International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 04 Issue: 07 July 2026
Page No: 4999-5004
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2026.0657

Smart Defense Area Monitoring Robot Using ESP32-CAM and Wireless Communication

Para Keerti[1], Vundekoti Nandini[2], Dhanavath Purnima[3], Danduri Chendra Manasa[4]
[1]Assistant Professor, Dept. of EEE, Stanley College of Engineering. and Technology for Women(A), Hyderabad,
[2,3,4]UG Scholar, Dept. of EEE, Stanley College of Engineering. and Technology for Women(A), Hyderabad,
Emails: *keerti@stanley.edu.in[1], vundekotinandini@gmail.com[2], dhanavathpurnima@gmail.com[3], chendramanasa@gmail.com[4]*

Abstract
This paper is to design and develop a wireless surveillance robot capable of performing real-time monitoring and reconnaissance in military combat zones and other hazardous environments, particularly under low-light and nighttime conditions. The system aims to enhance the safety of defense personnel by enabling remote surveillance and intelligence gathering without requiring direct human presence in hostile or high-risk areas. The robotic platform is powered by a rechargeable battery and utilizes DC motors for locomotion. Motor operations are controlled through an L298N motor driver module interfaced with an ESP32-CAM microcontroller, which serves as the central processing and communication unit. Based on wireless commands transmitted by the user, the robot can move in multiple directions, including forward, backward, left, and right, allowing flexible navigation across different terrains. To ensure effective operation in dark environments, the ESP32-CAM is integrated with infrared (IR) LEDs, providing enhanced night vision capability and improved image acquisition under low-light conditions. The wireless communication interface enables the operator to remotely control the robot while simultaneously viewing a live video stream, facilitating real-time monitoring and decision-making. The proposed system integrates embedded systems, wireless communication, computer vision, and robotic control to develop a compact, cost-effective, and efficient surveillance platform. Beyond military applications, the robot can also be deployed for border security, industrial inspection, disaster response, search and rescue operations, hazardous area monitoring, and remote surveillance in environments where human intervention is difficult, unsafe, or impractical.
Keywords: *Wireless Surveillance Robot, ESP32-CAM, Real-Time Video Streaming, Military Reconnaissance, Night Vision Surveillance, Infrared (IR) LEDs, L298N Motor Driver, Remote Monitoring, Embedded Robotic System mechanics.*

1. Introduction
The safeguarding of human life should not only be the main task but also be carried out with the utmost care and diligence at every level and in every activity. That is a fundamental value in any military or security operation. Deploying troops for reconnaissance under conditions of dark, unknown, or hostile environments places them at considerable risk from ambushes IEDs toxic substances, and enemy combatants. In contemporary conflict settings such as border surveillance, city warfare, and disaster response the collection of intelligence without risking human lives is becoming vital.An option with less risk are ground-UGVs that are mobile, communicate wirelessly, and have vision equipment. These machines can be quite a good and safe tool for the situations described. Standard security tools like CCTV cameras or patrols are not only low on mobility but also limited in the geographical reach. In addition, they cannot perform well in difficult or dimly lit locations. The paper deals with an inexpensive Defense Area Monitoring Robot created with the ESP32-CAM chip for wireless steering and night vision surveillance to counter these issues. The new robot allows the human being in control to guide the moving object through dangerous places using a camera and video feedback without endangering the operator personally.

1.1 The main objectives of this work are:

- To develop a compact, affordable robotic platform capable of real-time wireless video streaming and remote navigation.
- To integrate infrared (IR) illumination for effective night-vision capability in complete darkness.
- To implement a simple and responsive web-based control interface using a single ESP32-CAM module as the central controller.
- To evaluate the system's performance in terms of control range, video latency, and navigation in indoor and outdoor environments.

2. Literature Survey

The development of wireless surveillance robots has gained considerable attention in defence, security, and disaster management applications, primarily due to their ability to minimize human exposure to hazardous and life-threatening environments. Early surveillance systems relied heavily on fixed cameras, manual patrols, and basic RF-based remote-controlled robots. While these approaches provided some level of remote monitoring, they suffered from critical limitations such as restricted mobility, poor performance in low-light conditions, limited communication range, and the absence of real-time video feedback. Several researchers have contributed to the advancement of remotely operated robotic platforms for reconnaissance and surveillance. M. F. Syaifudin et al. (2020) developed a Wi-Fi controlled surveillance robot using Arduino Uno and a smartphone camera. Although the system demonstrated basic remote operation, it lacked night-vision capability and had a very limited operational range. Similarly, A. Sharma et al. (2021) proposed a Raspberry Pi-based robot with live video streaming. While this design offered improved video quality, it suffered from high power consumption and increased system cost, making it less suitable for large-scale or low-budget deployments. The emergence of the ESP32-CAM module has significantly influenced recent robotic designs due to its integrated camera, built-in Wi-Fi, low power consumption, and compact form factor. R. Kumar et al. (2022) utilized the ESP32-CAM in a firefighting robot for real-time video feedback; however, motor control was delegated to a separate Arduino board, resulting in higher complexity and cost. In contrast, the proposed system employs the ESP32-CAM as the sole controller for both video streaming and motor actuation, thereby reducing component count and overall system complexity. Night vision remains a critical requirement for defence and security applications. Effective low-light imaging is typically achieved using either costly thermal cameras or active infrared (IR) illumination. A. B. Putra et al. (2023) integrated IR LEDs with an ESP32-CAM module in a security robot and achieved usable video feed up to 5 meters in complete darkness. The proposed design adopts and optimizes this IR illumination approach with better LED placement and power management to support dynamic movement during surveillance operations. Motor control in small, unmanned ground vehicles (UGVs) is commonly achieved using H-bridge drivers. The L298N dual motor driver is widely adopted for its simplicity and reliability in differential drive configurations. While some advanced works have explored neural network-based control strategies, simple PWM-based control from the ESP32 remains efficient and sufficient for basic navigation tasks. Despite notable progress, most existing systems still exhibit one or more of the following limitations: multi-board architecture leading to higher cost and complexity, absence of reliable night-vision capability, limited control range, and high latency in video transmission. The proposed Défense Area Monitoring Robot addresses these gaps by integrating wireless control, live video streaming, and effective IR night vision into a compact, low-cost, single-board platform based on the ESP32-CAM module.

3. System Design and Hardware Architecture

The proposed Defense Area Monitoring Robot is engineered with a focus on affordability, compactness, reliability, and operational effectiveness in challenging environments such as defense zones, border areas, and low-light conditions. A key design decision was to use the ESP32-CAM as the single central controller, eliminating the need for multiple microcontrollers and thereby reducing cost, complexity, power consumption, and wiring issues

International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 04 Issue: 07 July 2026
Page No: 4999-5004
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2026.0657

3.1 System Architecture

The robot follows a differential drive configuration for agile movement (forward, backward, left, and right turns). The system architecture integrates three primary subsystems:

- Control and Communication Subsystem — ESP32-CAM
- Mobility Subsystem — L298N + DC motors
- Vision and Illumination Subsystem — camera + IR LEDs

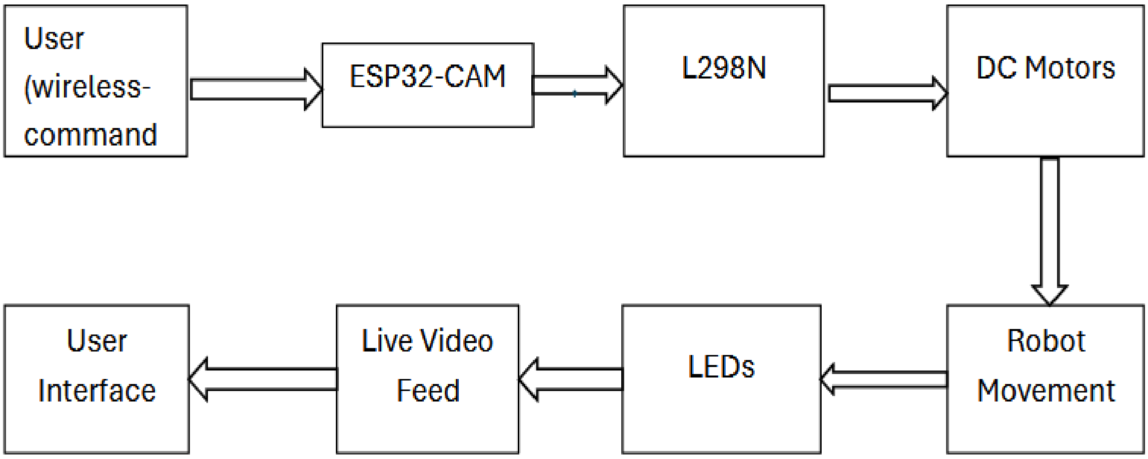

Figure 1 Block Diagram of the Proposed Defense Area Monitoring Robot

The block diagram illustrates how the ESP32-CAM simultaneously manages Wi-Fi-based command reception, motor actuation via PWM signals, camera streaming, and IR LED control.

3.2 Hardware Components

All components were selected for their low cost, easy availability, and compatibility. The complete bill of materials is given below:

It uses a differential drive mechanism with two rear-driven wheels and one or two front castor wheels for stability. The ESP32-CAM and camera are mounted at the front to provide a wide field of view, while the heavier components (battery and motor driver) are placed toward the rear for balanced weight distribution. The 3D-printed front and side panels provide protection to the electronics.

Figure 2 Disassembled view of all hardware components used in the prototype

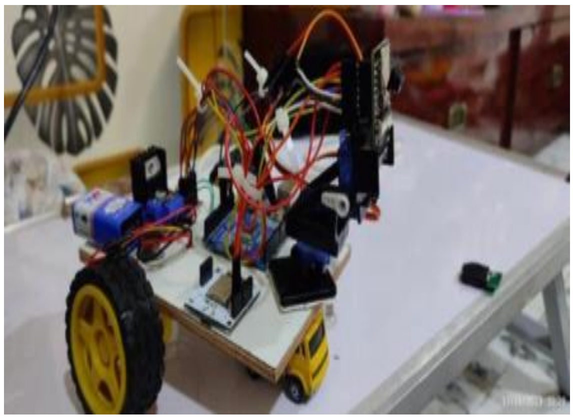

Figure 3 Fully Assembled Prototype of the Defense Area Monitoring Robot

3.3 Mechanical Assembly

The robot chassis is compact (approximately 22 cm × 16 cm × 12 cm) and lightweight (around 850 grams).

3.4 Electrical Circuit Design and Pin Connections

The electrical connections are designed for reliability and ease of debugging:

International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 04 Issue: 07 July 2026
Page No: 4999-5004
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2026.0657

Table 1 Component and Specification

Component	Specification	Quantity	Purpose
ESP32-CAM Module	ESP32-S + OV2640 Camera + Wi-Fi + PSRAM	1	Main controller, video streaming, Wi-Fi AP
L298N Motor Driver	Dual H-Bridge, 5-35V, Max 2A/channel	1	Bidirectional motor control
DC Geared Motors	12V, 300 RPM, High Torque	2	Propulsion
Wheels	65mm diameter, Rubber tires	2	Locomotion
IR LEDs	850nm wavelength, 5mm	6	Night vision illumination
Battery	18650 Li-ion cells (3.7V, 2000mAh each)	2	Power source (7.4V nominal)
Battery Holder	2S configuration with switch	1	Power management
Voltage Regulator	AMS1117-3.3V	1	Stable 3.3V supply for ESP32-CAM
Chassis	3D-printed + Acrylic sheets	1	Mechanical frame
Jumper Wires & Connectors	Male-Female, Dupont	As req.	Interconnections

- **Motor Control:** ESP32 GPIO12 (IN1), GPIO13 (IN2), GPIO14 (IN3), GPIO15 (IN4) connected to L298N inputs. PWM functionality is enabled for speed variation.
- **Night Vision:** Six IR LEDs connected in parallel to GPIO4 through a 220Ω current-limiting resistor.
- **Power Supply:** 7.4V from 2S Li-ion battery directly powers the L298N and motors, while the AMS1117 regulator steps it down to 3.3V for the ESP32-CAM.
- **Camera:** Built-in OV2640 camera is used for MJPEG streaming. Proper decoupling capacitors (100µF and 0.1µF) were added across power lines to prevent voltage drops during motor operation.

This integrated single-board approach makes the system significantly cheaper and simpler than traditional multi-controller designs (Arduino + Raspberry Pi combinations), while maintaining good performance.

4. Discussion

The Defense Area Monitoring Robot developed in this work represents a practical and cost-effective approach to wireless surveillance in hazardous and defense environments. This section discusses the key advancements, experimental findings, challenges, limitations, and comparison with existing systems.

International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 04 Issue: 07 July 2026
Page No: 4999-5004
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2026.0657

4.1 Advancements in the Proposed System

The most significant contribution of this work is the integration of the ESP32-CAM as a single central controller responsible for wireless communication, motor control, and live video streaming. This design greatly reduces system complexity, cost, and power consumption compared to traditional multi-board architectures (Arduino + Raspberry Pi). The incorporation of Infrared (IR) LEDs provides effective night-vision capability, enabling covert surveillance in complete darkness. The web-based control interface offers user-friendly remote operation, allowing the robot to be driven smoothly in forward, backward, left, and right directions. Experimental testing confirmed reliable performance with a control range of 30 meters (line-of-sight), video latency of 180–250 ms, and clear object detection up to 4 meters under IR illumination.

4.2 Experimental Results

The prototype was successfully tested in multiple scenarios including indoor corridors, open grounds, and completely dark rooms. The robot demonstrated good mobility using the differential drive mechanism and maintained stable operation throughout the tests. The total cost of the prototype was kept under ₹2,500, proving the feasibility of building a functional surveillance robot with low-cost components.

4.3 Challenges and Limitations

Despite the promising results, the system has some limitations:

- **Communication Range:** Restricted to approximately 30 meters in line-of-sight due to Wi-Fi limitations.
- **Night Vision Distance:** Effective only up to 4 meters in total darkness.
- **Battery Life:** Limited to 45–60 minutes of continuous operation.
- **Environmental Protection:** The current prototype is not waterproof or dust-resistant.
- **Autonomy:** The robot is fully manual and lacks intelligent features such as obstacle avoidance or object detection.

4.4 Comparison with Existing Systems

Compared to previous works [1–3], the proposed system offers better integration of night vision and control functions on a single ESP32-CAM board. While some commercial robots provide longer range and higher autonomy, they are significantly more expensive. This work successfully bridges the gap between high-cost advanced systems and very basic low-cost prototypes by providing a balanced, functional solution suitable for academic and small-scale defense applications.

5. Result and Conclusion

5.1 Results

The Defense Area Monitoring Robot was successfully implemented and tested under various real-world conditions, including indoor corridors, open grounds, and completely dark environments. The key experimental results are summarized below:

- **Control Range:** Reliable wireless control up to 30 meters in line-of-sight conditions using Wi-Fi Access Point mode.
- **Video Latency:** Average latency between 180 and 250 milliseconds, which is acceptable for real-time remote surveillance.
- **Night Vision Performance:** With IR LEDs activated, clear object detection and navigation were possible up to 4 meters in total darkness.
- **Mobility:** The differential drive system allowed smooth movement forward, backward, left, and right turns. The robot successfully navigated narrow spaces and uneven surfaces.
- **Power Consumption:** A 7.4V Li-ion battery provided approximately 45–60 minutes of continuous operation (motors + camera streaming + Wi-Fi).
- **Prototype Cost:** The total cost of the developed system was kept under ₹2,500, making it highly affordable.

These results validate the effectiveness of using a single ESP32-CAM module for integrated control, video streaming, and night vision.

Conclusion

This paper successfully presented the design, development, and implementation of a low-cost Defense Area Monitoring Robot using ESP32-CAM for wireless communication and night-vision surveillance. The proposed system effectively integrates remote motor control, live video streaming, and IR illumination into a compact, single-board platform. The prototype demonstrates that affordable embedded systems can deliver practical and reliable performance for real-time monitoring while significantly reducing risks to military and security personnel. The work addresses several limitations of existing low-cost surveillance robots, particularly the lack of integrated night vision and high system complexity.

Future Scope

Further improvements can be made in the following areas:

- Integration of AI/ML for autonomous navigation and object detection.
- Use of LoRa or 4G modules for extended communication range.
- Addition of environmental sensors (gas, temperature, ultrasonic, etc.).
- Development of a dedicated mobile application for enhanced control.
- Improving battery life, weatherproofing, and overall durability.

In conclusion, the proposed Defense Area Monitoring Robot provides a strong, cost-effective foundation for surveillance applications in defense, border security, industrial inspection, and disaster management. With continued development, such systems can play a vital role in modern security operations.

References

[1]. M. F. Syaifudin et al., “Design and Implementation of Wi-Fi Controlled Surveillance Robot Using Arduino Uno,” International Journal of Engineering Research & Technology, vol. 9, no. 5, 2020.

[2]. A. Sharma, S. Singh, and R. Kumar, “Raspberry Pi Based Wireless Surveillance Robot with Live Video Streaming,” International Journal of Innovative Research in Computer and Communication Engineering, 2021.

[3]. R. Kumar, P. Singh, and A. Gupta, “ESP32-CAM Based Firefighting Robot with Real-Time Video Feedback,” IEEE Conference on Emerging Technologies, 2022.

[4]. A. B. Putra, M. Santoso, and D. Wijaya, “Development of Night Vision Security Robot Using ESP32-CAM and IR LEDs,” Journal of Robotics and Control, vol. 4, no. 2, pp. 456-465, 2023.

[5]. Espressif Systems, “ESP32-CAM Datasheet and Technical Reference,” Espressif Inc., 2022. [Online]. Available: https://www.espressif.com

[6]. L298N Motor Driver Datasheet, STMicroelectronics.

[7]. P. Singh, V. Singh, H. Vardhan, N. Maurya, and A. Sharma, “Wireless Surveillance Robotic Car,” International Journal of Creative Research Thoughts, 2022.

[8]. S. Londhe, P. Shinde, S. Mendke, S. Dhage, and N. Futane, “Multipurpose Surveillance Robot,” International Journal of Research Publication and Reviews, 2023.

[9]. Herman Kruegle, CCTV Surveillance: Video Practices and Technology, 2nd ed., Butterworth-Heinemann, 2006.

[10]. William Stallings, Network Security Essentials: Applications and Standards, 6th ed., Pearson, 2020.

[11]. M. Schwartz and A. Kurniawan, Internet of Things with ESP32, 2021.

[12]. Paul Scherz and S. Monk, Practical Electronics for Inventors, 4th ed., McGraw-Hill, 2016.