

IOT-ENABLED REMOTE VIDEO SURVEILLANCE ROBOT USING NODEMCU

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ABSTRACT

Surveillance systems often face limitations such as restricted mobility, lack of dynamic coverage, and ineffective real-time monitoring in remote areas. Addressing these drawbacks, the Wireless Video Surveillance Robot introduces a mobile solution equipped with ESP32 CAM for live video streaming, ultrasonic sensors for obstacle detection, and motorized mobility driven by Node MCU and DC motors. Powered by a 12V battery, this robot enhances surveillance by offering autonomous navigation, remote control, and real-time video feedback. The compact design ensures ease of deployment in challenging and confined spaces. This system provides an efficient, portable, and adaptable solution to meet diverse surveillance needs.

Keywords: Wireless surveillance, video streaming, ESP32 CAM, mobile robot, obstacle detection, autonomous navigation, real-time monitoring.

I. INTRODUCTION

In the modern era, security and surveillance have become critical components in ensuring the safety of people, property, and critical infrastructure. Traditional surveillance systems, although widely used, often suffer from significant limitations such as fixed camera positions, limited monitoring range, and heavy dependence on continuous human supervision. These limitations reduce flexibility, particularly in remote, hazardous, or confined environments where installing static cameras is impractical or unsafe [1], [10]. Additionally, conventional surveillance systems often experience delayed real-time responsiveness due to constraints in wireless communication, data transmission, and manual monitoring processes [3].

To overcome these challenges, the integration of wireless communication, robotics, and Internet of Things (IoT) technologies has led to the emergence of intelligent and mobile surveillance solutions [1], [2]. IoT-based surveillance systems enable real-time data acquisition, remote accessibility, and intelligent decision-making while enhancing system scalability and security [2], [3]. The Wireless Video Surveillance Robot using Node MCU represents a practical implementation of these advancements by

combining robotic mobility with real-time video monitoring capabilities. Similar approaches using IoT-enabled robots for indoor and outdoor security have demonstrated improved situational awareness and reduced human intervention [5], [10].

The proposed system is designed to operate either autonomously or through remote control while streaming live video using an ESP32-CAM module, enabling continuous remote surveillance [9]. The robotic platform is equipped with ultrasonic sensors for obstacle detection and avoidance, allowing safe navigation in dynamic environments, as supported by prior research on mobile robot navigation systems [7]. Object detection techniques such as YOLO further enhance surveillance intelligence by enabling real-time identification of objects and potential threats [8].

At the core of the system, the Node MCU acts as the central processing unit, providing Wi-Fi connectivity for robot control and data transmission over the internet [2]. The ESP32-CAM module captures and transmits live video feeds to a remote user or server, facilitating real-time monitoring from virtually any location [9]. Ultrasonic sensors improve operational safety by preventing collisions during navigation [7]. The system is powered by a

12V battery, ensuring portability and uninterrupted operation in locations without direct power supply. The applications of this wireless surveillance robot extend across multiple domains, including military surveillance, disaster response operations, industrial safety monitoring, agricultural field inspection, and home security [5], [10]. Its mobility, rapid deployment capability, and real-time feedback mechanisms significantly enhance surveillance efficiency when compared to traditional fixed-camera systems.

Overall, this project aims not only to develop a reliable mobile video surveillance platform but also to demonstrate the transformative potential of IoT-based robotics in modern security infrastructures. With the growing demand for intelligent, adaptive, and scalable surveillance systems, the proposed solution presents a practical and future-ready approach to addressing contemporary security challenges [1], [3].

II. LITERATURE SURVEY

Several existing studies have demonstrated the effectiveness of IoT-based video surveillance systems that combine wireless communication, embedded controllers, and real-time monitoring. Prior research highlights that low-cost camera modules integrated with Wi-Fi-enabled microcontrollers can successfully stream real-time video for remote surveillance applications [9], [10]. Such systems are particularly suitable for small-scale security deployments due to their affordability, low power consumption, and ease of deployment [1]. The concept of integrating robotic mobility with surveillance has been widely explored in IoT-enabled security systems. Mobile surveillance robots controlled through wireless interfaces provide enhanced monitoring capabilities in locations that are inaccessible, hazardous, or unsafe for human presence [5], [10]. Studies emphasize that the inclusion of ultrasonic sensors enables effective obstacle detection and avoidance, allowing robots to

navigate safely in dynamic environments [7]. This improves operational reliability compared to static surveillance setups. Wireless communication technologies play a critical role in enabling real-time data transmission and remote accessibility in modern surveillance systems. Research on IoT architectures confirms that microcontrollers such as Node MCU and ESP-based platforms offer reliable connectivity, scalability, and compatibility with cloud-based monitoring services [2], [3]. These features support continuous video streaming and remote control through web or mobile interfaces, making IoT surveillance systems highly flexible. Real-time video processing and intelligent monitoring further enhance surveillance efficiency. Vision-based approaches, including real-time object detection frameworks, enable automated threat identification and situational awareness [8]. When combined with mobile robotic platforms, such techniques significantly reduce human dependency while improving response time and monitoring accuracy.

Comprehensive surveys on IoT-based smart surveillance systems indicate that the convergence of sensors, actuators, wireless communication, and embedded processing has transformed traditional monitoring infrastructures [3], [6]. Comparative analyses of hardware platforms highlight the suitability of Node MCU and ESP modules for surveillance applications due to their cost-effectiveness, compact design, and strong community support [2], [9].

Overall, existing literature [1]–[10] clearly supports the feasibility and effectiveness of IoT-enabled mobile surveillance robots. These studies validate the proposed Wireless Video Surveillance Robot as a scalable, intelligent, and practical solution that addresses the

limitations of conventional fixed-camera surveillance systems while meeting modern security requirements.

III. EXISTING SYSTEM

Traditional video surveillance systems predominantly rely on static CCTV cameras installed at fixed locations, which results in limited spatial coverage and reduced adaptability to dynamic surveillance requirements [1], [10]. Since these cameras remain stationary, they are unable to adjust their field of view or respond to changing security conditions in real time. Monitoring typically depends on centralized control rooms, requiring continuous human supervision, while remote access is often restricted or supported only through costly proprietary platforms [3].

Furthermore, conventional surveillance systems lack mobility, preventing them from investigating blind spots, tracking suspicious movement, or operating in hazardous or inaccessible environments [5]. Although certain Wi-Fi-enabled cameras provide remote viewing capabilities, they remain fixed in position and offer minimal interaction, intelligence, or autonomous control [9]. This significantly limits their effectiveness in complex and unpredictable environments.

Another major limitation of existing surveillance setups is the inadequate integration with Internet of Things (IoT) platforms. Features such as intelligent data logging, real-time alerts, and cloud-based monitoring are either limited or completely absent in traditional systems [2], [6]. As a result, these surveillance solutions function mainly in a reactive manner rather than proactively identifying and responding to potential threats.

Due to these constraints, current surveillance infrastructures are rigid, less scalable, and unsuitable for high-risk or rapidly changing environments [3], [10]. These shortcomings highlight the growing need for a mobile, IoT-enabled robotic surveillance system capable of real-time monitoring, intelligent decision-making, and remote accessibility to address modern security challenges effectively [1], [5].

IV. PROPOSED SYSTEM

The proposed system introduces a mobile IoT-enabled surveillance robot powered by a NodeMCU (ESP8266/ESP32) to overcome the limitations of traditional fixed-camera setups. The robot integrates a wireless camera module to stream live video over Wi-Fi, enabling users to monitor remote locations through a web dashboard or mobile interface from anywhere in real time. Using the NodeMCU as the core controller, the robot supports bidirectional communication, allowing users to control its movement (forward, reverse, left, right) while simultaneously receiving live visual feedback. Additional sensors—such as PIR motion sensors, ultrasonic obstacle detection, or environmental sensors—can enhance autonomous or semi-autonomous surveillance. The system leverages IoT cloud platforms for data logging, alerts, and remote access. This approach provides a cost-effective, flexible, and scalable mobile surveillance solution, capable of navigating blind spots, entering hazardous zones, and offering continuous real-time monitoring with remote control and intelligent sensing.

V. SYSTEM ARCHITECTURE

1. Sensor & Detection Modules (Edge Devices)

The proposed robot integrates essential sensing and video-capture components such as an ESP32-CAM / IP Camera module, ultrasonic sensors for obstacle detection, PIR sensors for motion detection, and optional environmental sensors (temperature, light intensity) mounted directly onto the mobile rover. These edge devices continuously capture the robot's surroundings—streaming real-time video frames, detecting motion, measuring object distance, and sensing environmental changes. A microcontroller (NodeMCU / ESP32) collects these readings and applies basic on-device filtering to reduce camera noise, eliminate false triggers, and stabilize video output. Any abnormal events such as sudden motion, object intrusion, or unexpected obstacles are instantly detected as surveillance alerts. The processed sensor outputs and video stream data packets are forwarded to the IoT gateway or user interface using Wi-Fi communication.

2. Edge Processing & Surveillance Intelligence Module

The NodeMCU/ESP32 performs computation on sensor readings and camera frames using rule-based logic and lightweight video-handling routines. This includes motion detection, obstacle-avoidance checks, and encoding/packetizing live video for efficient Wi-Fi streaming. When suspicious activity or an intrusion pattern is detected by the PIR sensor or video feed, the robot triggers the alert mechanism—sending real-time notifications to the user dashboard. The microcontroller also handles motor-control logic for movement (forward, reverse, left, right) and processes commands received from the remote operator. All sensitive video and control data is encrypted using AES-128/256 before transmission. Only optimized video streams, alert flags, and compact sensor logs are transmitted externally, while raw data is maintained locally to reduce bandwidth usage.

3. Communication Network & IoT Gateway

The mobile robot uses Wi-Fi as its primary communication interface, establishing a direct link or hotspot connection between the NodeMCU/ESP32 and the monitoring dashboard/mobile app. The gateway receives continuous video streams, distance readings, robot health status, and motion-detection alerts. Commands issued by the remote user—directional control, camera toggling, or mode switching—are sent back to the robot over MQTT/HTTP/WebSocket protocols. If the robot enters an area with poor connectivity, it automatically switches to offline safety mode, halting movement and storing logs locally until communication is restored. In extended designs, a GSM/4G/5G module can be added for long-range connectivity, enabling surveillance over the internet from anywhere.

4. Cloud / Remote Monitoring Backend

The cloud platform stores both real-time and historical surveillance data such as video logs, intrusion alerts, robot-path data, and timestamped event triggers. It provides a live dashboard where users can view the robot's camera feed, control its

movement, check system diagnostics, and review past alert logs. Machine learning models (optional) may analyze video segments for motion classification, anomaly detection, or unattended-object detection. Secure user authentication ensures that only authorized operators can access the feed or control the robot. In case of critical security events—such as detected intrusions or blocked paths—the cloud system instantly triggers push notifications, SMS alerts, or email warnings to the registered users.

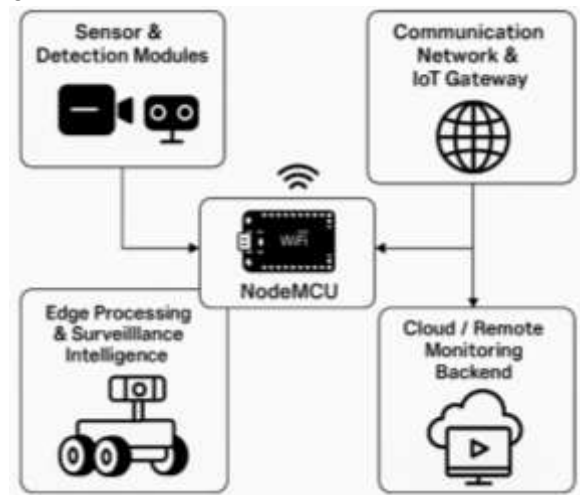


Fig 5.1: Structure of the Proposed System
Microcontroller Module (NodeMCU/ESP32 Core Unit)

The microcontroller functions as the central computing and control hub of the surveillance robot. It handles camera interfacing, sensor data acquisition, motor driver control, video streaming, secure communication, and alert generation. It synchronizes all modules to achieve smooth surveillance and real-time remote operation.

Key Components Include:

1. Sensor Interfaces (I²C / SPI / Analog / Digital Pins)

Used to connect ultrasonic sensors, PIR sensors, IR sensors, motor encoders, and optional temperature/light sensors. These interfaces capture real-time environmental data and structural information required for navigation and surveillance.

2. Wi-Fi Module (Built-in ESP32 / External ESP8266 NodeMCU)

Serves as the primary communication module, transmitting live video streams, alerts, and robot status updates to the IoT gateway or user dashboard. It receives control commands from the user for robot navigation and camera operations.

3. GSM/4G/5G Module (SIM800L / SIM7600 / Quectel – Optional)

Provides long-range connectivity where Wi-Fi is unavailable. Enables remote users to access live video streams and send control commands over mobile networks.

4. Digital GPIO Pins

Used to drive L298N motor driver, relay circuits, camera LEDs, buzzer alarms, and optional safety peripherals. These pins enable autonomous/smart behaviors such as obstacle avoidance and intrusion alert signaling.

5. Power Pins (3.3V / 5V / GND)

Provide regulated power to sensors, camera modules, the motor driver, and NodeMCU hardware. The robot can operate on rechargeable Li-ion batteries with onboard voltage regulation for stable performance.

6. Internal/External Antennas

Ensure stable Wi-Fi/GSM connectivity during robot movement, enabling uninterrupted video streaming and reliable command-response communication even in outdoor or obstructed environments.

VI. IMPLEMENTATION

The complete robot setup—including ESP32 CAM, NodeMCU, ultrasonic sensor, motor driver, and DC motors—was successfully assembled and powered using a 12V battery.

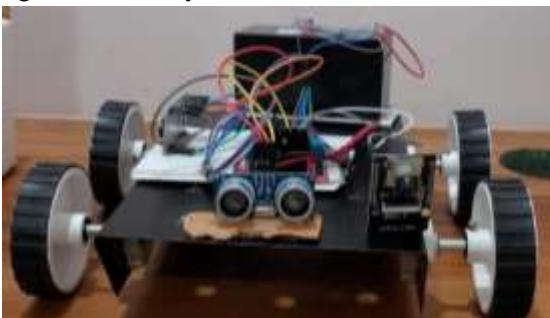


Fig 6.1: Surveillance Rover Prototype with NodeMCU & ESP32-CAM

A smartphone-based web interface or app was used to control the robot's movement wirelessly, allowing

real-time directional inputs.



Fig 6.2: OV2640 Camera Settings Interface (ESP32-CAM Web UI)

The ESP32 CAM provided smooth and stable live video feed to the control device via Wi-Fi, enabling real-time visual monitoring.

VII. CONCLUSION

The development of the Wireless Video Surveillance Robot using Node MCU provides a compact, mobile, and efficient solution to traditional surveillance system limitations. Unlike fixed CCTV cameras that offer limited field of view and require extensive wiring, this robot introduces dynamic and remote monitoring capabilities with real-time video streaming via the ESP32-CAM module. Its integration with ultrasonic sensors enhances autonomy by enabling obstacle detection and avoidance, ensuring the robot can navigate safely in diverse environments. The use of Node MCU as the control unit ensures seamless communication and wireless control through Wi-Fi, making the system user-friendly and adaptable to various use cases such as indoor monitoring, security in remote locations, and surveillance in areas hazardous to human presence. The robot's portability, cost-effectiveness, and real-time feedback make it an ideal solution for smart surveillance, with applications extending to defense, disaster management, and industrial safety. Overall, the project successfully meets the objective of creating a wireless, real-time, IOT-enabled mobile surveillance platform that enhances the scope and efficiency of monitoring activities. With further improvements such as night vision, cloud storage, and voice control, this system holds potential for

even more advanced and intelligent surveillance solutions.

VIII. FUTURE SCOPE

The proposed IoT-enabled surveillance robot has significant potential for expansion into more advanced, intelligent, and autonomous security systems. Future enhancements may include integrating AI-based video analytics such as facial recognition, human detection, intrusion classification, and anomaly detection directly on the edge using lightweight machine-learning models. Upgrading the communication system with 4G/5G modules can enable long-range operation without relying on local Wi-Fi networks. The robot can be equipped with GPS tracking, enabling autonomous patrolling and route planning across large areas such as campuses, industrial sites, and agricultural fields. Additional mechanical improvements like robotic arms, night-vision cameras, and PTZ (Pan–Tilt–Zoom) modules can further enhance surveillance capability.

Battery optimization and solar-charging modules can help support long-duration missions, while swarm connected robots can perform coordinated multi-robot surveillance. Integrating the system with cloud-based predictive analytics and real-time alerting platforms can enable advanced features like threat prediction and automated reporting. These developments position the robot as a scalable, intelligent, and highly adaptable security solution for smart cities, defense applications, disaster monitoring, and next-gen IoT ecosystems.

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