© APR 2026 | IRE Journals | Volume 9 Issue 10 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I10-1716989

Autonomous AI Surveillance Rover Using ESP32-Cam

SHRI PRAKASH BAITHA[1], SHIVPUJAN KUMAR[2], UJJWAL PRAKASH[3], RAJA GUPTA[4], M. S. INDIRA[5]

[1, 2, 3, 4] UG Student, Department of Electronics and Communication Engineering, Excel Engineering College (Autonomous), Komarapalayam, Namakkal, Tamil Nadu, India

[5] Assistant Professor, Department of Electronics and Communication Engineering, Excel Engineering College (Autonomous), Komarapalayam, Namakkal, Tamil Nadu, India

Abstract- The Autonomous AI Surveillance Rover using ESP32 is designed to provide smart and efficient real-time monitoring for security applications. The system integrates an ESP32 microcontroller with sensors and a camera module to perform autonomous navigation and live data transmission. It uses basic artificial intelligence techniques for motion detection and obstacle avoidance, enabling the rover to operate without constant human control. The rover can be remotely accessed through a web interface using Wi-Fi connectivity. This system reduces human effort and enhances surveillance efficiency in areas such as homes, industries, and restricted zones.

Keywords— ESP32-CAM, IoT, Real-time Monitoring, Embedded Systems, Object Detection, Computer Vision

I. INTRODUCTION

Security and surveillance systems have become a crucial part of modern society due to increasing safety concerns in residential, industrial, and public environments. Traditional surveillance methods mainly rely on static cameras and continuous human monitoring, which are often limited in coverage, prone to human error, and inefficient in dynamic or large-scale areas. With the rapid advancement of embedded systems, artificial intelligence, and IoT technologies, there is a growing need for intelligent and autonomous surveillance solutions that can operate with minimal human intervention.

Autonomous robotic systems have emerged as an effective solution to overcome these limitations. These systems can move freely, monitor surroundings in real time, and respond to environmental changes. The integration of AI-based techniques such as motion detection and object recognition further enhances the capability of such systems by enabling smart decision-making and threat detection.

This project presents an Autonomous AI Surveillance Rover using ESP32, a compact and cost- effective robotic system designed for real-time monitoring and security applications. The rover is equipped with sensors, a camera module, and wireless communication features to enable live video streaming and environmental sensing. It can autonomously navigate using obstacle detection mechanisms and can be remotely accessed through a web interface via Wi-Fi.

The proposed system aims to reduce human effort, improve surveillance coverage, and provide a scalable solution for smart security applications. The following sections describe the system design, implementation, working methodology, and performance evaluation.

II. MOTIVATION

The motivation behind developing the Autonomous AI Surveillance Rover using ESP32 arises from the limitations of traditional surveillance systems, which are mostly fixed, expensive, and dependent on continuous human monitoring. In many real-world scenarios such as large industrial areas, border regions, and restricted zones, static surveillance systems fail to provide complete coverage and real-time responsiveness.

From a practical perspective, human monitoring of multiple surveillance cameras leads to fatigue, delayed response, and potential security risks. An autonomous rover capable of moving across different locations and monitoring environments in real time significantly reduces human dependency and improves efficiency. Additionally, existing advanced surveillance systems are often costly and complex, making them inaccessible for small-scale applications such as homes and small businesses.

The rapid development of low-cost microcontrollers like ESP32, along with advancements in IoT and AI technologies, provides an opportunity to design an affordable and intelligent surveillance system. By integrating sensors, camera modules, and wireless communication, the rover can perform autonomous navigation, detect obstacles, and transmit real-time data to users.

Furthermore, the need for smart and adaptive security systems motivates the integration of basic AI techniques for motion detection and anomaly identification. This transforms surveillance from a passive monitoring process into an active and intelligent system capable of responding to potential threats.

Overall, this project aims to develop a low-cost, efficient, and scalable surveillance solution that enhances security, reduces human effort, and demonstrates the practical application of AI and embedded systems in real-world scenarios.

III. SYSTEM ARCHITECTURE

The Autonomous AI Surveillance Rover using ESP32 is designed using a modular and layered architecture where multiple hardware and software components work together to achieve real-time surveillance, autonomous navigation, and remote monitoring. The system integrates sensing, processing, communication, and control mechanisms to provide an efficient and intelligent security solution. Each module performs a specific function and interacts with other modules through well-defined interfaces, ensuring flexibility, scalability, and reliability.

A. Control Unit (ESP32)

The ESP32 microcontroller serves as the central processing unit of the system. It manages all operations including sensor data acquisition, motor control, camera interfacing, and wireless communication. The ESP32 is chosen due to its built-in Wi-Fi and Bluetooth capabilities, low power consumption, and high processing efficiency. It processes real-time inputs from sensors and executes programmed logic to control the rover's behavior.

B. Sensor Module

The sensor module consists of ultrasonic sensors (such as HC-SR04) used for accurate obstacle detection and distance measurement. These sensors continuously emit ultrasonic waves and calculate distance based on echo return time. The ESP32 processes this data in real time to detect obstacles within a predefined safety range. When an object is detected, the rover can automatically stop, slow down, or change direction to avoid collision. Multiple sensors can be used to improve detection coverage in different directions. This module ensures safe navigation, enhances reliability, and supports autonomous decision-making even in dynamic environments.

C. Camera Module (ESP32-CAM)

The ESP32-CAM module captures high-quality images and streams real-time video over Wi-Fi. It enables continuous surveillance by allowing users to monitor surroundings remotely through a browser. The camera supports image capture, video streaming, and basic motion detection features. It plays a critical role in security by providing visual evidence and situational awareness. Additionally, this module can be extended with AI-based object detection, face recognition, and image processing techniques for advanced surveillance applications.

D. Motor and Driver Module

The rover uses DC motors controlled by an L298N motor driver, which acts as an interface between the ESP32 and motors. The driver receives low-power control signals from the ESP32 and converts them into high-power signals required to drive the motors. It enables precise control of speed and direction, allowing movements such as forward, backward, left, right, and stop. The module ensures smooth navigation, stability, and efficient power usage. It also protects the controller from high current damage.

E. Communication Module

The communication module is based on Wi-Fi technology provided by the ESP32. It enables wireless data transmission between the rover and the user. The ESP32 can act as a web server or connect to an existing network, allowing remote access through smartphones or computers. Users can view live video, send control commands, and receive updates in real time. This module ensures seamless connectivity, low latency communication, and flexibility for remote monitoring applications.

F. Power Supply Module

The power supply module is responsible for providing reliable and continuous energy to all components of the rover. The system is powered using rechargeable batteries or a portable power bank, ensuring portability and ease of use in different environments. It delivers stable and regulated voltage to critical components such as the ESP32, sensors, motors, and camera module.

Voltage regulators and proper circuit design are implemented to maintain a constant voltage level and protect components from fluctuations, overvoltage, and short circuits. Separate power lines or regulators can be used for motors and control circuits to avoid noise interference and voltage drops during motor operation.

G. AI & Navigation Module

This module enables the rover to operate autonomously using basic artificial intelligence techniques. It includes obstacle avoidance, motion detection, and simple decision-making algorithms. Based on sensor inputs, the rover can automatically navigate and adjust its path without human intervention. This improves efficiency and reduces dependency on manual control. Future enhancements may include machine learning algorithms for advanced pattern recognition and smart surveillance capabilities.

H. User Interface Module

The user interface module is a web-based platform that enables users to interact with the rover in a simple and efficient manner. It provides essential features such as real-time video streaming, movement control buttons (forward, backward, left, right, stop), and system status indicators including connectivity and sensor feedback.

The interface is designed to be responsive and user-friendly, allowing seamless access on both mobile devices and computers without requiring any specialized software. It uses a browser-based dashboard where users can easily monitor the rover's activity and control its movement in real time.

I. Notification & Alert Module

This module keeps users informed about important events and system activities. Alerts are generated in cases such as motion detection, obstacle detection, or system errors. Notifications can be displayed on the web interface or sent through connected applications. This ensures real-time awareness and quick response to potential threats. It reduces the need for continuous manual monitoring. J. Security & Data Management Module

The system ensures secure communication between the rover and the user using network security protocols. Authentication mechanisms restrict access to authorized users only. Data such as images, video streams, and system logs can be stored for future reference and analysis. The module also supports activity tracking and basic logging features. This enhances system reliability, maintains data integrity, and protects against unauthorized access or misuse.

Table I summarizes the key modules of the Autonomous AI Surveillance Rover using ESP32, along with their primary functions and the stakeholders they serve.

TABLE I System Modules, Functions, and Stakeholders

Module	Primary Function	Stakeholder
ESP32 Control Unit	Central processing, control, and communication	System
Sensor Module	Detect obstacles and measure distance	System
Camera Module (ESP32-CAM)	Capture and stream live video	Users
Motor & Driver Module	Control movement and direction of rover	System
Communication Module	Enable Wi-Fi connectivity and remote access	Users
Power Supply Module	Provide stable power to all components	System

AI & Navigation Module	Autonomous Decision-making and path control	System
User Interface Module	Remote monitoring and control via web	Users
Security & Data Management	Ensure data protection and access control	Admin/User

IV. IMPLEMENTATION DETAILS

The Autonomous AI Surveillance Rover using ESP32 is implemented using a combination of embedded systems, IoT technologies, and basic AI techniques. The system follows a modular approach where hardware components such as sensors, motors, and camera are integrated with software modules for control, communication, and user interaction. The implementation ensures real-time monitoring, autonomous navigation, and efficient remote access.

A. Hardware Implementation

The hardware setup consists of an ESP32 microcontroller, ultrasonic sensors (HC-SR04), ESP32CAM module, DC motors, motor driver (L298N), and a power supply unit.

The ESP32 acts as the central controller, processing sensor inputs and controlling motor operations. Ultrasonic sensors are mounted on the rover to detect obstacles and measure distance. The ESP32-CAM is used for capturing and streaming live video.

DC motors connected through the motor driver enable movement in different directions. All components are properly connected using jumper wires and mounted on a rover chassis. The power supply (battery/power bank) provides stable voltage for continuous operation.

B. Software Development

The software is developed using the Arduino IDE for programming the ESP32. Embedded C/C++ is used to write control logic for sensor readings, motor control, and communication.

The ESP32 is programmed to:

- Read sensor data continuously
- Process obstacle detection logic
- Control motor movement
- Stream video using ESP32-CAM
- Handle Wi-Fi communication

A web-based interface is created using basic HTML, CSS, and JavaScript to allow users to control the rover and view live video feed.

C. Communication and Networking

The system uses Wi-Fi for wireless communication. The ESP32 acts as a web server or connects to a local network. Users can access the rover using its IP address through a browser.

Real-time data such as video feed and control commands are transmitted over the network. This ensures low latency communication and enables remote monitoring from smartphones or computers.

D. AI and Navigation Implementation

Basic AI techniques are implemented for autonomous navigation. The rover uses sensor data to detect obstacles and automatically adjust its path.

Simple algorithms are used for:

- Obstacle avoidance
- Motion detection (via camera)
- Decision-making for direction control

These features allow the rover to operate without constant human intervention and improve surveillance efficiency. E. System Integration and Testing

All hardware and software components are integrated and tested to ensure proper functioning. Individual modules such as sensors, motors, and camera are first tested separately, followed by full system integration.

Testing includes:

- Obstacle detection accuracy
- Motor response and movement control
- Video streaming quality
- Wi-Fi connectivity and range

The system is evaluated under different conditions to ensure reliability and performance.

F. Power Management Implementation

Efficient power management is implemented to ensure long-duration operation. Voltage regulators are used to maintain stable power supply. Battery performance is monitored to avoid sudden shutdowns.

Low-power features of ESP32 are utilized to reduce energy consumption, making the system more efficient and suitable for field use.

V. DEVELOPMENT PROCESS

The Autonomous AI Surveillance Rover using ESP32 is developed using a structured yet flexible approach inspired by the Software Development Life Cycle (SDLC). The process includes planning, design, development, testing, and deployment phases. This approach ensures that both hardware and software components are properly integrated and optimized for real-time surveillance and autonomous operation.

1) Requirement Analysis
In this phase, the project requirements are identified and analyzed. The main objective is to design a rover capable of real-time surveillance, obstacle detection, and remote control.

Functional requirements include:

- Live video streaming
- Obstacle detection and avoidance
- Remote control via Wi-Fi
- Autonomous navigation Non-functional requirements include:
- Low cost and energy efficiency
- Real-time performance
- System reliability and stability

All requirements are finalized before moving to the design phase.

2) System Design
The system design phase defines both hardware and software architecture.

- Hardware Design: Selection of components such as ESP32, sensors (HC-SR04), ESP32-CAM, motors, and motor driver. Circuit connections and rover structure are planned.
- Software Design: Control logic, communication flow, and user interface design are prepared.
- Block Diagram: A complete system block diagram is created to show interaction between all modules.

This phase ensures a clear blueprint for implementation.

3) Development Phase
The development is carried out in stages:

- Stage 1: Setup of ESP32 and basic programming
- Stage 2: Sensor integration and testing (obstacle detection)
- Stage 3: Motor driver and movement control implementation
- Stage 4: Camera module setup and video streaming
- Stage 5: Wi-Fi connectivity and web interface development
- Stage 6: Integration of AI-based obstacle avoidance

Each stage is tested individually before moving to the next.

4) System Integration
In this phase, all modules (sensors, camera, motors, and communication) are integrated into a single system.

- Data from sensors is linked with movement control
- Camera streaming is synchronized with web interface
- Communication between user and rover is verified This ensures smooth coordination between all components.

5) Testing
Different types of testing are performed:

- Unit Testing: Testing individual components (sensor, motor, camera)
- Integration Testing: Checking interaction between modules
- System Testing: Full rover operation in real-time conditions
- Performance Testing: Checking response time, video quality, and obstacle detection accuracy

This phase ensures reliability and proper functioning of the system.

6) Deployment

After successful testing, the rover is deployed for real-time use. The system is powered using batteries and operated in different environments.

- The rover is connected to Wi-Fi for remote access
- Users can control and monitor it via web interface
- Final adjustments are made based on performance The system is now ready for practical surveillance applications.

VI. CHALLENGES AND FUTURE SCOPE

The development of the Autonomous AI Surveillance Rover using ESP32 involves several technical and practical challenges. Understanding these challenges is important to improve system performance and ensure future enhancements.

One of the main challenges is hardware limitations. The ESP32 has limited processing power and memory, which restricts the implementation of advanced AI algorithms and high-quality video processing. Handling real-time video streaming along with sensor processing can sometimes affect performance and cause delays.

Another challenge is power management. Since the rover operates on batteries, maintaining long battery life while running motors, sensors, and camera simultaneously is difficult. Improper power distribution can lead to voltage drops and unstable system behavior.

Network connectivity is also a major issue. The system depends on Wi-Fi for communication, and unstable or weak signals can interrupt video streaming and remote control. This limits the rover's effectiveness in large or remote areas. Obstacle detection accuracy can be affected by environmental conditions. Ultrasonic sensors may not perform well with soft surfaces, angled objects, or outdoor interference, leading to incorrect readings and navigation errors.

User handling and system control is another challenge. Users may face difficulty in controlling the rover smoothly due to delay (latency) or lack of experience with remote interfaces.

Future Scope

The system can be further improved by integrating advanced technologies and additional features.

- Implementation of advanced AI algorithms such as object detection, face recognition, and human tracking for smarter surveillance
- Use of better sensors (like LiDAR or IR sensors)
- for more accurate obstacle detection
- Integration of GPS module for location tracking and path navigation
- Development of a mobile application for easier and faster control
- Use of cloud storage for saving video data and analysis
- Improvement in battery efficiency using solar panels or high-capacity batteries
- Expansion to multi-rover systems for large-area surveillance

With these enhancements, the system can evolve into a more powerful, intelligent, and scalable surveillance solution suitable for real-world applications such as security monitoring, military use, and industrial inspection.

VII. CONCLUSION

This project presented the design, development, and implementation of an Autonomous AI Surveillance Rover using ESP32, which provides a smart and efficient solution for real-time monitoring and security applications. The system integrates key components such as ESP32 microcontroller, ultrasonic sensors, camera module, motor driver, and Wi-Fi communication to enable autonomous navigation and live surveillance.

The rover overcomes the limitations of traditional surveillance systems by offering mobility, real-time monitoring, and reduced dependency on human intervention. The integration of basic AI techniques such as obstacle detection and motion sensing allows the system to operate intelligently in dynamic environments. The web- based user interface further enhances usability by enabling remote control and live video streaming through simple devices like smartphones and computers.

The implementation demonstrates that a low-cost and compact system can deliver effective surveillance performance. The modular architecture ensures flexibility, scalability, and easy future upgrades. Testing results show that the rover performs reliably in obstacle detection, navigation, and real-time communication.

Although challenges such as limited processing power, battery constraints, and network dependency exist, the system provides a strong foundation for future improvements. By integrating advanced AI algorithms, better sensors, and cloud-based technologies, the rover can be further enhanced into a more intelligent and robust surveillance system.

Overall, this project highlights the potential of combining embedded systems, IoT, and AI to develop practical, scalable, and cost-effective security solutions suitable for real-world applications such as home security, industrial monitoring, and defense surveillance.

REFERENCES

[1] Espressif Systems, *ESP32 Technical Reference Manual*, 2020.

[2] Espressif Systems, *ESP32-CAM Camera Module Datasheet*, 2019.

[3] Arduino, *Arduino IDE Documentation*, Available: https://www.arduino.cc

[4] K. Ogata, *Modern Control Engineering*, Prentice Hall, 2010.

[5] H. K. Khalil, *Nonlinear Systems*, Prentice Hall, 2002.

[6] D. Cook and S. Das, *Smart Environments: Technology, Protocols and Applications*, Wiley, 2004.

[7] M. A. Mazidi, *The 8051 Microcontroller and Embedded Systems*, Pearson, 2011.

[8] J. McRoberts, *Beginning Arduino*, Apress, 2013.

[9] R. Siegwart and I. Nourbakhsh, *Introduction to Autonomous Mobile Robots*, MIT Press, 2011.

[10] S. Russell and P. Norvig, *Artificial Intelligence: A Modern Approach*, Pearson, 2016.

[11] *L298N Motor Driver Module Datasheet*, STMicroelectronics.

[12] *HC-SR04 Ultrasonic Sensor Datasheet*.

[13] A. S. Tanenbaum, *Computer Networks*, Pearson, 2010.

[14] *IoT Fundamentals: Networking Technologies, Protocols, and Use Cases*, Cisco Press.

[15] *IEEE Papers on Autonomous Surveillance Systems*, IEEE Xplore Digital Library.