

# IoT-Enabled Night Patrolling Robot for Smart Security Surveillance

Mansha Saluja, Vansh Sharma, Wajeeha Azeem, Ritika, Saurabh Srivastava

Department of Computer Science & Engineering  
Moradabad Institute of Technology, Moradabad, India

manshasaluja4@gmail.com  
vanshsharma4441@gmail.com  
wajeehaazeemsiddiqui@gmail.com  
ritikagola1003@gmail.com  
srbh.spn@gmail.com

## Abstract

This paper presents the design and implementation of an IoT-enabled night patrolling robot to enhance smart security surveillance systems. The proposed system integrates sensors such as Passive Infrared (PIR) and Infrared (IR), along with an ESP32-CAM module to enable real-time monitoring, motion detection, and autonomous navigation. Controlled via IoT platforms, the robot streams live video and effectively responds to intrusions, ensuring secure surveillance during nighttime in critical environments like military zones, warehouses, and restricted urban areas. With an emphasis on cost-effectiveness, scalability, and ease of deployment, the project introduces a robust solution to the growing demand for automated patrolling systems.

**Keywords:** Smart Surveillance, Night Patrolling Robot, Security Robotics, Real-time Monitoring, Remote Surveillance

## I. Introduction

The importance of security in modern infrastructure, ranging from military installations and government facilities to educational institutions and commercial complexes, has significantly increased in recent years, leading to the rapid development of advanced surveillance technologies. Traditional security methods such as manual patrolling and static CCTV systems, although still in use, exhibit several limitations, including restricted coverage areas, vulnerability during low-light or nighttime conditions, delayed response times, and human fatigue or error during extended operations [1], [2], [3]. These limitations necessitate the development of more efficient and reliable alternatives.

The advent of autonomous robotic surveillance systems has emerged as a promising solution to address these concerns. These mobile units are capable of continuous operation without fatigue, and they can be programmed to perform intelligent surveillance tasks, detect intrusions, and provide real-time alerts. Furthermore, integrating these robotic systems with the Internet of Things (IoT) allows for a more dynamic and interconnected surveillance infrastructure. IoT facilitates enhanced data collection through sensors, remote accessibility, real-time communication, and decentralized control of the robot's movement and monitoring functions [4] [5]

This paper proposes the design and implementation of an IoT-enabled mobile patrolling robot integrated with an ESP32-CAM module, a Passive Infrared (PIR) sensor, an ultrasonic sensor, and Infrared (IR) sensors. The ESP32-CAM not only provides live video streaming over a Wi-Fi connection but also supports edge computing features such as face detection and motion sensing, making it ideal for surveillance in isolated or critical areas [6]. The PIR sensor is employed for motion detection, the ultrasonic sensor ensures obstacle avoidance, and the IR sensors assist in night vision and close-range obstacle sensing. Together, these components facilitate autonomous navigation, anomaly detection, and real-time video transmission, reducing the need for human monitoring while improving response efficiency and security coverage.

By leveraging such a system, surveillance can be carried out more comprehensively and intelligently, especially in scenarios where continuous human monitoring is impractical. The fusion of IoT with mobile robotics paves the way for scalable and adaptive surveillance systems, essential for safeguarding modern infrastructure.

## II. Related Work

Researchers have explored diverse approaches to developing mobile surveillance robots, each targeting specific challenges in monitoring and threat detection. For instance, an autonomous security robot integrating RFID and GPS technologies was proposed for perimeter surveillance, enabling location-based tracking and automated patrolling around predefined zones [7]. In another study, drone-based surveillance systems were introduced to perform aerial mapping and real-time motion detection, demonstrating the advantages of mobility and aerial perspective for large-area monitoring [6], [8]. Other approaches have focused on vision-based robotic patrols, utilizing machine learning algorithms for threat classification and behavior analysis, thus adding a layer of intelligence to autonomous surveillance [9].

While these advancements mark significant progress, many existing systems tend to be either cost-intensive, requiring sophisticated hardware and infrastructure, or overly complex, making them less feasible for widespread deployment, particularly in low-resource settings. Moreover, factors such as power consumption, limited range, and maintenance requirements further hinder their scalability and long-term utility.

Recent studies have highlighted the potential of Internet of Things (IoT)-based surveillance systems in enhancing monitoring capabilities through remote access, data sharing, and real-time control. For example, works in [7], [10] and [6] discuss smart surveillance frameworks using IoT sensors and cloud platforms to enable efficient monitoring across geographically distributed environments. However, the integration of IoT technologies with autonomous robotic platforms—especially for tasks like patrolling and night-time surveillance—remains underexplored and presents a valuable area of innovation.

This paper addresses this gap by proposing a hybrid system that combines mobile robotic functionality with IoT-based modules for intelligent, real-time, and autonomous surveillance. The system is specifically designed for night operations, leveraging components such as the ESP32-CAM for live video streaming, along with motion and proximity sensors to detect intrusions and navigate autonomously. Through this approach, we aim to offer a low-cost, flexible, and effective solution suitable for both indoor and outdoor security applications.

### III. System Design and Architecture

The proposed IoT-enabled night patrolling robot is a mobile surveillance unit designed to operate autonomously and wirelessly, offering real-time monitoring during nighttime security operations. The system architecture consists of tightly integrated hardware and software components that facilitate seamless interaction between sensing, communication, and control modules.

#### a. Hardware Components:

##### 1. ESP32-CAM Module

Powerful microcontroller with built-in Wi-Fi and a camera. It captures and streams live video feeds over a wireless network and supports AI-based image processing capabilities.

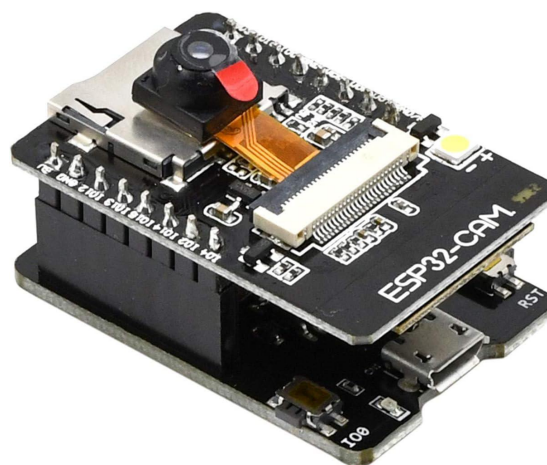


Figure 1. ESP32-CAM Module

## 2. PIR (Passive Infrared) Sensor

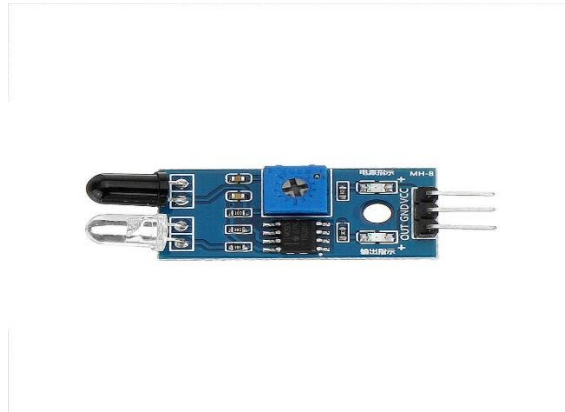
Detects motion based on the infrared radiation emitted by objects, especially human bodies. It plays a crucial role in intrusion detection.



**Figure 2.** PIR (Passive Infrared) Sensor

## 3. IR (Infrared) Sensors

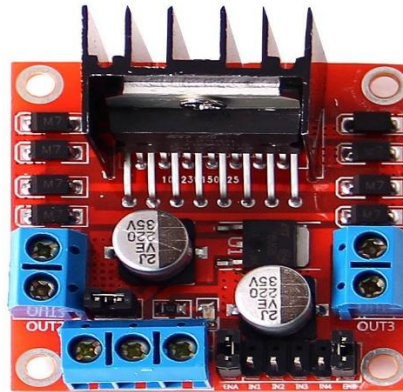
These sensors help in obstacle avoidance and line-following functionalities, particularly in low-light or dark environments.



**Figure 3.** IR (Infrared) Sensors

## 4. L298N Motor Driver Module

Acts as the interface between the microcontroller and the motors, enabling bidirectional control and speed regulation of the robot's wheels.



**Figure 4.** L298N Motor Driver Module

**5. DC Motors and Chassis**

Provides mobility to the robot. The lightweight chassis houses all components and supports movement over flat indoor and moderately uneven outdoor surfaces.



**Figure 5.** DC Motors and Chassis

**6. Rechargeable Battery Pack**

Powers the entire system, ensuring uninterrupted operation during patrol routines.



**Figure 6.** Rechargeable Battery Pack

## 7. Wheels and Frame Assembly

A robust 2- or 4-wheel configuration ensures balance and traction. The frame provides mechanical support to mount sensors, a camera, and electronics.



**Figure 7.** Wheels and Frame Assembly

## 8. Ultrasonic Sensor

The ultrasonic sensor is employed for precise distance measurement and obstacle avoidance. It works by emitting ultrasonic waves and measuring the time it takes for the echo to return after hitting an object.



**Figure 8.** Ultrasonic Sensor

## 9. Servo Motor

Servo motors are used to provide precise angular motion for components like cameras or IR/PIR sensors. By adjusting the direction of these modules, the robot can scan a wider field without needing to move the entire chassis.



**Figure 9.** Servo Motor

#### **b. Software and Communication Architecture:**

##### **1. Programming Environment:**

The system is developed using the Arduino IDE and programmed in Embedded C, C++ for controlling sensors, motors, and the camera module.

##### **2. IoT Platform Integration:**

Real-time monitoring and alerts are handled via platforms like **Blynk** and **ThingSpeak**. These platforms provide dashboards for video streaming, historical data visualization, and control interfaces.

##### **3. Wireless Communication:**

The ESP32-CAM connects to the internet over Wi-Fi. Data is transmitted using **MQTT** or **HTTP** protocols to ensure low-latency communication between the robot and cloud platforms.

##### **4. Cloud Storage and Analytics:**

Cloud storage retains data logs, event alerts, and video streams for later analysis. Edge analytics using ESP32's onboard processing enables real-time decision-making.

#### **IV. Model Development**

The system follows a multi-phase development approach comprising design, integration, testing, and deployment. The flowchart below illustrates the high-level process.

##### **1. Mechanical and Hardware Integration:**

- Assemble the chassis and mount all components securely.
- Connect sensors, ESP32-CAM, and motor driver using appropriate wiring.
- Calibrate sensor orientation and camera angle for optimal field of view.

##### **2. Firmware Development and Upload:**

- Code is written in Arduino C++ for sensor input processing, camera streaming, and motor control logic.
- Modules for Wi-Fi connectivity, motion detection, and alert triggers are embedded in the firmware.
- Upload to ESP32-CAM using FTDI programmer and USB interface.

### 3. IoT Configuration:

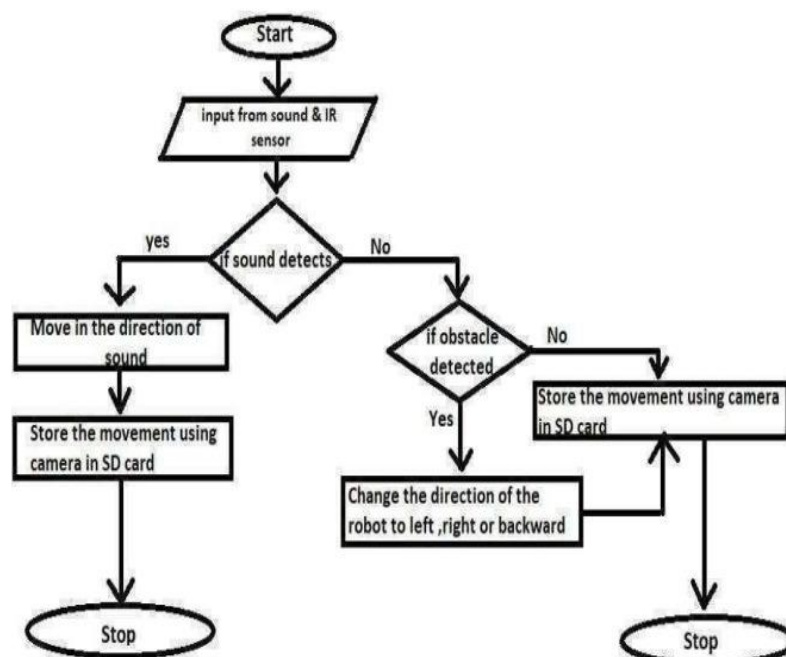
- Configure **ThingSpeak/Blynk** dashboards to receive data from the robot.
- Set up motion alert thresholds, control buttons, video feed widgets, and notification services.
- Use Google Firebase or IFTTT to send mobile or email alerts on motion detection.

### 4. Real-Time Navigation and Monitoring:

- The robot patrols pre-defined routes using a line-following algorithm or random movement logic.
- IR sensors ensure obstacle detection, while PIR triggers alert mechanisms during intrusions.
- The video feed is streamed in real time via Wi-Fi.

### 5. Alert Mechanism and Data Logging:

- Upon detecting motion or anomalies, the system captures a snapshot or brief video.
- Triggers an alert to the cloud platform, logging the event with a timestamp.
- Sends an immediate notification to users via mobile app or email.

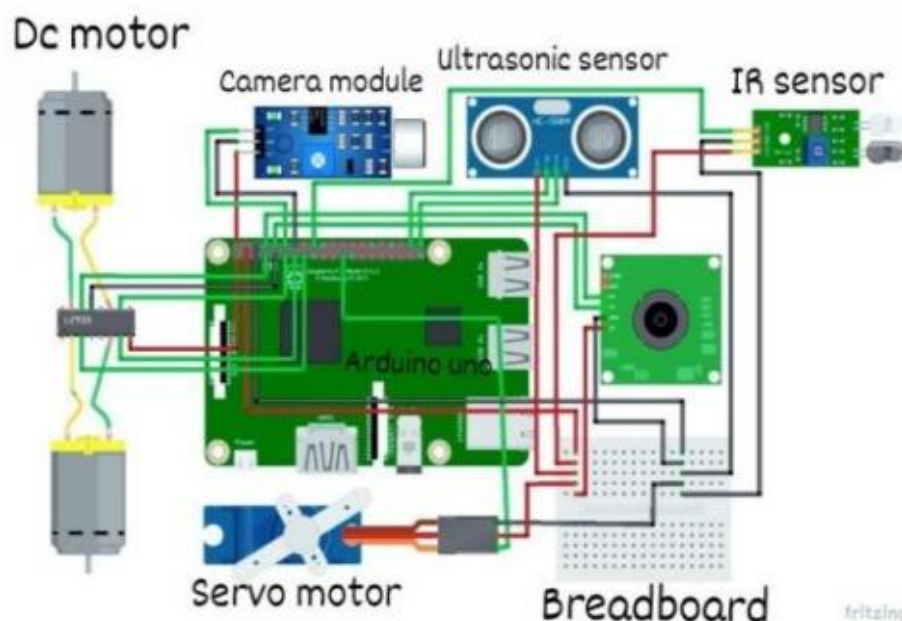


**Figure 10.** Flowchart Of IoT-Enabled Night Patrolling Robot For Smart Security Surveillance

This flowchart represents the decision-making process of a robot using sound and infrared (IR) sensors for movement and obstacle detection. The process begins with the robot receiving input from both sensors. The first decision point checks if sound is detected. If sound is detected, the robot moves toward the source of the sound and records the movement using a camera, storing the footage on an SD card before stopping. If no sound is detected, the system then checks for obstacles. If an obstacle is detected, the robot adjusts its direction by moving left, right, or backward to avoid the obstacle before stopping. If no obstacle is detected, the robot simply records the movement using a camera and stores it on an SD card, then halts.

This flowchart highlights an efficient method for a robot to navigate its environment using sensory inputs and programmed logic. It showcases a structured approach to movement, ensuring that the robot responds dynamically to sound and obstacles while maintaining a record of its navigation. Such a system is useful in automation, robotics, and AI-driven autonomous navigation applications, providing a simple yet effective way for a robot to interact with its surroundings and make real-time decisions.

## 6. Circuit diagram



**Figure 11.** Circuit diagram of IoT-Enabled Night Patrolling Robot for Smart Security Surveillance

The image presents a detailed wiring diagram for an Arduino Uno-based electronic project featuring multiple integrated components. At the core of the setup is the Arduino Uno, connected to an L293D motor driver, which controls two DC motors for movement. A servo motor is also included, likely for precise angle adjustments, and an ultrasonic sensor helps detect obstacles by measuring distances. Additionally, the IR sensor plays a role in detecting

objects or motion, commonly used for automation or security applications. A camera module is incorporated, suggesting the project could involve vision-based detection or surveillance functionality. The diagram also includes a breadboard, facilitating connections among various sensors, motors, and the microcontroller by enabling efficient circuit design.

This type of configuration is commonly found in robotics, automation, and smart vehicle applications. The presence of multiple sensors and actuators indicates the project is designed for autonomous functionality, where the Arduino receives input from sensors and makes real-time decisions to control movement or interaction. Whether used in robotics, home automation, or security systems, this arrangement showcases a well-integrated combination of electronic components working together seamlessly for efficient functionality. The structured wiring diagram provides a clear guide for building a robust system, allowing precise execution of programmed tasks.

## V. Challenges and Limitations

Despite the promising potential of the IoT-enabled night patrolling robot, the current implementation encounters several technical and operational challenges that limit its full-scale deployment:

1. **Limited Night Vision Clarity:** While the ESP32-CAM can function in low-light conditions, it lacks dedicated night vision capabilities such as infrared (IR) illumination or thermal imaging. This reduces image clarity and object detection accuracy during complete darkness or poorly lit environments [11].
2. **Connectivity Dependency:** The robot relies on stable Wi-Fi for streaming video and sending alerts. In environments with poor network coverage or interference, the system may experience lags, data loss, or complete communication failure, compromising surveillance reliability [12].
3. **Battery Efficiency:** Continuous operation of sensors, motors, and camera streaming consumes a significant amount of power. The limited capacity of the onboard battery restricts patrol duration and necessitates frequent recharging, making long-term deployment impractical without power optimization.
4. **Obstacle Navigation Limitations:** Although ultrasonic and IR sensors assist in obstacle detection, the robot struggles with certain complex or transparent obstacles like glass doors, steep inclines, or small debris. This may result in navigation errors or system halts [13].
5. **Scalability and Terrain Adaptability:** The current model is optimized for indoor or flat-surface environments. Its mobility and sensor range are not yet suitable for large outdoor areas, rugged terrains, or adverse weather conditions.
6. **Lack of AI-Based Threat Analysis:** The system currently detects motion but does not classify or analyze threats intelligently. This may lead to false alerts due to non-human movements such as pets, shadows, or falling objects [14].
7. **Security and Privacy Concerns:** As the robot transmits data over wireless networks and cloud platforms, it may be vulnerable to cyberattacks or data breaches if not secured with robust encryption and access controls [15].

## VI. Future Enhancements

To improve the performance, adaptability, and intelligence of the IoT-enabled night patrolling robot, the following future enhancements are proposed:

1. **Integration of Infrared Night Vision or Thermal Cameras:** Incorporating IR LEDs or thermal imaging modules can significantly improve night-time visibility and allow the robot to detect intruders even in total darkness [16].
2. **Advanced Power Management and Solar Charging:** To extend operation time, implementing low-power modes for sensors and using energy-efficient motors is recommended. Additionally, integrating a compact solar panel can provide autonomous charging during daytime operations [17].
3. **AI-Based Threat Classification:** Embedding lightweight machine learning models for object detection and classification directly on the ESP32 (or an upgraded module like Raspberry Pi) can reduce false positives and enable real-time differentiation between humans, animals, or inanimate objects [18].
4. **Multi-Network Support (LTE/GSM/Wi-Fi Hybrid):** For improved connectivity, supporting cellular networks (4G/5G) alongside Wi-Fi will allow the robot to maintain communication even in remote or low-network zones, ensuring uninterrupted video streaming and alerts [17].
5. **Autonomous Path Planning with GPS and SLAM:** Integrating GPS modules and Simultaneous Localization and Mapping (SLAM) algorithms can allow the robot to map and navigate complex environments autonomously, without relying on pre-defined paths [19].
6. **All-Terrain Mobility and Weather-Proofing:** Developing a more robust chassis with better wheels or tracks can enable outdoor patrolling across uneven or wet terrain. Weather-proof casing for electronic components will ensure durability in diverse environmental conditions [20].
7. **Collaborative Swarm Deployment:** Future versions can include a swarm intelligence approach, where multiple patrolling robots coordinate with each other via IoT to cover larger areas more efficiently, sharing tasks and data in real time [21].
8. **Enhanced Cybersecurity Protocols:** Implementing data encryption (SSL/TLS), two-factor authentication, and secure cloud APIs will protect the system from unauthorized access and cyber threats, ensuring privacy and integrity of surveillance data [22].

## VII. Conclusion

The proposed IoT-based mobile patrolling robot demonstrates a promising and cost-effective approach to enhancing real-time night surveillance capabilities. By integrating key components such as the ESP32-CAM module, Passive Infrared (PIR) sensors, ultrasonic sensors, and Infrared (IR) sensors with IoT connectivity, the system enables autonomous patrolling, obstacle detection, and live video streaming over a wireless network. This

integration supports remote monitoring, real-time alerts, and minimal human intervention—crucial features for 24/7 security in both public and private infrastructures.

Compared to traditional surveillance methods and more complex robotic systems, the presented solution is notably low-cost, lightweight, and easier to deploy, making it suitable for small-scale installations like educational campuses, residential areas, and industrial perimeters. The ability to operate effectively in low-light conditions further enhances its practical value for night-time surveillance tasks.

Despite these advantages, certain challenges remain, including battery efficiency, terrain adaptability, and limited AI-based decision-making. These limitations suggest areas for future improvement, such as integrating renewable energy sources, enhancing autonomous navigation algorithms, and incorporating advanced threat recognition using edge-based artificial intelligence.

Overall, this work contributes to the growing field of smart security systems by laying a scalable foundation for further research and real-world deployment of IoT-enabled autonomous surveillance robots. As the demand for intelligent and responsive security continues to rise, the convergence of IoT and robotics holds significant potential for transforming surveillance into a more adaptive and efficient system.

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