedback, and stable mobility across uneven terrains. Addressing these challenges is essential to enhance soldier safety, improve mission effectiveness, and support modern defense strategies through the adoption of smart, IoT-enabled military robotics.

III. OBJECTIVE

- To design a mobile robot integrated with ESP32 for wireless control and automation in defense applications.
- To implement live video surveillance using the ESP32- CAM module with cloud-based streaming for real-time remote monitoring.
- To detect metallic objects or explosives using a metal detector for bomb detection purposes.
- To enable smoke and gas detection using appropriate gas sensors for hazard identification and early alerts.
- To track the robot’s real-time location using a GPS module to ensure accurate navigation and field monitoring.

IV. LITERATURE SURVEY

1. Design and Development of Surveillance Robot

This study presents a remotely operated surveillance robot developed for military applications to minimize human involvement in dangerous and hostile environments. The system is built using the BeagleBone Black board as the main processing unit and incorporates wireless communication along with a camera module for real-time video streaming. The robot is designed to continuously monitor sensitive and high-risk areas, thereby improving operational safety and surveillance efficiency [1].

2. Smart Surveillance Robot for Milita Applications Using IoT

This paper proposes an IoT-enabled smart surveillance robot using NodeMCU ESP8266 and ESP32-CAM for image capture and live video streaming. The robot integrates PIR sensors for human detection, IR sensors for obstacle

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sensing, and a GPS module for real-time location tracking through the Blynk IoT platform. The system enhances remote monitoring and improves situational awareness in military and defense operations [2].

3. Surveillance Robot for Military Application

This research introduces an autonomous surveillance robot intended for military border security applications. The system is implemented using NodeMCU and an ESP32 camera module and is equipped with a metal detector for identifying landmines and ultrasonic sensors for obstacle avoidance. The proposed robot strengthens border security by enabling automated navigation and early threat detection [3].

4. Design and Development of Multipurpose Robot for Military Spying and Patrolling

This paper presents a multipurpose military robot designed for spying, surveillance, and patrolling activities. The robot is developed using Raspberry Pi and Python, with the integration of artificial intelligence and autonomous control features. It uses multiple wireless communication technologies such as Bluetooth, Wi-Fi, and ZigBee to ensure reliable and secure communication. The inclusion of real-time video and audio streaming improves surveillance and reconnaissance performance [4].

5. Design and Develop of a Communication Module for a Military Surveillance Robot

This study focuses on the development of a robust communication module for military surveillance robots. The system is based on Raspberry Pi 3 B+ and a NoIR camera for night vision monitoring. It also includes GPS and IMU sensors for accurate positioning and orientation tracking. The communication system achieves a long- range wireless transmission distance of up to 600 meters using a dual-antenna 2.4 GHz network, making it suitable for field surveillance applications [5].

V. PROPOSED SYSTEM

A. System Overview

The proposed system is a smart IoT-enabled military robot designed to perform real-time surveillance, hazardous environment monitoring, and explosive detection while minimizing human involvement in dangerous military operations. The robot operates either remotely or in a semi- autonomous mode and transmits live video, sensor data, and alert notifications to a remote monitoring station. By integrating embedded systems, wireless communication, and intelligent sensing technologies, the system enhances situational awareness, improves operational efficiency, and ensures soldier safety in high-risk environments.

B. Hardware Architecture

The hardware architecture consists of an ESP32 microcontroller that serves as the central control unit of the system. It interfaces with various modules, including the ESP32-CAM for live video streaming, GPS module for real- time location tracking, metal detector for explosive identification, gas and smoke sensors for hazardous substance detection, motor driver circuit for motion control, and DC motors for mobility. All hardware components are powered through a rechargeable battery system with proper voltage regulation to ensure stable operation and long mission duration.

C. Sensor Suite and Threat Detection

The robot is equipped with a comprehensive sensor suite to detect multiple threats in military environments. A metal detector is used to identify hidden metallic objects such as landmines or unexploded ordnance. Gas and smoke sensors detect toxic or flammable gases, providing early warnings of chemical hazards. The GPS module continuously tracks the robot's position, enabling location-based monitoring and mission logging. Sensor data is processed in real time by the ESP32 and transmitted to the control station for threat analysis and decision-making.

D. Surveillance and Vision System

For visual monitoring, the system uses an ESP32-CAM module capable of capturing and streaming live video over a wireless network. This allows operators to observe enemy activity, terrain conditions, and potential threats from remote or inaccessible locations. The real-time video feed, combined with sensor data, enhances situational awareness and supports effective tactical planning. The vision system is particularly useful in low-visibility or hazardous areas where direct human observation is unsafe.

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E. Communication and IoT Connectivity

Wireless communication is a critical component of the proposed system. The built-in Wi-Fi capability of the ESP32 enables IoT-based data transmission between the robot and a remote monitoring station or cloud platform. Live video streams, sensor readings, GPS coordinates, and alert messages are transmitted in real time. This connectivity allows military personnel to monitor the robot's status, receive threat alerts, and control robot movements from a secure location. Future upgrades may include encrypted communication protocols for enhanced data security.

F. Mobility and Control Mechanism

The robot is designed with a four-wheel-drive mechanism powered by DC motors, providing stable and efficient movement across uneven terrains such as sand, rocks, and debris. A motor driver circuit interfaces with the ESP32 to control direction and speed based on user commands or predefined navigation logic. The robot can be operated manually through a remote interface or programmed for semi-autonomous movement, enabling flexible deployment in various mission scenarios.

G. Software Design and Control Interface

The software system is developed using a modular firmware approach to ensure reliability and ease of maintenance. Separate software modules handle motor control, sensor data acquisition, video streaming, and wireless communication. A remote-control interface displays live video feeds, real-time sensor values, GPS location, and alert notifications. The interface is designed to be user- friendly, allowing operators to issue control commands, monitor threats, and respond quickly during critical operations.

H. Safety, Reliability, and Future Enhancements

Safety and reliability are key design considerations in the proposed system. Electrical isolation, stable power management, and fail-safe mechanisms are incorporated to prevent system failure during missions. The modular design allows for easy upgrades, such as the integration of a robotic arm for explosive handling, autonomous navigation with obstacle avoidance, advanced sensor fusion, and secure encrypted communication. These enhancements aim to further improve the robot's effectiveness, adaptability, and reliability in modern military operations.

VI. SYSTEM DESIGN

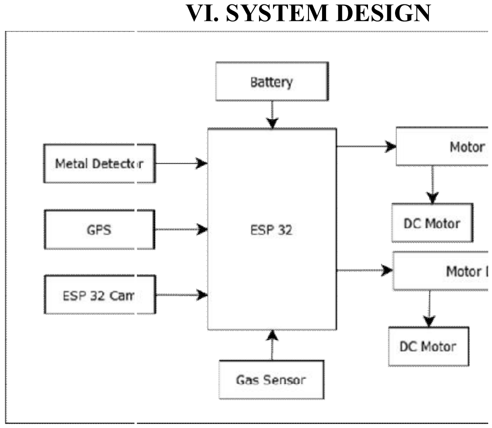

Fig 3: System Architecture

The block diagram of the Smart Military Robot for Surveillance and Explosive Handling illustrates the functional relationship between sensing, control, communication, and mobility modules. The system is centered around the ESP32 microcontroller, which acts as the main control unit responsible for processing sensor data, managing motor operations, and enabling wireless communication. The robot integrates surveillance, threat detection, and remote operation to reduce human involvement in high-risk military environments.

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1. ESP32 Microcontroller

The ESP32 microcontroller functions as the core processing and control unit of the smart military robot. It collects data from all sensors, processes control logic, and generates output signals for motor control and communication. With its built-in Wi-Fi and Bluetooth capabilities, the ESP32 enables seamless IoT connectivity for real-time data transmission and remote monitoring. Its dual- core architecture allows simultaneous handling of sensor processing and communication tasks, improving system reliability and response time during critical operations.

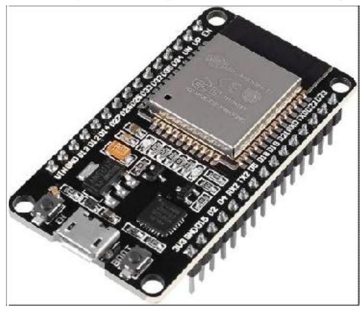

Fig 4: ESP32 Microcontroller

Component Specification
• Model: ESP32-WROOM-32 / ESP32 DevKit V1
• Processor: Dual-core Tensilica Xtensa LX6
• Clock Speed: Up to 240 MHz
• Operating Voltage: 3.0V – 3.6V
• Flash Memory: 4 MB (typical)

2. ESP32-CAM Module

The ESP32-CAM module provides visual intelligence to the robotic system by capturing live video and images of the surrounding environment. This module allows military personnel to remotely monitor high-risk areas without direct physical presence. Its compact design and low power consumption make it suitable for continuous surveillance missions. The module also supports image storage and cloud streaming, enabling post-mission analysis and evidence collection.

The ESP32-CAM module integrates a camera interface with the ESP32 microcontroller, allowing it to process images and stream video. It supports Wi-Fi connectivity, making it suitable for real-time monitoring applications. Because of its small size and low power consumption, it is often used in smart home systems, robotics, and IoT security devices.

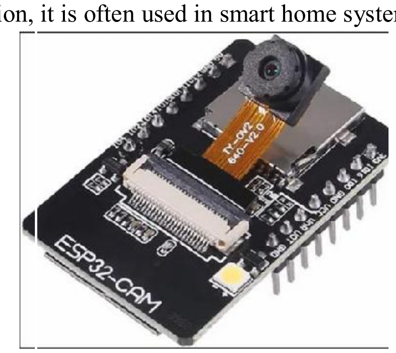

Fig 5: ESP32-CAM Module

Component Specification
• Model: ESP32-CAM / OV2640 Camera Module
• Resolution: Up to 2 Megapixels (1600 × 1200)

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• Video Streaming: Supports real-time video transmission over Wi-Fi
• Image Format: JPEG, BMP
• Operating Voltage: 3.3V – 5V
• Interface: SPI / Serial Camera Interface
• Function in System: Provides live video monitoring of the battlefield or hazardous area.

3. GPS Module (NEO-6M)

The GPS module enables real-time location tracking of the robot by receiving signals from multiple satellites. It provides accurate latitude and longitude data that helps operators monitor the robot's movement and mission progress. GPS data can be used to mark hazardous locations such as detected explosives or gas zones on digital maps. This feature is especially useful for navigation, rescue, and retrieval operations in large or unfamiliar terrains.

Fig 6: GPS Module (NEO-6M)

Component Specification
• Model: HC-SR04
• Operating Voltage: 5V DC
• Detection Range: 2 cm – 400 cm
• Accuracy: ±3 mm
• Working Frequency: 40 kHz
• Interface: Trigger and Echo pins connected to ESP32 GPIO
• Function in System: Detects obstacles and helps the robot navigate safely.

4. Metal Detector Sensor

The metal detector sensor is used to identify buried or concealed metallic objects that may pose threats, such as landmines or unexploded ordnance. By continuously scanning the ground surface, the sensor helps prevent accidental triggering of explosives. Upon detection, the system alerts the operator and can automatically stop robot movement for safety. This sensor significantly reduces the risk faced by soldiers during mine detection and clearance operations.

Fig 7: Metal Detector Sensor

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Component Specification
• Model: MQ-2 / MQ-135
• Operating Voltage: 5V DC
• Detection Gases: LPG, Methane, Smoke, Hydrogen (MQ-2)
• Response Time: < 10 seconds
• Output Type: Analog and Digital output
• Function in System: Detects dangerous gases or explosive substances in the environment.

5. Gas/Smoke Sensor (MQ-2)

The MQ-2 gas and smoke sensor detects harmful gases and smoke in the environment, providing early warnings of toxic or flammable conditions. It plays a vital role in protecting both the robot and human operators from chemical hazards. The sensor output helps determine whether an area is safe for further exploration or human entry. Continuous air quality monitoring enhances the robot's effectiveness in chemical warfare zones or disaster-affected areas.

Fig 8: Gas/Smoke Sensor (MQ-2)

Component Specification
• Model: L298N Dual H-Bridge Motor Driver
• Operating Voltage: 5V – 35V
• Motor Current: Up to 2A per channel
• Control Interface: Logic level signals from ESP32
• Number of Motors Supported: 2 DC motors (or 4 small motors)
• Function in System: Controls the direction and speed of the robot motors.

6. DC Motors (4-Wheel Drive)

DC motors provide the mechanical movement required for the robot to navigate various terrains. The four-wheel- drive configuration ensures better traction, stability, and control, especially on uneven or rough surfaces. Independent motor control allows precise movement and turning. This mobility system ensures the robot can carry sensors and payloads efficiently without compromising performance.

Fig 9: DC Motors (4-Wheel Drive)

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Component Specification
• Voltage Rating: 6V – 12V DC
• Speed: 100 – 300 RPM (depending on gear ratio)
• Torque: High torque for rough terrain movement
• Gear Type: Metal or plastic gear reduction system
• Function in System: Enables movement of the robot in forward, reverse, left, and right directions.

7. Motor Driver (L298N)

The motor driver acts as a power interface between the ESP32 and the DC motors. It amplifies control signals from the microcontroller to drive the motors with sufficient current. The driver supports speed and directional control using PWM techniques. By isolating high-current motor circuits from sensitive electronics, it improves system safety and longevity.

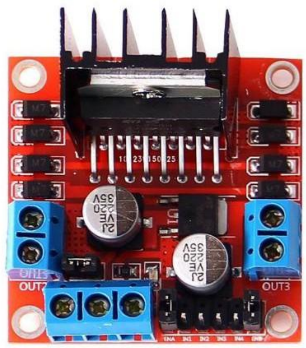

Fig 10: Motor Driver (L298N)

Component Specification
• Model: SG90 / MG996R Servo Motor
• Operating Voltage: 4.8V – 7.2V
• Rotation Angle: 0° – 180°
• Control Signal: PWM from ESP32
• Torque:
o SG90: ~1.8 kg/cm
o MG996R: ~10–12 kg/cm
• Function in System: Used to pick up or manipulate suspicious objects or explosives.

8. Battery Pack

The battery pack supplies power to all components of the robot, enabling autonomous field operation. Rechargeable batteries are selected to provide sufficient energy for extended missions. Power regulation ensures stable voltage delivery to sensitive modules. Efficient battery management enhances mission duration and reduces downtime between operations.

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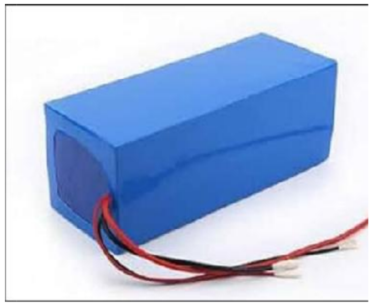

Fig 11: Battery Pack

Component Specification
• Technology: Wi-Fi / Bluetooth
• Frequency: 2.4 GHz
• Range:
• Wi-Fi: Up to 100 meters (open area)
• Bluetooth: 10–30 meters
• Function in System: Allows remote control and monitoring of the robot via smartphone or control station.

9. Chassis Frame

The chassis frame provides structural support and protects internal components from physical damage. It ensures proper weight distribution and mechanical stability during movement. A well-designed chassis allows easy maintenance and future expansion. Its durability ensures reliable operation in harsh military environments.

Fig 12: Chassis Frame

Component Specification
• Battery Type: Lithium-ion / Li-Po Battery Pack
• Voltage: 7.4V – 12V
• Capacity: 2200 mAh – 5000 mAh
• Regulator Module: LM2596 Buck Converter
• Output Voltage: 5V / 3.3V regulated
• Function in System: Supplies stable power to microcontroller, sensors, and motors.

10. Wheels

The wheels convert motor rotation into movement across the ground. Their design directly affects traction, speed, and maneuverability. All-terrain wheels allow the robot to operate efficiently on different surfaces such as sand, gravel, or concrete. Proper wheel selection improves control and reduces slippage during movement.

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Fig 13: Wheels

Component Specification

• Material: Aluminum / Acrylic / Steel frame
• Wheel Type: Off-road rubber wheels
• Drive Type: 2WD or 4WD
• Load Capacity: 3 – 5 kg
• Function in System: Provides mechanical support and stability to all components.

11. Connecting Wires

Connecting wires transmit power and control signals between components. High-quality insulated wires reduce power loss and prevent short circuits. Proper wire routing minimizes electromagnetic interference. Organized wiring improves system reliability and simplifies troubleshooting.

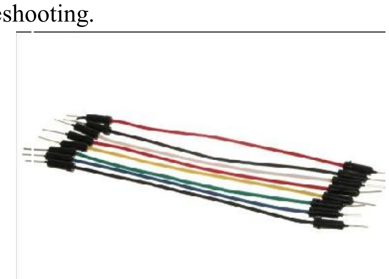

Fig 14: Connecting Wires

12. Breadboard / PCB

The breadboard is used during the prototyping stage to test and modify circuits easily. Once the design is finalized, a PCB is used for permanent and compact assembly. A PCB improves durability, reduces wiring complexity, and enhances signal integrity. This ensures stable long-term operation of the robotic system.

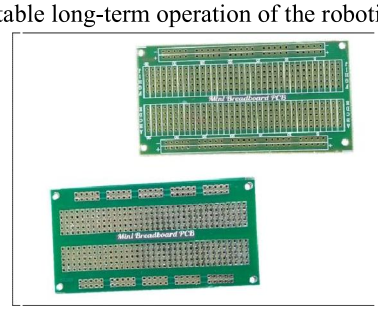

Fig 15: Breadboard / PCB

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Mathematical Calculations

1. BATTERY LIFE CALCULATION

To estimate how long the robot can operate: Formula

Battery Life (hours) = Battery Capacity (mAh) ÷ Total Current Consumption (mA)

Example Calculation Battery Capacity = 2200 mAh Current Consumption:

- ESP32 = 240 mA
- Motors (2 DC Motors) = 600 mA
- Sensors $(Gas + Metal + GPS) = 160\ mA$
- WiFi Communication = 200 mA Total Current Consumption

Total Current = 240 + 600 + 160 + 200

Total Current = 1200 mA Battery Life

Battery Life = 2200 ÷ 1200

Battery Life ≈ 1.83 hours

Robot can operate approximately 1 hour 50 minutes.

2. MOTOR POWER CALCULATION

Power required by the DC motor: Formula

$P = V \times I$

Where

P = Power (Watts)

V = Voltage (Volts)

I = Current (Amps)

Example

Motor Voltage = 12V

Motor Current = 0.5A

$P = 12 \times 0.5$

P = 6 Watts per motor

If two motors are used:

$Total\ Power = 6 \times 2$

Total Power = 12 Watts

3. ROBOT SPEED CALCULATION

Robot speed depends on wheel diameter and motor RPM.

$Speed = \pi \times D \times RPM$

D = Wheel Diameter (meters) Example

Wheel Diameter = 0.065 m Motor Speed = 200 RPM

$Speed = 3.14 \times 0.065 \times 200$

Speed = 40.82 m/min Convert to m/s

$Speed = 40.82 \div 60$

Speed ≈ 0.68 m/s

4. WIFI COMMUNICATION RANGE CALCULATION

Free Space Path Loss formula:

$FSPL = 20\ log10(d) + 20\ log10(f) + 32.44$

Where

d = Distance (km)

f = Frequency (MHz) Example:
WiFi Frequency = 2400 MHz Distance = 0.1 km (100 meters)
$FSPL = 20\ log10(0.1) + 20\ log10(2400) + 32.44$

5. SENSOR DETECTION PROBABILITY
Security detection accuracy can be estimated as: Detection Rate
$Detection\ Accuracy$
$= (Correct\ Detections\ /\ Total\ Tests)$
$\times 100$
Example:
Correct Detections = 92 Total Tests = 100
$Accuracy = (92\ /\ 100) \times 100$
Accuracy = 92%
6. DATA TRANSMISSION RATE (IOT COMMUNICATION)
Formula
$Data\ Rate = Data\ Size \div Transmission\ Time$
Example:
Data Size = 500 KB Transmission Time = 2 seconds
$Data\ Rate = 500 \div 2$
Data Rate = 250 KB/s
7. ROBOT EFFICIENCY CALCULATION
$Efficiency = (Output\ Power \div Input\ Power) \times 100$
Example:
Input Power = 20 W Output Power = 15 W
Efficiency = (15 ÷ 20) × 100
Efficiency = 75%

PCB Designing

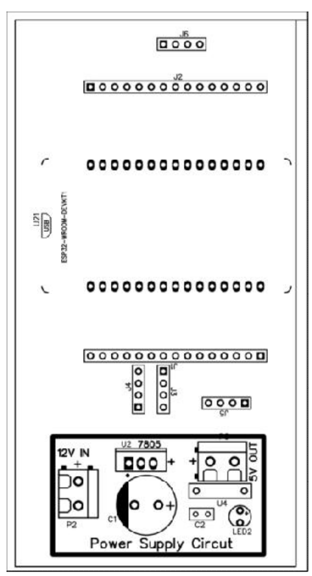

Fig 16: PCB layout

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Pseudocode

Start
Initialize WiFi with SSID and
Password Initialize motor control pins
Initialize sensor pins (Gas sensor and Metal sensor)
Initialize GPS module using UART communication
Start Web Server on port 80
WHILE system is running
Read GPS data
IF GPS data available THEN
Update latitude and longitude ENDIF
Read Gas Sensor value
Read Metal Sensor value IF Gas detected
THEN
Display Danger status on web interface
ELSE
Display Safe status ENDIF
IF Metal detected THEN
Show Metal detection alert
ENDIF
Wait for user command from web server IF command = Forward THEN
Move robot forward
ELSE IF command = Backward THEN Move robot backward
ELSE IF command = Left THEN Turn robot left
ELSE IF command = Right THEN Turn robot right
ELSE IF command = Up THEN Move robotic arm up
ELSE IF command = Down THEN
Move robotic arm down
ELSE IF command = Grip Open THEN Open gripper
ELSE IF command = Grip Close THEN Close gripper
ELSE IF command = Stop THEN Stop all motors
ENDIF
END WHILE END

VII. RESULTS

The IoT-based Security Robot was successfully designed, implemented, and evaluated through a series of practical experiments conducted under controlled conditions. The obtained results confirm that the system performs reliably in real-time security and surveillance applications. All integrated hardware and software components worked cohesively, achieving the intended objectives of remote monitoring, threat detection, and safe operation in hazardous environments.

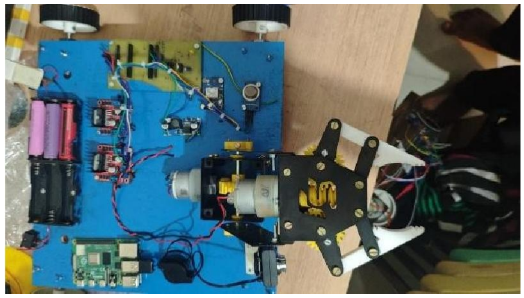

Fig 17: Hardware Integration Layout

During experimentation, the robot demonstrated stable and smooth movement across different surfaces. The motor control system responded accurately to remote commands, allowing precise navigation and positioning. The structural design of the robot ensured mechanical stability, enabling continuous operation without performance degradation. This confirms the effectiveness of the selected chassis, motors, and motor driver circuitry.

The surveillance functionality of the system showed promising results. The ESP32-CAM module successfully captured and transmitted live video streams to the monitoring interface with minimal latency. The video feed remained clear and consistent within the operational wireless range, providing real-time visual awareness of the surrounding environment. This capability significantly enhances situational assessment and supports effective decision- making during security operations.

The Hardware Integration Layout represents how all the physical components of a system are connected and arranged to work together efficiently different components and ensures proper system operation.

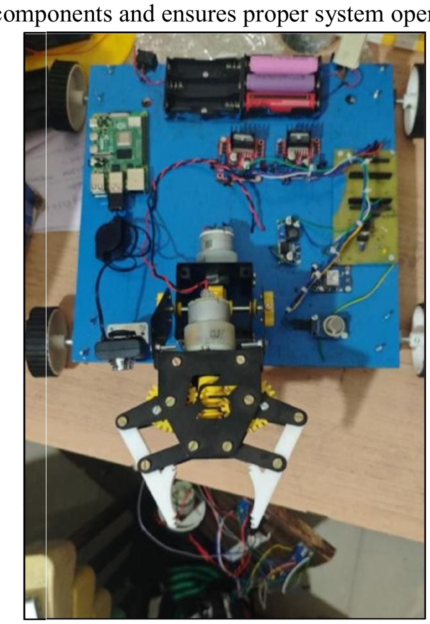

Fig 18: Complete Experimental Setup

Sensor-based detection results indicate high responsiveness and accuracy. The metal detector sensor reliably identified metallic objects and potential landmines, immediately triggering alert mechanisms and stopping robot movement to avoid danger. Similarly, the gas and smoke detection sensor effectively sensed the presence of hazardous gases and smoke, generating timely warnings. These sensor responses enable early threat identification and contribute to improved safety.

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VIII. CONCLUSION

The Smart Military Robot for Surveillance and Explosive Handling represents a significant step forward in modern defense technology by combining intelligent mobility, advanced sensing, and wireless communication into a single integrated system. By utilizing components such as the ESP32 microcontroller, ESP32-CAM, GPS module, gas and smoke sensors, and metal detection unit, the robot effectively performs real-time surveillance, hazardous gas detection, and explosive identification while ensuring the safety of military Flowchart

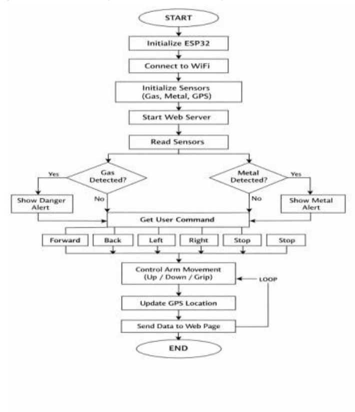

Fig 19: Flowchart

personnel. The ability to stream live video, track location accurately, and operate remotely or autonomously provides enhanced situational awareness and supports informed decision-making in high-risk environments. Beyond military applications, the system also demonstrates strong potential in disaster management and hazardous industrial operations. Its modular and scalable design enables future enhancements, including robotic manipulators for bomb handling, obstacle avoidance mechanisms, and cloud-based coordination for multi-robot missions. With further optimization of hardware, software, and control strategies, the proposed system can evolve into a reliable, adaptable, and intelligent robotic asset that significantly reduces human exposure to danger while strengthening national security and technological innovation.

IX. FUTURE SCOPE

The proposed smart military robot offers significant opportunities for future enhancement through the integration of advanced technologies. Artificial intelligence–based object recognition can be incorporated to automatically identify humans, weapons, and explosive materials in real time, further reducing the need for human supervision. The addition of thermal imaging and night vision cameras would greatly improve surveillance capabilities in low-light, nighttime, or foggy conditions. Long-range and low-latency communication can be achieved by adopting 5G or LoRa technologies, enabling reliable operation in remote or border areas. A robotic arm equipped with high-precision actuators can be introduced to safely pick up, handle, or neutralize explosive devices, enhancing operational safety. Autonomous navigation can be improved using LiDAR or ultrasonic sensors, allowing the robot to move intelligently without continuous manual control. Furthermore, the incorporation of solar panels or advanced power management systems can extend battery life and support long-duration missions. These enhancements will transform the robot into a more intelligent, autonomous, and resilient platform suitable for complex defense and security operations.

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