

# REAL TIME NIGHT VISION ROBOT FOR DEFENSE APPLICATIONS USING IOT & RF CONTROL

Suganthi B

Associate Professor  
Department of Electronics and  
Communication Engineering  
RVS College of Engineering and  
Technology  
Coimbatore, India  
suganth.b@gmail.com

Venkateswaran Vijayan

Assistant Professor  
Department of Electronics and  
Communication Engineering  
RVS College of Engineering and  
Technology  
Coimbatore, India  
rvjvenkat@gmail.com

Subhasree V

Department of Electronics and  
Communication Engineering  
RVS College of Engineering and  
Technology  
Coimbatore, India  
subhasreevadi2324@gmail.com

Subalakshmi M

Department of Electronics and  
Communication Engineering  
RVS College of Engineering and  
Technology  
Coimbatore, India  
subal5949@gmail.com

Shaashwadha Sri N

Department of Electronics and  
Communication Engineering  
RVS College of Engineering and  
Technology  
Coimbatore, India  
shaashwadha04@gmail.com

Adarsha V

Department of Electronics and  
Communication Engineering  
RVS College of Engineering and  
Technology  
Coimbatore, India  
v.adarsha2004@gmail.com

**Abstract** - Border security and military surveillance activities need to be conducted in regions that are highly sensitive and risky for human involvement. This calls for continuous monitoring in regions that are dark or have low visibility, especially at night. This paper presents the design and implementation of a real-time night vision reconnaissance robot for efficient border security and military surveillance activities through the Internet of Things (IoT) and Radio Frequency (RF) communication technologies. The proposed system comprises an Arduino Uno microcontroller, an ESP32-CAM module, RF transmitter and receiver units, a PIR motion sensor, a motor driver circuit, and wireless communication interfaces. The proposed system can efficiently transmit real-time video streams through a Wi-Fi network. This enables efficient and effective remote monitoring and control. The proposed system also comprises a night vision camera for efficient and effective operation in dark or low-light environments. The PIR sensor also enables motion detection, thereby triggering an alarm in case of potential intrusion or unauthorized activities. The experimental results verify that the system provides stable mobility, communication performance, low-latency data transmission, and monitoring capabilities under various environmental conditions. The suggested solution improves situational awareness, reduces the operational risk for the personnel, and offers a cost-effective, scalable, and efficient solution for contemporary automated defense and surveillance systems.

**Keywords** - Internet of Things (IoT), Night Vision Robot, RF Communication, Military Surveillance, Border Security, ESP32-CAM, Arduino Uno, Wireless Monitoring, Real-Time Video Streaming, PIR Motion Sensor, Embedded Systems, Remote Surveillance

## I. INTRODUCTION

In recent times, military surveillance and monitoring of borders have emerged as critical issues, owing to the escalating threats of terror, infiltration, and cross-border conflicts. Traditional surveillance practices are mostly based on manual patrolling by soldiers, which often puts them in high-risk situations, especially in unfriendly terrains and conflict zones. These risks are further intensified during night patrols, owing to poor visibility, which often makes it difficult to detect potential threats lurking in the darkness. Thus, there is a pressing need to introduce advanced technology to enable better monitoring with minimal human involvement in such risky terrains [1].

Robotic surveillance systems have been proposed as a promising solution to overcome the challenges mentioned above, as it can provide remote control, navigation, and data acquisition capabilities. The robotic system can perform tasks in a dangerous environment, hence reducing the workload for the military personnel. Due to recent developments in embedded systems, communication systems, and IoT, it is possible to integrate several communication modules into a robotic platform to increase the efficiency of the system. The robotic system generally includes cameras, motion detectors, microcontrollers, and communication modules to collect environmental data and send it to a remote location for analysis [2].

The Night Vision Reconnaissance Robot, which has been proposed, has been particularly developed to aid surveillance

activities within military border regions, particularly when operating in low light or nighttime conditions. Radio Frequency (RF) technology has been used to ensure efficient remote control of robot movement via a network connection. This ensures uninterrupted robot functionality even when operating within regions where network connectivity may be limited. Moreover, an ESP32-CAM module has been implemented to transmit video feeds via a Wi-Fi connection. This provides a real-time video feed of the target region. A Passive Infrared (PIR) sensor has been integrated to aid in the detection of human presence based on infrared radiation. This improves the functionality of the robot in detecting any intrusion. A defense trigger mechanism has been implemented to aid in response when threats are present.

The major aim of this research is to develop a cost-effective, energy-efficient, and effective robotic surveillance system that is capable of operating in night environments, providing real-time situational awareness. By integrating IoT communication, RF wireless, and processing technologies, the proposed system is expected to increase the effectiveness of border surveillance operations and minimize the risk to military personnel. The system is also designed to be modular and flexible, enabling the incorporation of advanced features such as AI-based object detection, thermal sensing, and autonomous navigation in the future [3].

## II. RELATED WORKS

### A. IoT - Based Surveillance Systems

In recent times, there have been various advancements in Internet of Things (IoT) technology, which have enhanced the capabilities of modern surveillance systems. IoT technology enables various platforms to obtain data in real time, monitor them, and communicate with other devices and control centers efficiently. This technology integrates various devices such as sensors and cameras, and cloud computing, to obtain situational awareness in real time. For example, smart surveillance systems based on IoT technology have been designed to monitor critical infrastructure and border regions using various sensor devices and wireless communication protocols. However, there are various issues with such IoT-based surveillance systems, such as network delay, bandwidth, and security threats, which must be considered in such systems [4],[5].

### B. RF-Controlled Robotic Systems

The use of Radio Frequency (RF) control systems has been popular in robotic applications due to their reliability and real-time communication. RF modules allow direct and stable communication between the operator and the robotic platform, with minimal reliance on internet availability. Various research works have shown the potential use of RF-controlled robots in defense and surveillance operations. RF control systems have been found to be effective in real-time operations. However, RF communication may also have some

limitations in terms of communication range and possible interferences in complex environments [6], [7].

### C. Night Vision and Low-Light Imaging Technologies

The role of night vision technology is significant in the implementation of surveillance systems, especially when the environment is low lit. Modern night vision systems use infrared lighting, thermal imaging, and low-light cameras to provide clear video in a completely dark environment. Various studies have also proposed the implementation of night vision cameras along with embedded systems to provide continuous vision in military applications. However, it has also been noticed that the implementation of night vision technology comes at a higher cost, which is a major issue for low-cost robots [8].

### D. Robotic Systems for Military Surveillance

The robotic systems have been increasingly employed in defense scenarios to carry out various operations like reconnaissance, monitoring, and detection of threats. The robots are capable of moving across difficult terrains and are intended to offer real-time information to the military staff. Various robotic systems involve autonomous robots, remotely operated robots, and hybrid robots, which are based on the combination of IoT and AI technologies. Despite the fact that the robots are efficient and reduce the risk to the military staff, various existing robotic systems are costly and lack the integration of communication technologies [9].

### E. Research Gap and Motivation

While there have been considerable advancements in IoT-based surveillance, RF control robotics, and night vision capabilities, there is a lack of a comprehensive system that incorporates all of these capabilities in a cost-effective and efficient manner. There is a lack of a system that is based on both IoT and RF communication, which is very much required in a changing environment. Furthermore, there is a lack of a system that incorporates real-time video streaming, motion detection, and defense capabilities in a comprehensive manner. This research aims to bridge this gap by developing a hybrid robot that incorporates IoT, RF communication, and night vision capabilities in a comprehensive manner [10].

## III. SYSTEM ARCHITECTURE

### A. Overview of the Proposed System

The proposed system consists of a real-time night vision reconnaissance robot suitable for military surveillance. This system incorporates an Internet of Things (IoT) communication protocol and Radio Frequency (RF) control. This provides an efficient system since it can work well in a



monitoring. The system also includes a PIR motion sensor to detect human movement by detecting infrared rays. This increases the robot's surveillance ability. The system also includes a motor driver circuit to move the robot in a particular direction. The microcontroller sends control signals to the motor driver circuit to move the robot in a particular direction. The system also includes a rechargeable battery unit to provide a stable voltage supply to the system. This two-architecture system enables efficient coordination between the execution of remote-control signals and real-time monitoring, thereby increasing the reliability and efficiency of the surveillance system. [13].

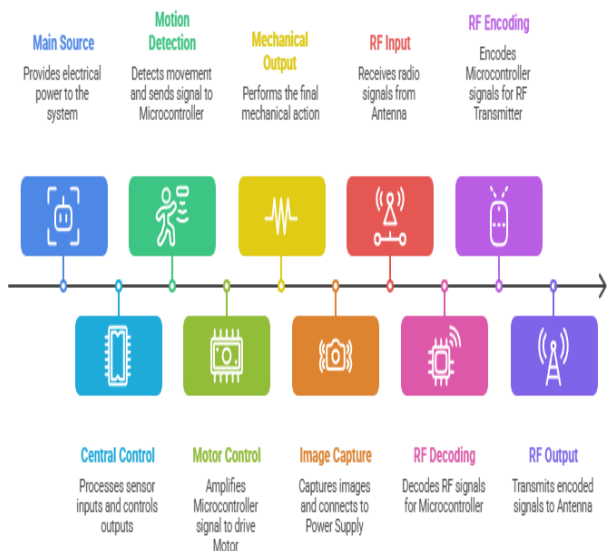


Fig. 3. Spy Robot Architecture

#### D. Software Architecture

The software architecture is developed using embedded programming in Arduino IDE, and it is capable of IoT-based communication and RF signal processing. It is designed to handle various tasks such as sensor data acquisition, control of motors, video streaming, and communication management. It is based on ESP32-CAM, which acts as a web server and provides a facility to access video streaming using a web browser or mobile devices. RF communication protocols are integrated to decode incoming control signals and convert them into movement commands. It is based on modular software architecture, which provides a facility to incorporate advanced features such as object detection and navigation algorithms.

#### E. Communication Architecture (IoT and RF Integration)

The communication infrastructure utilizes both IoT-based wireless communication and RF communication to ensure proper and efficient communication. The communication infrastructure allows the robot to be controlled from a distance using the IoT communication protocol, referred to as Wi-Fi, and at the same time, the dedicated communication infrastructure provides efficient communication through the RF communication protocol. The communication

infrastructure provides efficient communication to the robot, even when the internet is not accessible, due to the utilization of both communication protocols. The communication infrastructure provides efficient communication to the robot, even when the internet is not accessible, due to the utilization of both communication protocols. The communication infrastructure provides efficient communication to the robot, even when the internet is not accessible, due to the utilization of both communication protocols.

## IV. HARDWARE & SOFTWARE IMPLEMENTATION

### A. Hardware Implementation

The hardware implementation of the suggested system aims to provide a reliable performance, low power consumption, and real-time response in surveillance activities. The system consists of several electronic components that work cooperatively to provide sensing, processing, communication, and control. In this system, an Arduino Uno board is used as a central processing unit to process RF communication signals, control robot movement, and receive sensor signals. Similarly, an ESP32-CAM module is employed to capture images in real-time and transmit signals wirelessly over a Wi-Fi network. This helps provide a real-time image of the robot's environment to the operator. Moreover, an RF transmitter-receiver module is employed to provide efficient communication between the control room and the robot. This helps ensure efficient robot movement even in an environment where internet access may be limited. A PIR motion sensor is employed to sense infrared radiation. This helps identify a person's presence in the robot's surrounding environment. A motor driver module, i.e., an L298N module, is employed to control robot movement in different directions. A rechargeable battery unit provides a stable voltage level to all components [14].

Table 1: Hardware Components and Specifications

Component	Specification	Function
Arduino Uno	ATmega328P, 16 MHz	Central control and processing unit
ESP32-CAM	OV2640 Camera, Wi-Fi	Video capture and streaming
RF Module	433 MHz Transmitter/Receiver	Wireless control communication
PIR Sensor	HC-SR501	Motion detection
Motor Driver	L298N Dual H-Bridge	Motor control
DC Motors	6V/12V Gear Motors	Robot locomotion
Power Supply	Li-ion Battery (7.4V/12V)	Power source

## B. Circuit Integration and Interfacing

The hardware components are interconnected with the help of suitable interfacing techniques to enable smooth communication between them. The Arduino Uno is interfaced with the RF receiver using digital input pins, and the control signals for the motors are interfaced with the L298N driver using PWM and GPIO pins, respectively. The ESP32-CAM is interfaced independently for video processing, and power and ground connections are shared with other components of the system. The PIR sensor is interfaced with a digital input pin of the microcontroller, which enables interrupt-based motion detection. Smooth grounding and voltage regulation are maintained to avoid any issues with system performance [15].

**Table 2: Pin Configuration of Arduino Uno**

Component	Arduino Pin	Purpose
RF Receiver	D2	Data input
PIR Sensor	D3	Motion detection input
Motor Driver IN1	D5	Motor control
Motor Driver IN2	D6	Motor control
Motor Driver IN3	D9	Motor control
Motor Driver IN4	D10	Motor control
VCC	5V	Power supply
GND	GND	Ground

## C. Software Implementation

The software implementation is carried out by using the Arduino IDE with Embedded C programming for the Arduino Uno and integrated firmware for the ESP32-CAM module. The system software is designed to handle various functionalities such as RF communication, motor control, sensor data processing, and real-time video streaming. The Arduino Uno is programmed to monitor incoming RF signals, decode command inputs, and control the motor driver accordingly. Conditional statements are included in the Arduino IDE to handle various directions such as forward, backward, left, and right movements of the robot. Interrupt-based programming is also included in the PIR sensor to detect motion and trigger alerts or responses accordingly. The ESP32-CAM module is integrated with a web server to enable real-time video streaming by providing an IP-based interface to access the video stream from a remote location by using a browser or a mobile application with a network connection. [16].

## D. Control Algorithm

The system employs a structured control algorithm to provide synchronization among hardware modules. The steps in the workflow are as follows:

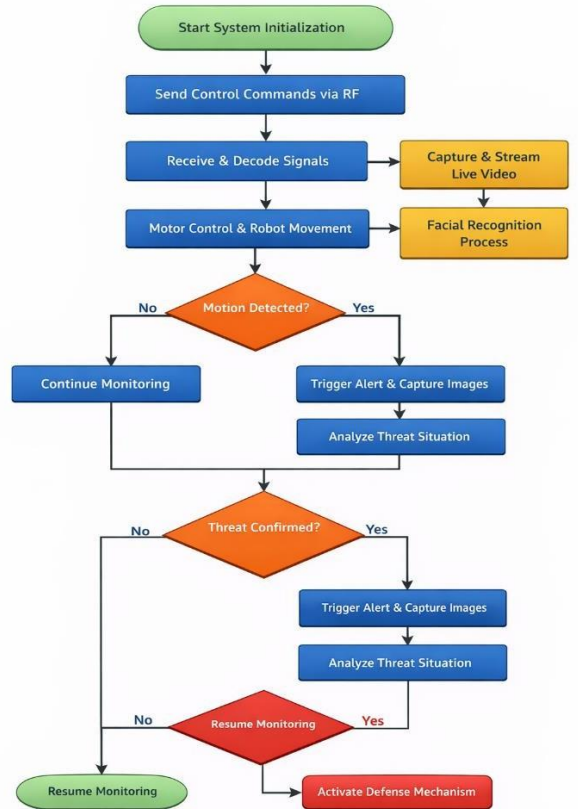
1. Initialize all hardware modules
2. Establish RF communication link
3. Capture user commands from RF transmitter
4. Process commands in microcontroller
5. Control motor driver for navigation
6. Continuously monitor PIR sensor for motion detection
7. Stream real-time video using ESP32-CAM
8. Trigger alert/defense mechanism

The control algorithm ensures coordination among the processes.

## V. METHODOLOGY

### A. System Workflow

The process of the suggested robot surveillance system consists of a series of steps that facilitate an efficient control process. Firstly, an operator sends control signals via a computer or a mobile device connected to a control interface. This signal is then sent via the RF transmitter module, which receives signals from the RF receiver module installed on the robot. This signal is then decoded and sent to the Arduino microcontroller. This helps in precise control of the robot. [17].



**Fig. 4. System Workflow**

At the same time, the ESP32-CAM continues to capture real-time video images from the surveillance environment. The video images are then processed and transmitted through a Wi-Fi network to the monitoring station. The ESP32-CAM acts as a web server to allow the operator to access the real-time video feed through a browser or mobile application [18].

C. Motion Detection Mechanism

In order to improve the surveillance capability of the system, a Passive Infrared (PIR) sensor is also included to detect movement in the area under surveillance. The PIR sensor detects changes in infrared levels as humans move in the area and sends a signal to the microcontroller when motion is detected. Once the motion is detected, the microcontroller sends an alarm signal and activates the camera module to capture more images or focus on the area. This way, the system can respond to possible intrusion in a dynamic way and avoid unnecessary monitoring.

D. Threat Analysis and Response

Once the operator is alerted by the motion alerts and video data, they analyze the situation to ascertain if the motion is a potential threat or not. Depending on this, actions are initiated accordingly. If there is a threat, there is a provision to activate a defense trigger mechanism remotely. This feature makes the system more efficient in defense situations and enables quick decision-making in a hostile environment [19].

E. Facial Recognition-Based Identification

In order to further improve the intelligence level of the surveillance system, a face recognition feature is introduced. A set of multiple images of faces is collected and stored in the database during the training phase. Each person provides multiple images with different facial expressions, angles, and illumination conditions. In the real-time operating phase, the face recognized by the ESP32-CAM module is compared with the stored dataset in the database by employing feature matching. The person under surveillance is classified as an authorized or unknown person by comparing the similarity measures. This increases the reliability of the surveillance system by validating the identities and detecting unknown persons.



Fig. 5. Face Dataset used for Training the Recognition System

A. Experimental Setup

The proposed Night Vision Surveillance Robot has been tested in a controlled indoor and semi-outdoor environment to assess its performance in various lighting conditions. The experimental setup includes a robot platform with an Arduino Uno board, ESP32-CAM module, RF communication system, PIR sensor, and motor driver circuit. The testing environment includes dark and low-light conditions to test the night vision functionality of the proposed system and areas with obstacles to test the mobility and accuracy of the proposed system's control mechanism. A mobile device and laptop are used at the control station for transmitting RF signals and receiving video feeds using Wi-Fi technology.

B. Performance Metrics

The system performance was evaluated based on the following parameters:

- Communication Range (RF and Wi-Fi)
- Video Streaming Latency
- Motion Detection Accuracy
- Power Consumption
- System Response Time

C. Communication Performance

The RF communication system was seen to provide reliable control within a range of 80-100 meters. The video transmission through Wi-Fi also provided stable connectivity within a range of 30-50 meters. The latency in command transmission through RF communication was found to be very low (<100 ms). The latency in video streaming was between 300-500 ms.

Table 3: Communication Performance Analysis

Parameter	Observed Value
RF Range	80–100 meters
Wi-Fi Range	30–50 meters
RF Latency	<100 ms
Video Streaming Latency	300–500 ms

D. Night Vision Performance

The ESP32-CAM module was seen to work effectively in low-light conditions when assisted by infrared illumination. The system was capable of taking recognizable images in

near dark conditions and was thus effective in night surveillance operations. The quality of images obtained by the system slightly deteriorated with increased distance and reduced lighting, but detection was possible within a range of 5-8 meters.

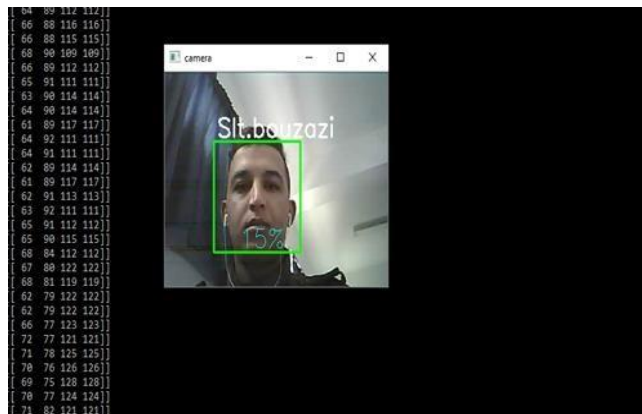


Fig. 6. Real – Time Face Detection & Recognition Output

#### E. Motion Detection Accuracy

The PIR sensor was tested to detect human movements within its working range. It was found that the sensor had an average accuracy of 90-95% in such a scenario. False alarms were noted in instances of sudden temperature variations or non-human heat sources.

Table 4: Motion Detection Performance

Parameter	Value
Detection Range	5–7 meters
Detection Accuracy	90–95%
False Trigger Rate	Low

#### F. Power Consumption Analysis

The total power consumption of the system was also evaluated during its operation. The robot's power consumption was found to be approximately 6-8W during normal operation. The power consumption increased during video streaming and motor activity. The rechargeable battery allowed the robot to operate for an average of 2-3 hours.

#### G. System Reliability and Response

The system showed stable performance during continuous operation, with minimal communication loss and response to control commands. The combination of RF and IoT communication provided redundancy, enhancing the

reliability of the system. The response time to motion detection and alert generation was observed to be less than 1 second, allowing for prompt response to threats.

#### H. Comparative Analysis

In comparison to other conventional surveillance systems, this proposed robot provides better mobility, real-time monitoring, and reduced human risk. Unlike other conventional CCTV systems, this robot is capable of navigating through various terrains for dynamic surveillance.

Table 5: Comparison with Existing Systems

Feature	Traditional Systems	Proposed System
Mobility	No	Yes
Night Vision	Limited	Enhanced
Real-Time Monitoring	Yes	Yes
Remote Control	Limited	Yes (RF + IoT)
Cost	High	Moderate

#### I. Discussion

The experimental results validate that the proposed system provides reliable communication, efficient motion detection, and night surveillance. Although the proposed system performs better in a controlled environment, there are some limitations in the system, such as the range of Wi-Fi communication and environmental interference. These limitations may be overcome in the future by incorporating long-range communication systems and AI detection systems [20] - [22].

## VII. CONCLUSION AND FUTURE WORK

#### A. Conclusion

In this paper, the design and implementation of a real-time night vision reconnaissance robot for defense and border surveillance using IoT and RF communication have been presented. In this system, the integration of remote navigation, real-time video transmission, motion detection, and a responsive control mechanism has been successfully implemented in a compact and cost-effective platform. RF communication plays a vital role in this system, providing real-time control. In addition, ESP32-CAM provides real-time video transmission even in low-light conditions. Experimental results show that this proposed system provides stable communication, efficient mobility, and motion detection, thereby improving the safety of military personnel.

Moreover, the modularity of this system provides the advantage of easily incorporating other features, thereby making this system suitable for many surveillance scenarios.

### B. Future Work

Further improvements may be directed at enhancing the intelligent, robustness, and scalability characteristics of the system. For example, artificial intelligence technologies such as real-time object recognition and facial recognition may be integrated to improve the accuracy of threat recognition.

Further improvements may be directed at adding intelligent navigation capabilities to the system. This may be achieved through the integration of sensors such as ultrasonic or LiDAR sensors. Thermal imaging technologies may also be integrated to enhance performance in extremely low-light conditions.

Further improvements may be directed at adding long-range communication technologies such as LoRa or 5G technologies. This may be directed at enhancing connectivity in remote conditions. Security technologies such as encrypted communications may be integrated to enhance safe operation in military environments.

## REFERENCES

- [1] A. Kumar and B. Singh, "Autonomous surveillance systems for border security applications," *IEEE Access*, vol. 10, pp. 112345–112356, 2022.
- [2] M. N. Halgamuge and D. Niyato, "Adaptive edge security framework for dynamic IoT environments," *Computers & Security*, vol. 148, p. 104128, 2025.
- [3] S. R. Patil, P. Deshmukh, and R. Kulkarni, "IoT-enabled intelligent surveillance robot for defense applications," *IEEE Internet of Things Journal*, vol. 11, no. 3, pp. 2456–2468, 2024.
- [4] L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A survey," *IEEE Communications Magazine*, vol. 54, no. 12, pp. 72–79, 2016.
- [5] J. Lin, W. Yu, N. Zhang, X. Yang, H. Zhang, and W. Zhao, "A survey on Internet of Things: Architecture, enabling technologies, security and privacy," *IEEE Internet of Things Journal*, vol. 4, no. 5, pp. 1125–1142, 2017.
- [6] S. Sharma and R. Gupta, "RF-based wireless controlled robotic vehicle for surveillance applications," *International Journal of Engineering Research & Technology*, vol. 9, no. 6, pp. 45–50, 2020.
- [7] K. P. Singh and A. Verma, "Design and implementation of RF controlled robot for military applications," *Procedia Computer Science*, vol. 85, pp. 210–217, 2016.
- [8] B. Bhushan and A. Kumar, "Night vision technologies for surveillance systems: A review," *Optical Engineering*, vol. 59, no. 4, pp. 041205, 2020.
- [9] R. Murphy, *Introduction to AI Robotics*, Cambridge, MA, USA: MIT Press, 2019.
- [10] M. R. Palattella et al., "Internet of Things in the 5G era: Enablers, architecture, and business models," *IEEE Journal on Selected Areas in Communications*, vol. 34, no. 3, pp. 510–527, 2016.
- [11] A. Al-Fuqaha et al., "Internet of Things: A survey on enabling technologies, protocols, and applications," *IEEE Communications Surveys & Tutorials*, vol. 17, no. 4, pp. 2347–2376, 2015.
- [12] H. Ning and H. Liu, "Cyber-physical-social based security architecture for future internet of things," *Advances in Internet of Things*, vol. 2, no. 1, pp. 1–7, 2012.
- [13] S. Monk, *Programming Arduino: Getting Started with Sketches*, 2nd ed., New York, NY, USA: McGraw-Hill, 2016.
- [14] P. Banerjee and S. Dutta, "Design and implementation of IoT-based smart surveillance systems," *IEEE Sensors Journal*, vol. 21, no. 4, pp. 5678–5685, 2021.
- [15] A. K. Verma and S. Tripathi, "Embedded system design for robotic control applications," *Microprocessors and Microsystems*, vol. 79, p. 103280, 2020.
- [16] Espressif Systems, "ESP32-CAM Technical Reference Manual," 2023.
- [17] R. Szeliski, *Computer Vision: Algorithms and Applications*, Springer, 2022.
- [18] Espressif Systems, "ESP32-CAM Video Streaming and Wi-Fi Networking Guide," 2023.
- [19] W. Zhao, R. Chellappa, P. J. Phillips, and A. Rosenfeld, "Face recognition: A literature survey," *ACM Computing Surveys*, vol. 35, no. 4, pp. 399–458, 2023.
- [20] D. Zhang et al., "Real-time IoT-based surveillance systems: Performance evaluation and challenges," *IEEE Access*, vol. 9, pp. 145678–145689, 2021.
- [21] J. Redmon et al., "You Only Look Once: Unified, real-time object detection," *Proc. IEEE CVPR*, 2016.
- [22] H. Kim and J. Park, "Low-power embedded vision systems for surveillance applications," *IEEE Embedded Systems Letters*, vol. 12, no. 3, pp. 85–88, 2020.