iJRASET
International Journal For Research in
Applied Science and Engineering Technology


# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

**Volume:** 13 **Issue:** IX **Month of publication:** September 2025

**DOI:** https://doi.org/10.22214/ijraset.2025.74233

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IX Sep 2025- Available at www.ijraset.com

# SindoorBot: A Tactical Multi-Sensor UGV for Combat Zone Surveillance and Hazard Mitigation

Aishwarya V[1], Mohan Gowda M[2], Pavana R[3]
*Electronics and Communication Engineering, East West College of Engineering, Bengaluru, India*

***Abstract: This work presents the design and deployment of SindoorBot, an unmanned ground vehicle (UGV) tailored for combat support, real-time hazard detection, and tactical surveillance. The platform integrates an ESP32-based microcontroller network utilizing the ESP-NOW protocol to facilitate low-latency wireless communication, independent of internet infrastructure. The system features a four-wheel-drive chassis, equipped with fire and gas detection sensors, temperature monitoring, live video feed via ESP32-CAM, and a laser diode for simulated engagement. A custom-developed Android application, interfaced through Firebase Realtime Database, enables remote monitoring and control, providing situational awareness and reactive capabilities in real-time. The modular and field-adaptable architecture of SindoorBot renders it suitable for operations in harsh, communication-constrained, and high-risk environments.***
***Keywords: ESP32, ESP-NOW, Unmanned Ground Vehicle (UGV), real-time hazard detection, tactical surveillance, flame detection, Firebase, embedded systems, remote engagement, IoT robotics***

## I. INTRODUCTION

Modern military and border operations demand compact, reliable, and remotely operable systems. SindoorBot addresses this through a four-wheel drive robotic platform integrating hazard detection, live video surveillance, and remote weapon simulation. The system operates without internet dependency, employing ESP-NOW for joystick-controlled mobility and uses Firebase for real-time alerts and command reception via a mobile app.

### *A. Problem Statement*

1) High cost and inaccessibility of tactical robots.
2) Dependency on Wi-Fi or cellular networks for control.
3) Lack of integrated hazard detection and engagement capabilities.
4) Delays in real-time threat notification.
5) Absence of remote combat simulation in low-cost platforms.
6) Power limitations in field operations.
7) Complexity in control interfaces.

### *B. Proposed Solution*

SindoorBot proposes a modular, low-cost, field-deployable UGV controlled via ESP-NOW with the following features:

1) Remote joystick-based mobility control.
2) Fire, smoke, and gas detection using flame sensor, MQ-series, and DHT11.
3) Real-time alerts and live video via ESP32-CAM and Firebase-integrated Android app.
4) Simulated laser-based weapon system for remote engagement.
5) Powered by rechargeable battery packs with external supply support.

### *C. Key Contributions*

The key contributions of this work are as follows:

1) Peer-to-peer ESP-NOW-based wireless movement control.
2) Real-time environmental hazard alerts with physical and app-based feedback.
3) ESP32-CAM for live streaming to mobile devices.
4) Simulated engagement mechanism via laser diode.
5) Modular hardware and intuitive joystick-mobile interface.

## II. RELATED WORK

### A. *Existing Fire Detection Systems*

Conventional fire detection systems are primarily engineered for controlled, stationary environments such as residential complexes, commercial buildings, and industrial facilities. These systems typically employ fixed-position smoke detectors, heat sensors, or sprinkler mechanisms, which are not suitable for deployment in dynamic and infrastructure-less environments such as battlefields or remote terrains. Due to their stationary nature, they lack the adaptability to track mobile hazards or respond in real time to evolving threats. Moreover, they do not provide integrated data communication capabilities for remote alerting or visual verification. Their limited coverage, infrastructure dependency, and absence of autonomous feedback mechanisms make them inadequate for tactical or field-based hazard mitigation applications.

### B. *Hazard Monitoring Technologies*

Modern hazard monitoring systems utilize a range of sensors, including gas detectors, temperature monitors, and humidity sensors, to provide localized environmental data. While useful in industrial and laboratory settings, such systems are often isolated, lacking integration with mobile platforms or real-time communication infrastructure. Additionally, they depend on continuous internet or network availability, which is often unavailable in field or combat scenarios. The absence of multi-sensor fusion and live alerting mechanisms further restricts their effectiveness in fast-changing operational conditions. These limitations are particularly evident in applications where autonomous mobility, peer-to-peer communication, and real-time hazard response are critical.

### C. *Robotics in Hazardous Environments*

Robotics has increasingly been adopted for use in dangerous environments, notably in explosive ordnance disposal (EOD), search and rescue (SAR), and hazardous site inspection. Many existing systems are either manually controlled via long-range radio or semi-autonomous with pre-defined tasks. However, such systems tend to focus on specific missions—bomb disposal, surveillance, or mapping—and rarely integrate multi-modal hazard detection or simulated engagement capabilities. Furthermore, a large number of these platforms are reliant on external communication infrastructure such as Wi-Fi routers or satellite uplinks, making them impractical in disconnected or signal-compromised environments. Their operational complexity and high cost also restrict accessibility for low-cost defense and academic research use cases.

### D. *Novelty*

SindoorBot addresses the limitations of the above technologies by offering a low-cost, modular, and fully wireless tactical robotic platform. Unlike conventional systems, SindoorBot integrates real-time fire, smoke, and gas detection using a combination of flame sensors, MQ-series gas detectors, and a DHT11 temperature/humidity sensor, all managed by a dedicated ESP32 microcontroller. The system employs the ESP-NOW protocol—a low-latency, infrastructure-independent wireless communication protocol—for peer-to-peer control between a joystick-equipped transmitter and the robot's receiver. Live video streaming via an ESP32-CAM module and Firebase-integrated alerts enable remote situational awareness through a mobile application. Additionally, a laser diode mounted on the robot simulates directed-energy weapon engagement, providing tactical response training without operational risk. The integration of surveillance, hazard detection, remote control, and engagement in a single compact platform—without requiring Wi-Fi or cellular networks—establishes SindoorBot as a novel and field-adaptable solution for real-time combat support, reconnaissance, and remote hazard mitigation.

## III. SYSTEM ARCHITECTURE

The overall architecture comprises four core subsystems:

1) Mobility Subsystem: A 4WD robotic platform driven by four geared DC motors and an L298D dual H-bridge motor driver.
2) Sensing Subsystem: Onboard sensors including a flame detector, MQ-series smoke sensor, and DHT11 for temperature/humidity monitoring.
3) Surveillance and Engagement Subsystem: A front-mounted ESP32-CAM for real-time video and a laser diode simulating directed-energy engagement.
4) Communication and Control Subsystem: ESP32 microcontrollers communicating via ESP-NOW protocol and a Firebase-connected Android interface for remote operations.
5) Each subsystem is governed by one or more ESP32 microcontrollers to ensure distributed task execution and robustness distributed task execution and robustness.

## IV. METHODOLOGY

### *A. Motion Control and Locomotion:*

1) The UGV utilizes a four-wheel-drive chassis to maximize maneuverability on uneven terrain.
2) L298D motor driver regulates motor direction and speed.
3) Transmitter Module: An ESP32 interfaced with a two-axis joystick module converts analog input into motion commands.
4) Receiver Module: A separate ESP32 onboard the robot receives directional commands using ESP-NOW and translates them into motor control logic.

This distributed control scheme allows decoupling of navigation from sensor processing and video handling.

### *B. Environmental Hazard Detection*

1) Flame Sensor: Detects infrared radiation from open flames within a 100 cm range.
2) MQ-series Gas Sensor (e.g., MQ-2 or
3) MQ-135): Detects combustible and toxic gases like CO, methane, and LPG.
4) DHT11 Temperature Sensor: Measures ambient temperature and humidity (0–50°C, 20–80% RH).

On fire or gas detection:

- A buzzer and high-intensity red LED are activated locally.
- A real-time alert is pushed to the mobile application via Firebase Realtime Database.

This configuration provides both physical and remote alerts for immediate response.

### *C. Real-Time Video Surveillance*

1) The robot is equipped with an ESP32-CAM module integrating an OV2640 camera.
2) Video is streamed via station mode Wi-Fi, accessible through browsers or embedded in the mobile application.
3) Frame rate: ~15–25 FPS, depending on resolution and network conditions.
4) Field of view: ~75°, sufficient for tactical observation.

This module operates independently of control functions to preserve system modularity.

### *D. Simulated Engagement Module*

1) A low-power red laser diode is mounted to simulate a directed-energy weapon.
2) Controlled via a transistor-based switching circuit and GPIO from the sensor ESP32.
3) Activation is triggered from the mobile app, enabling remote engagement in simulated scenarios.
4) Inspired by the DRDO Mk-II(A) high-energy laser system, this module supports tactical training without risk.

### *E. Mobile Application and Data Management*

Developed using MIT App Inventor, the Android application supports:

1) Real-time fire/smoke/gas notifications
2) Remote laser activation
3) Live video access

Firebase Realtime Database acts as the cloud communication layer, enabling bidirectional data flow between robot and app. This architecture offers asynchronous event-based updates for enhanced responsiveness.

### *F. Wireless Communication*

1) ESP-NOW protocol:
2) Low-latency, peer-to-peer data exchange.
3) Operates offline up to ~300 meters (unobstructed).
4) Supports encrypted communication.
5) Firebase for real-time app data updates and alert management.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue IX Sep 2025- Available at www.ijraset.com

*G. Power Management*

1) Powered by a 2S/3S Li-ion or LiPo battery pack (7.4V/11.1V), supporting:
   - Motors
   - ESP32 units
   - Peripherals including laser and LED
2) Voltage regulators (e.g., LM7805) ensure stable 5V supply across subsystems.
3) Optional external power jack allows field recharging or bypass.

Battery life varies with activity but is optimized for ~1–2 hours under normal operation.

*H. Communication Protocol: ESP-NOW*

1) Protocol Type: Peer-to-peer, connectionless communication by Espressif.
2) Range: Up to 300m (open space), 500–700m with external antennas.
3) Latency: Sub-millisecond command propagation.
4) Security: Supports encryption, peer-to-peer key authentication.
5) Throughput: ~2 Mbps, 250-byte packet payload.

ESP-NOW enables multi-node communication without router infrastructure—ideal for disconnected tactical zones.

## V. HARDWARE COMPONENTS

| Component | Function Description |
|---|---|
| ESP32 (x3 units) | Transmitter (joystick), Receiver (motors), Sensor controller |
| ESP32-CAM | Video surveillance with OV2640 sensor |
| Joystick Module | 2-axis analog input for directional control |
| L298D Driver | Controls motor direction and power |
| DC Motors (x4) | High torque, geared motors for 4WD mobility |
| MQ Sensor | Gas/smoke detection |
| DHT11 Sensor | Temperature and humidity monitoring |
| Flame Sensor | IR-based fire detection |
| Laser Diode | Low-power simulated weapon module |
| Buzzer & Red LED | Local fire/gas alerts |
| Battery Pack | 7.4V or 11.1V Li-ion/LiPo |
| Voltage Regulators | Safe voltage distribution |
| Safe voltage distribution | Mechanical stability and prototyping |

## VI. SOFTWARE STACK

| Layer | Technology |
|---|---|
| Programming | Arduino IDE CAM) |
| Mobile App | MIT App Inventor |
| Backend | Firebase Realtime Database |
| Communication | ESP-NOW protocol |
| Video Streaming | MJPEG via ESP32-CAM HTTP server |

## VII. SYSTEM ADVANTAGES

1) Low Cost: Built with open-source, inexpensive modules.
2) Offline Control: Independent of internet access.
3) Real-Time Alerts: Instant data push to app using Firebase.
4) Surveillance: On-demand live visual feedback.
5) Scalability: Modular design for multi-node or swarm use.
6) Training-Safe Engagement: Laser diode provides simulation without harm.
7) User-Friendly Interface: Joystick and Android app simplify operation.

## VIII. LIMITATIONS

1) Limited Communication Range: ESP-NOW range diminishes indoors or around metal.
2) Sensor Precision: Basic sensors like MQ and DHT11 may have tolerances unsuitable for critical thresholds.
3) Battery Dependency: Extended missions require backup or solar charging.
4) Single-Camera Feed: No multi-angle or night-vision support.

## IX. APPLICATION DOMAINS

1) Military Reconnaissance: Real-time surveillance of enemy zones.
2) Border Monitoring: Patrolling and threat detection without risk to soldiers.
3) Fire/Smoke Detection: Early alerts in bunkers, tunnels, or storage units.
4) Search and Rescue: Safe navigation through debris and hazards.
5) Industrial Monitoring: Detect gas leaks or fires in hazardous facilities.
6) Academic Research: Platform for IoT, robotics, and sensor network experiments.
7) Combat Simulation: Non-lethal training tool for defense academies.

## X. FUTURE SCOPE

1) Sensor Upgrade: Integration of GPS, LiDAR, and thermal cameras.
2) AI Integration: ML-based autonomous path planning and decision-making.
3) Swarm Robotics: Multi-UGV coordination for wide-area operations.
4) Power Optimization: Solar-powered extension and advanced power management.
5) Weatherproofing: Enhancing durability for outdoor deployment.

## XI. CONCLUSION

SindoorBot exemplifies a low-cost, modular tactical robot offering real-time surveillance, environmental monitoring, and simulated combat engagement. Its offline-capable architecture using ESP-NOW and app-based control makes it a suitable solution for defense, security, and research applications. Future iterations can incorporate GPS, AI path planning, and extended battery systems for enhanced autonomy.