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Border Surveillance Robot with Dummy Gun Using ESP32 and ESP32-CAM

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Abstract: ***Border security requires continuous observation of restricted areas and timely reporting of possible intrusions. This project proposes a small mobile surveillance robot using an ESP32-based controller and an ESP32-CAM module. The camera captures images or video of the area, while the controller manages movement, communication, and status reporting. A remote operator can view the camera feed, control the robot, and receive an alert when a person or movement is detected, depending on the implemented detection method. A non-functional dummy gun-shaped prop is included only as a visual model of a defence robot; it has no firing, launching, or harmful mechanism. The project is intended as an educational prototype for remote monitoring and human-supervised response. Performance depends on lighting, Wi-Fi coverage, battery capacity, camera placement, and the selected detection software. The system should be tested in a controlled environment and must not be treated as a certified security or autonomous defence system.***

Keywords: Border Surveillance, Mobile Robot, ESP32, ESP32-CAM, Human Detection, Wireless Monitoring, IoT, Remote Dashboard, Dummy Gun Prop, Human-in-the-Loop Control.

I. INTRODUCTION

Borders and restricted zones need regular monitoring to identify unusual movement and help security personnel respond quickly. Manual patrols can be time-consuming and may not provide continuous visual coverage of every location. A compact remotely operated robot can provide a camera view from areas that are difficult or inconvenient for a person to inspect. The proposed Border Surveillance Defence Robot uses an ESP32 controller for basic robot control and wireless communication, together with an ESP32-CAM for image capture and live viewing. The robot can be moved using a motor driver and DC motors. A web dashboard or mobile interface can display camera output, robot status, and alerts. Person detection may be implemented on a suitable external computer or server if the selected ESP32-CAM firmware cannot run the required model efficiently. The dummy gun is a non-functional prop for project demonstration only. It is not connected to a firing circuit and cannot shoot. Any real-world security action must remain under trained human supervision and follow applicable law and safety procedures.

The core objectives are:

1) To design a mobile robot prototype for remote visual monitoring of a restricted area.
2) To use ESP32 for robot movement control and wireless communication.
3) To use ESP32-CAM to capture images and provide a camera view to an operator.
4) To provide a dashboard for manual movement commands, camera viewing, and status messages.
5) To generate an alert when a configured motion/person-detection event is reported.
6) To demonstrate a non-functional dummy gun-shaped prop without any firing or harmful mechanism.
7) To evaluate basic performance such as response time, camera visibility, communication range, and battery operation.

II. LITERATURE SURVEY

The following survey uses verifiable foundational work and technical documentation relevant to embedded vision, object detection, and the ESP32-CAM platform. These sources support the building blocks of the proposed prototype; they do not claim that the exact proposed robot has already been validated.

Various researchers have contributed to the development of surveillance robots and embedded vision systems. Mandal et al. (2025) developed an IoT-based surveillance robot using ESP32-CAM modules for real-time video streaming and remote control through a mobile application [1]. Barad et al. (2024) reviewed an ESP32-CAM-based surveillance car with pan, tilt, and zoom capabilities for remote monitoring [2]. Redmon et al. (2016) proposed the YOLO object-detection method, which identifies and locates objects in images using a single neural network [3]. Kumar et al. (2026) presented an ESP32-CAM-based robot for monitoring restricted and hazardous areas using wireless video streaming and remote movement control [4].

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Rajaiah et al. (2026) developed an IoT-based ESP32-CAM surveillance robot for wireless real-time video monitoring and navigation [5]. These studies provide a foundation for developing a mobile surveillance robot with camera monitoring, remote control, and event alerts.

III. METHODOLOGY

A. *Overview*

The system is divided into a mobile robot unit, camera unit, wireless communication link, and operator dashboard. The operator sends movement commands through a local Wi-Fi network. The controller interprets the commands and drives the motors through a motor-driver board. The ESP32-CAM captures images or video and makes the camera view available to the operator. If detection software is included, it analyses frames and sends an alert when the configured condition is met.

B. *System Design Steps*

Step 1: Requirement Analysis

- Decide the prototype's operating area, required camera view, expected run time, and control distance.
- Select a suitable chassis, ESP32 board, ESP32-CAM, motor driver, motors, battery, and dashboard method.
- Define safe stop behaviour when the Wi-Fi link is lost or a command is not received.

Step 2: Hardware Design

- ESP32 controller: receives operator commands and controls motor-driver inputs.
- ESP32-CAM: captures images/video and provides the camera stream over Wi-Fi.
- Motor driver: supplies the current required by the DC motors; motors must not be driven directly from ESP32 GPIO pins.
- DC gear motors and chassis: provide movement of the prototype.
- Battery and regulated power supply: power the controller, camera, and motor system using suitable voltage/current ratings.
- Dummy gun-shaped prop: fixed, lightweight, and entirely non-functional; it has no actuator or firing mechanism.
- Optional status LED/buzzer: indicates connection, alert, or low-battery status.

Step 3: Software Development

- Program the ESP32 using Arduino IDE and the ESP32 board support package.
- Configure ESP32-CAM image capture and camera streaming at a resolution suitable for the available network and memory.
- Create a dashboard with forward, reverse, left, right, and stop commands, plus a camera-view panel and status/alert area.
- Use a detection method only if supported by the processing hardware. An external computer/server may analyse the camera stream and report possible person detection.
- Add a communication timeout so the robot stops when valid control commands are no longer received.

Step 4: Integration

- Mount the camera securely and check that its view covers the intended demonstration area.
- Connect the motor driver, motors, controller, and power system according to each module's electrical requirements.
- Connect the dashboard, video stream, and alert messages over the selected network.
- Keep motor power and logic power appropriately regulated and share ground where required by the circuit design

Step 5: Testing and Validation

- Test each motor direction and verify the stop command before testing remote operation.
- Check camera image quality at different distances and lighting conditions.
- Measure command response and video delay at different distances from the Wi-Fi access point.
- Test network-loss behaviour, battery run time, and restart/recovery behaviour.
- If person detection is implemented, record true detections and false alarms across several controlled trials. Do not claim accuracy values until they have been measured.

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Step 6: Deployment and Evaluation

As a student prototype, the robot should be demonstrated in a controlled, permission-based area. Record test conditions and observed results. Do not use the device to impersonate official equipment, monitor people without permission, or make real security decisions without authorised supervision.

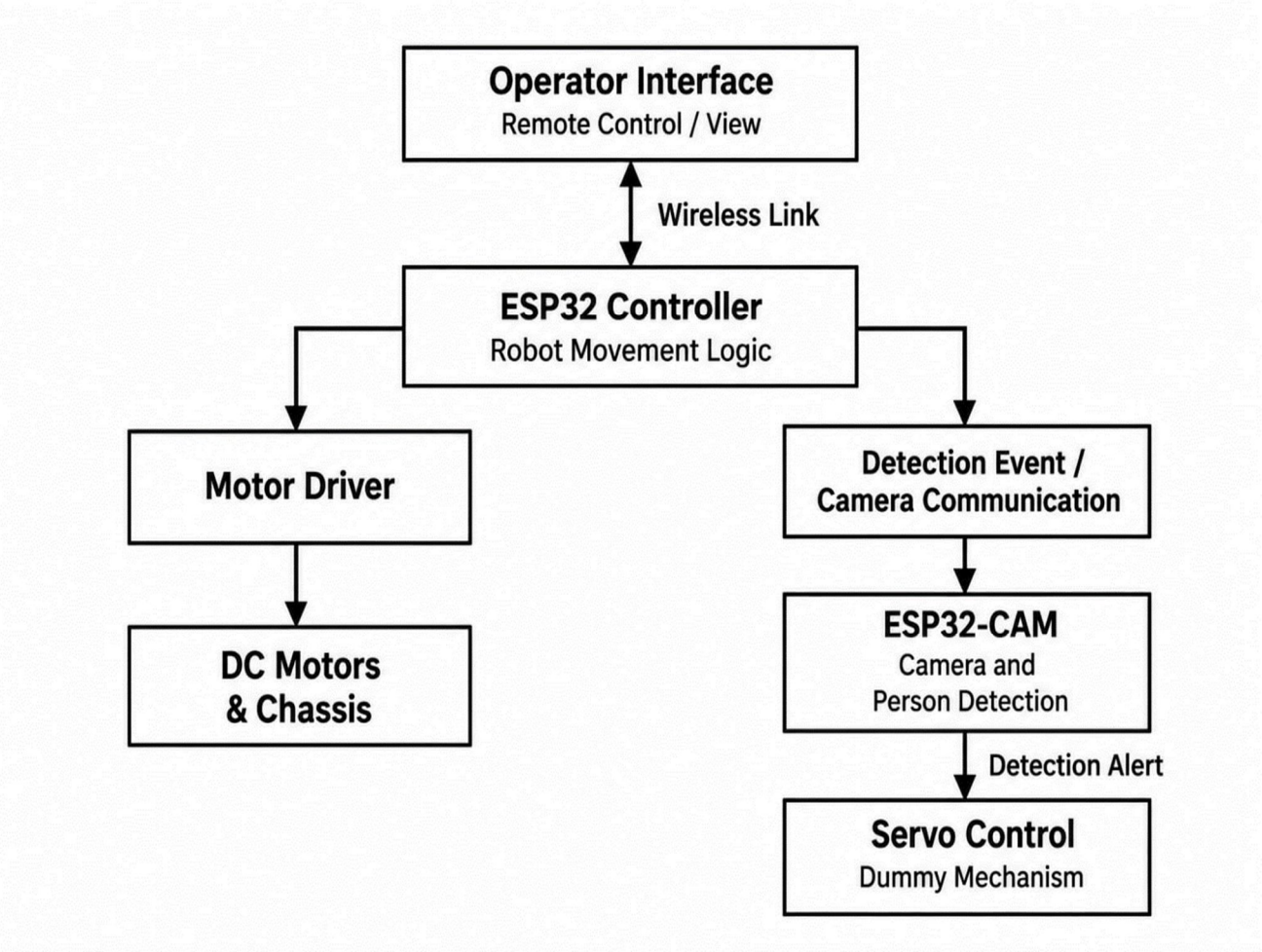
C. Expected Output

- A mobile prototype that can be controlled remotely over Wi-Fi.
- A camera view from the ESP32-CAM on a dashboard or browser.
- A status indication for connection and movement commands.
- Optional person/motion alerts, depending on the implemented detection software.
- A visible but non-functional dummy prop for demonstration only.

D. Advantages of the Methodology

- Uses relatively accessible embedded hardware for an educational prototype.
- Allows an operator to inspect an area remotely using a camera.
- Combines mobility, camera monitoring, and basic alerts in one platform.
- Can be expanded with improved networking, lighting, sensors, and external vision processing.
- Supports human-supervised observation rather than autonomous harmful action.

IV. BLOCK DIAGRAM, COMPONENTS & THEIR USE



Component	Function
ESP32 development board	Main control and Wi-Fi communication; reads dashboard commands and controls motor-driver inputs.
ESP32-CAM	Main control and Wi-Fi communication; reads dashboard commands and controls motor-driver inputs.
OV2640 camera	Image sensor commonly fitted to ESP32-CAM boards.
GPS Module	Retrieves the real-time geographic location (latitude & longitude) of the user.
Motor driver module	Drives DC motors from a separate motor supply based on low-power control signals.
DC gear motors and chassis	Move the robot forward, backward, and turn.
Battery and regulator	Provides suitable power to logic, camera, and motors.
Wi-Fi router/access point	Carries commands, video and alerts.
Laptop/mobile dashboard	Shows camera view and sends operator commands.
Dummy gun-shaped prop	Visual demonstration component only.
Optional LED/buzzer	Shows system state or alerts.

V. HARDWARE AND SOFTWARE REQUIREMENT

A. Hardware Implementation

1) ESP32 development board

- ESP32-CAM module with camera
- Robot chassis and two or four DC gear motors
- Compatible motor-driver module
- Battery pack and voltage regulator(s)
- Jumper wires, connectors, mounting hardware, and switch
- Wi-Fi router or access point
- Laptop/mobile phone for the dashboard
- Non-functional dummy gun-shaped prop (optional; visual use only)
- Optional LED/buzzer and external computer for vision processing

B. Software Implementation

- Arduino IDE and ESP32 board support package
- ESP32 camera example/library compatible with the selected board
- Embedded C/C++
- Web dashboard or mobile interface for remote control
- Browser or local server for camera viewing, depending on implementation
- Optional Python and a computer-vision framework on an external computer/server for person detection
- Wi-Fi network and basic testing/logging tools

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VI. ALGORITHM

Start the system.
Initialize ESP32 pins, Wi-Fi, motor-driver outputs, and status indicators.
Initialize ESP32-CAM and start the camera service.
Wait for a valid command from the operator dashboard.
Check the command and drive the motors only for recognised movement commands.
If the stop command is received, stop all motors.
If the command link times out, stop all motors and show a connection warning.
Capture and transmit camera images/video to the operator.
If an optional detection service reports a possible person/motion event, send an alert for human review.
Continue monitoring until the operator ends the session; then stop motors and close the system safely

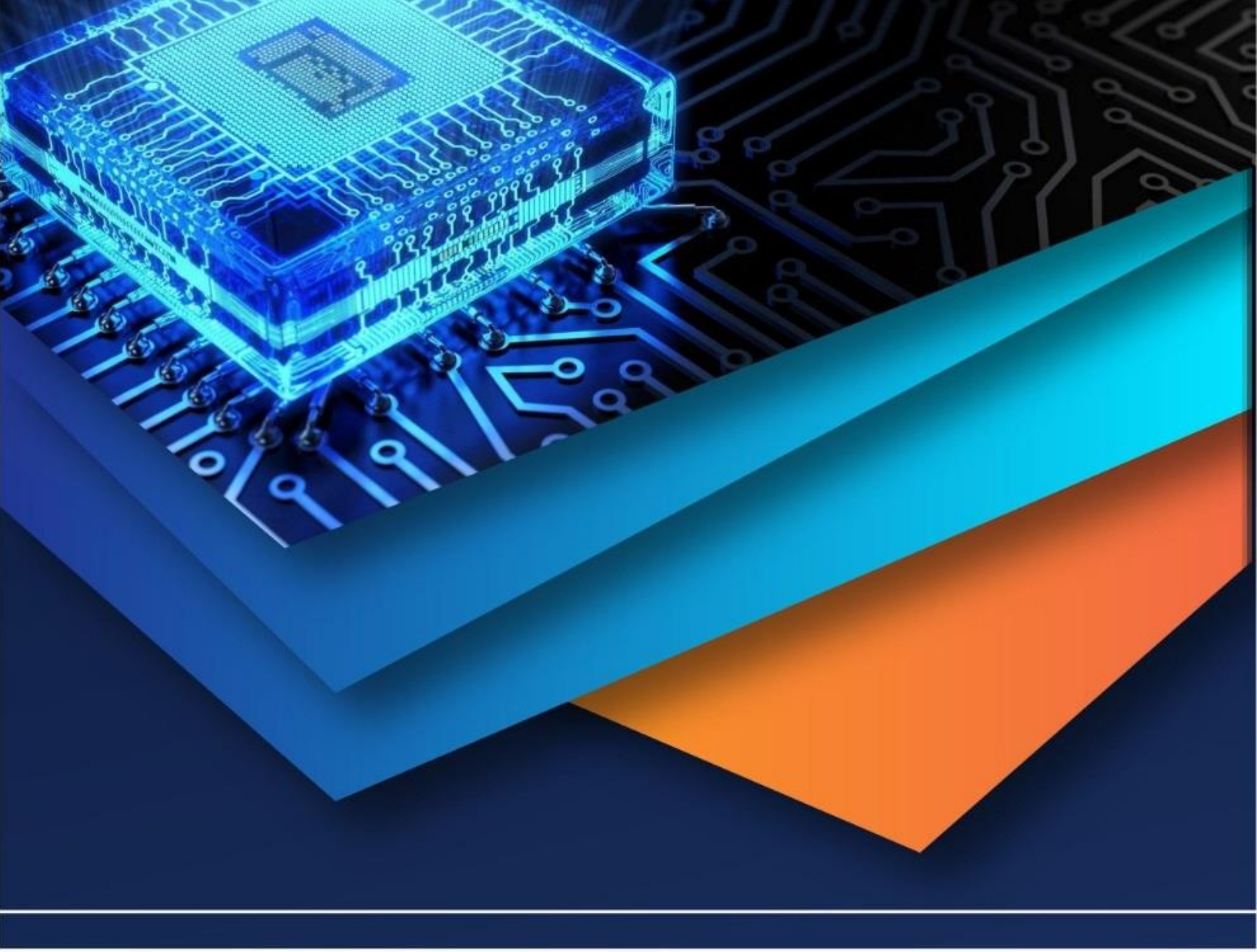
VII. CONCLUSION

The Border Surveillance Defence Robot with Dummy Gun Using ESP32 and ESP32-CAM is an educational prototype for mobile visual monitoring. ESP32 provides basic control and wireless communication, while ESP32-CAM supplies camera images or video for remote observation. A dashboard can allow an operator to control movement, view the area, and receive alerts. The project also demonstrates the integration of embedded hardware, motor control, networking, and camera systems. Its performance must be established through practical testing, and limitations such as Wi-Fi range, low-light image quality, processing capacity, and false alarms must be documented. The dummy gun is strictly non-functional, and the robot is intended for human-supervised observation only.

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