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Full Length Article

Intrusion Detection System Using Regulated Patrolling Robot

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Abstract
Robotics and the Internet of Things (IoT) are rapidly transforming the field of remote monitoring and automation. This project presents the design and implementation of a Wi-Fi-controlled surveillance robot vehicle capable of real-time video streaming and remote navigation through a web-based interface. The primary objective of the system is to develop a low-cost, portable, and efficient robotic platform that can be utilized for surveillance in environments where human access is difficult, hazardous, or impractical.
The surveillance robot is built around the ESP32-CAM module, which integrates a microcontroller, Wi-Fi connectivity, and an onboard camera into a compact platform. An L298N motor driver is employed to control two BO motors, enabling the robot to move in forward, backward, left, and right directions. The entire system is powered by a rechargeable battery, making the robot fully wireless, portable, and suitable for remote operations.
The ESP32-CAM functions as a web server, providing live video streaming to a smartphone or computer over a Wi-Fi network. Users can access a web-based control interface to monitor real-time video and transmit navigation commands to the robot. This functionality enables the robot to operate as a mobile surveillance unit for monitoring both indoor and outdoor environments remotely.
The proposed system offers an effective and economical solution for applications such as security surveillance, military monitoring, disaster rescue operations, industrial inspection, and home automation. The project demonstrates the successful integration of IoT and robotics technologies to develop a smart, scalable, and cost-effective surveillance robot vehicle.

Keywords— *Internet of Things (IoT), ESP32-CAM, Surveillance Robot, Wi-Fi Control, Real-Time Video Streaming, Robotics, Remote Monitoring, L298N Motor Driver, Web-Based Interface, Wireless Robot Vehicle.*

Introduction

The rapid advancement of robotics and Internet of Things (IoT) technologies has significantly improved the development of intelligent monitoring and surveillance systems. Modern security applications require continuous observation of sensitive environments such as industrial facilities, residential buildings, military installations, disaster-stricken regions, and hazardous workplaces. In many of these situations, direct human intervention may be unsafe, impractical, or economically inefficient. Consequently, autonomous and remotely operated robotic platforms have emerged as an effective solution for performing surveillance tasks while minimizing human exposure to risk.

Unlike conventional surveillance systems that rely on fixed-position cameras, mobile robotic surveillance systems provide greater operational flexibility by navigating through different locations and capturing visual information from multiple viewpoints. Their ability to move within an environment enables continuous monitoring of areas that are inaccessible to stationary cameras, thereby improving situational awareness and inspection efficiency.

The proposed Wi-Fi Controlled Surveillance Robot Vehicle is designed as a compact, economical, and portable robotic platform capable of remote navigation and real-time video transmission. The system employs the ESP32-CAM module, which combines a microcontroller, wireless communication, and an onboard camera into a single embedded device. Motion control is achieved through an L298N motor driver interfaced with two DC BO motors, enabling multidirectional movement including forward, reverse, left, and right navigation.

Wireless communication is established through the ESP32-CAM, which functions as a web server hosting a browser-based control interface. Users can access this interface from any smartphone, tablet, or computer connected to the same Wi-Fi network to observe live video and remotely control the robot without requiring dedicated mobile applications. This architecture simplifies deployment while maintaining low implementation cost.

The proposed robotic surveillance platform is suitable for security monitoring, industrial inspection, disaster management, military reconnaissance, and smart home applications. By integrating embedded systems, wireless communication, and robotic mobility, the system demonstrates an affordable and scalable approach for intelligent remote surveillance.

Literature Survey

The development of intelligent robotic surveillance systems has attracted considerable research attention due to the increasing demand for automated security solutions. Traditional surveillance infrastructures generally rely on stationary cameras, which provide limited field coverage and require continuous monitoring by security personnel. These limitations have encouraged researchers to investigate mobile robotic platforms capable of autonomous or remotely controlled surveillance.

Several studies have demonstrated the effectiveness of integrating embedded controllers with wireless communication technologies to develop low-cost surveillance robots. Microcontrollers equipped with Wi-Fi modules enable remote operation through web-based interfaces while simultaneously transmitting live video streams for real-time observation. The availability of compact embedded devices such as the ESP32-CAM has further simplified the implementation of portable surveillance systems by combining image acquisition, wireless networking, and processing capabilities into a single module.

Researchers have also explored the incorporation of multiple sensing technologies, including ultrasonic sensors, passive infrared (PIR) sensors, infrared sensors, and vision-based systems, to improve obstacle detection, motion recognition, and environmental awareness. These sensing techniques enhance navigation performance while reducing collision risks during autonomous or semi-autonomous operation.

Recent developments have increasingly focused on integrating IoT platforms with robotic surveillance systems to enable remote monitoring, cloud connectivity, data storage, and intelligent decision-making. Advanced approaches further incorporate machine learning and computer vision algorithms for object recognition, human detection, and anomaly identification. Despite these advancements, many existing systems remain relatively expensive or computationally complex for small-scale deployments.

The proposed surveillance robot addresses these challenges by utilizing the ESP32-CAM module to provide an economical, lightweight, and portable solution that supports wireless navigation and real-time video streaming. The system demonstrates that efficient surveillance can be achieved through the integration of embedded hardware, IoT communication, and robotic mobility while maintaining simplicity, scalability, and affordability.

System Design and Implementation

System Overview

The proposed intrusion detection system is developed using a regulated patrolling robot capable of performing continuous surveillance in both indoor and outdoor environments. The system combines embedded control, wireless communication, intelligent sensing, and robotic mobility to provide an automated security solution. Unlike conventional surveillance systems that depend on stationary cameras and manual supervision, the proposed robot continuously patrols a predefined region, allowing it to monitor dynamic environments and detect suspicious activities from multiple locations.

The robot is built around the ESP32 microcontroller and the ESP32-CAM module, which together provide computational capability, wireless networking, and real-time video acquisition. Sensor information obtained from ultrasonic sensors is continuously processed by the controller to identify nearby obstacles and potential intrusions. Based on the processed information, the robot performs navigation, obstacle avoidance, and alert generation while simultaneously transmitting monitoring data through a web-based interface. The integration of hardware and software enables reliable operation with minimal human intervention, making the system suitable for smart security applications.

Existing Security Systems and Their Limitations

Conventional security infrastructures primarily employ closed-circuit television (CCTV) cameras, electronic alarm systems, and manual surveillance personnel. Although these approaches provide basic protection, they suffer from several operational limitations that reduce their effectiveness in large-scale or dynamic environments.

Fixed CCTV installations offer continuous visual monitoring but are restricted to predetermined viewing angles, leaving blind spots that cannot be observed without installing additional cameras. Furthermore, continuous observation by security personnel is required to identify suspicious events, which increases operational costs and introduces the possibility of delayed responses.

Electronic alarm systems generally depend on simple sensing mechanisms that detect unauthorized access. However, these systems frequently generate false alarms due to environmental disturbances and cannot provide visual confirmation of intrusion events. Similarly, manual surveillance requires significant human resources and is susceptible to fatigue, inconsistent monitoring, and human error during prolonged operation.

These limitations demonstrate the necessity for an intelligent mobile surveillance platform capable of autonomous movement, real-time sensing, and wireless monitoring.

Functional Architecture

The overall architecture of the proposed surveillance robot consists of sensing, processing, communication, actuation, and monitoring modules that operate cooperatively under the control of the ESP32 microcontroller.

The ESP32 functions as the central processing unit, receiving sensor inputs, executing navigation algorithms, controlling motor operation, and managing wireless communication. The ESP32-CAM module extends the system by providing real-time image acquisition and live video streaming through a web server.

Power for the embedded system is supplied through a rechargeable battery, while a buck converter regulates the voltage to ensure reliable operation of the controller and peripheral devices. Obstacle detection is achieved using an ultrasonic sensor that continuously measures the distance between the robot and surrounding objects. The measured information is processed by the ESP32 to determine appropriate navigation decisions.

Locomotion is accomplished using two DC BO motors driven by an L298N motor driver, which controls motor direction and speed according to commands generated by the controller. A servo motor is incorporated to provide precise angular positioning of the ultrasonic sensor, thereby increasing the effective sensing range during patrolling. A buzzer provides audible alerts whenever abnormal conditions or potential intrusion events are detected.

The ESP32 hosts an embedded web server that generates a browser-based graphical interface through which users can observe live video, monitor system status, and remotely control robot movement using any Wi-Fi-enabled device.

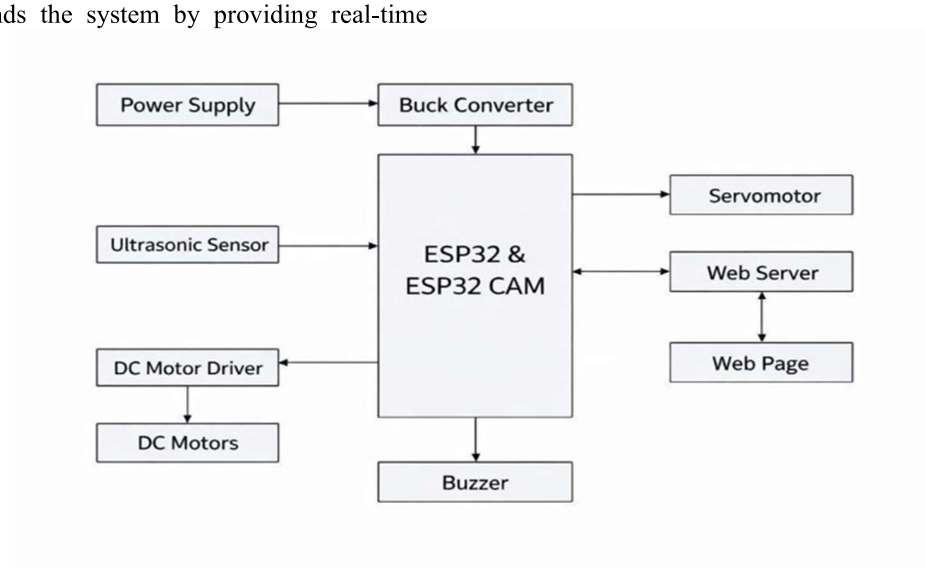

Figure 1; block diagram of the proposed intrusion detection patrolling robot.

Design Methodology

The proposed system follows a modular design methodology that simplifies implementation, testing, and future expansion. Hardware and software components are independently developed and subsequently integrated into a unified surveillance platform.

Initially, system requirements are identified, including wireless communication, obstacle detection, video streaming, remote control, and autonomous navigation. Based on these requirements, suitable hardware components including the ESP32, ESP32-CAM, ultrasonic sensor, servo motor, L298N motor driver, DC motors, buzzer, rechargeable battery, and voltage regulator are selected.

The embedded software is developed to continuously acquire sensor data, execute navigation algorithms, and control robot movement in real time. The ESP32 simultaneously hosts a web server that enables wireless communication with external devices through a standard web browser. Sensor measurements and user commands are processed concurrently to maintain uninterrupted monitoring and responsive navigation.

The modular architecture also facilitates future integration of additional sensing devices, cloud-based monitoring, artificial intelligence algorithms, and advanced security features without requiring significant hardware modifications.

System Analysis

A comprehensive system analysis is performed before implementation to determine hardware compatibility, processing requirements, communication protocols, and power consumption. Particular attention is given to reliable wireless connectivity, efficient motor control, real-time obstacle detection, and stable power regulation. The communication interface is optimized to ensure low-latency transmission of control commands and video streams between the robot and remote users.

Module Design

Each subsystem is designed to perform a dedicated function while maintaining seamless interaction with the remaining components. The ESP32 serves as the primary controller responsible for data acquisition, decision-making, and actuator control. The ESP32-CAM module captures live video and supports web-based monitoring. Ultrasonic sensing provides distance measurements for obstacle detection, whereas the motor driver regulates the speed and direction of the DC motors. The servo motor performs controlled angular movement to improve environmental scanning, and the buzzer generates audible notifications whenever abnormal conditions are detected. The regulated power supply ensures stable voltage delivery throughout the system, thereby improving operational reliability.

System Integration

Following individual module verification, all hardware and software components are integrated into a single embedded platform. The ESP32 continuously receives measurements from the ultrasonic sensor while controlling the servo motor to perform environmental scanning. Distance information is processed in real time to determine the presence of nearby obstacles or possible intrusions.

Simultaneously, the ESP32-CAM transmits live video through the embedded web server, allowing remote users to observe the surveillance area and manually control robot movement whenever necessary. Whenever the measured distance falls below the predefined safety threshold, the controller initiates corrective actions such as stopping, changing direction, or activating the buzzer. This continuous sensing, processing, communication, and navigation cycle enables reliable real-time surveillance with minimal human intervention.

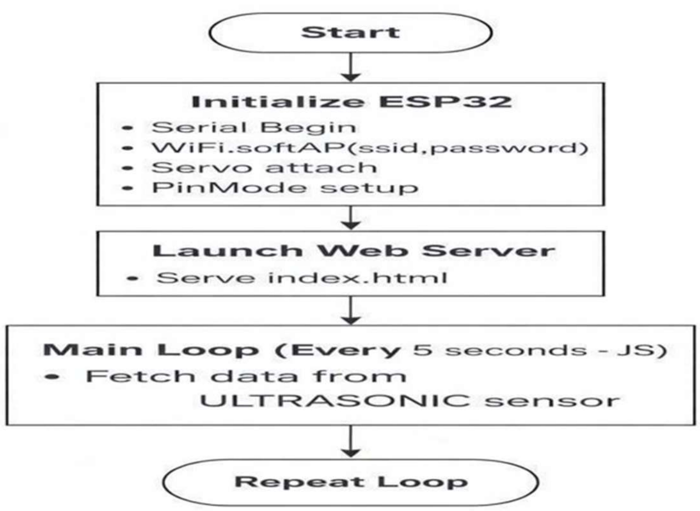

Figure 2; flowchart illustrating the operational sequence of the proposed intrusion detection system using the regulated patrolling robot.

Results and Discussion

The proposed surveillance robot was successfully implemented using the ESP32-CAM, ESP32 controller, ultrasonic sensor, L298N motor driver, DC motors, servo motor, and a browser-based control interface. Experimental testing confirmed that the robot could autonomously patrol the designated surveillance area while maintaining stable wireless connectivity over the local Wi-Fi network. The embedded web server continuously streamed live video, enabling users to remotely observe the monitored environment and control the robot in real time.

The intrusion detection mechanism performed reliably during repeated experimental trials. Human movement and nearby objects were successfully detected within the predefined sensing range, after which the controller immediately initiated the corresponding alert mechanism. Mobile notifications, including *"Motion Detection Triggered"* and *"Human Detection Triggered,"* were successfully generated, confirming the correct operation of the sensing and notification modules. Simultaneously, the live video feed allowed visual verification of the detected event, thereby improving the reliability of the surveillance process.

The navigation subsystem demonstrated smooth forward, reverse, left, and right movement with minimal delay. The ultrasonic sensor continuously monitored the robot's surroundings and effectively prevented collisions by enabling timely obstacle avoidance. Throughout the testing process, wireless communication remained stable, ensuring uninterrupted command transmission and continuous video streaming.

The successful integration of sensing, embedded processing, robotic mobility, and IoT-based communication resulted in a compact and dependable surveillance platform. The developed system fulfilled the intended design objectives by providing continuous monitoring, intelligent obstacle avoidance, real-time video transmission, and prompt intrusion alerts. These capabilities make the proposed robot suitable for applications such as residential security, industrial inspection, warehouse surveillance, educational laboratories, and disaster response operations.

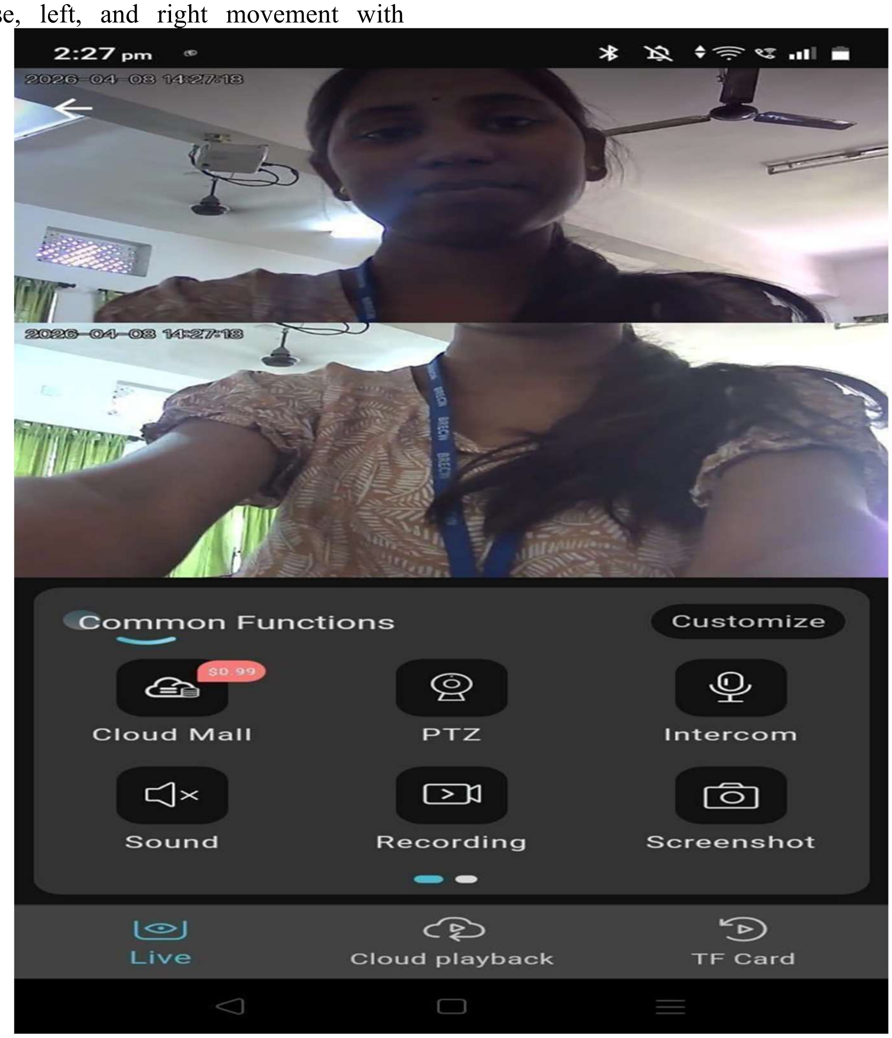

Figure 3; Real Time Surveillance Output Of Patrolling Robot

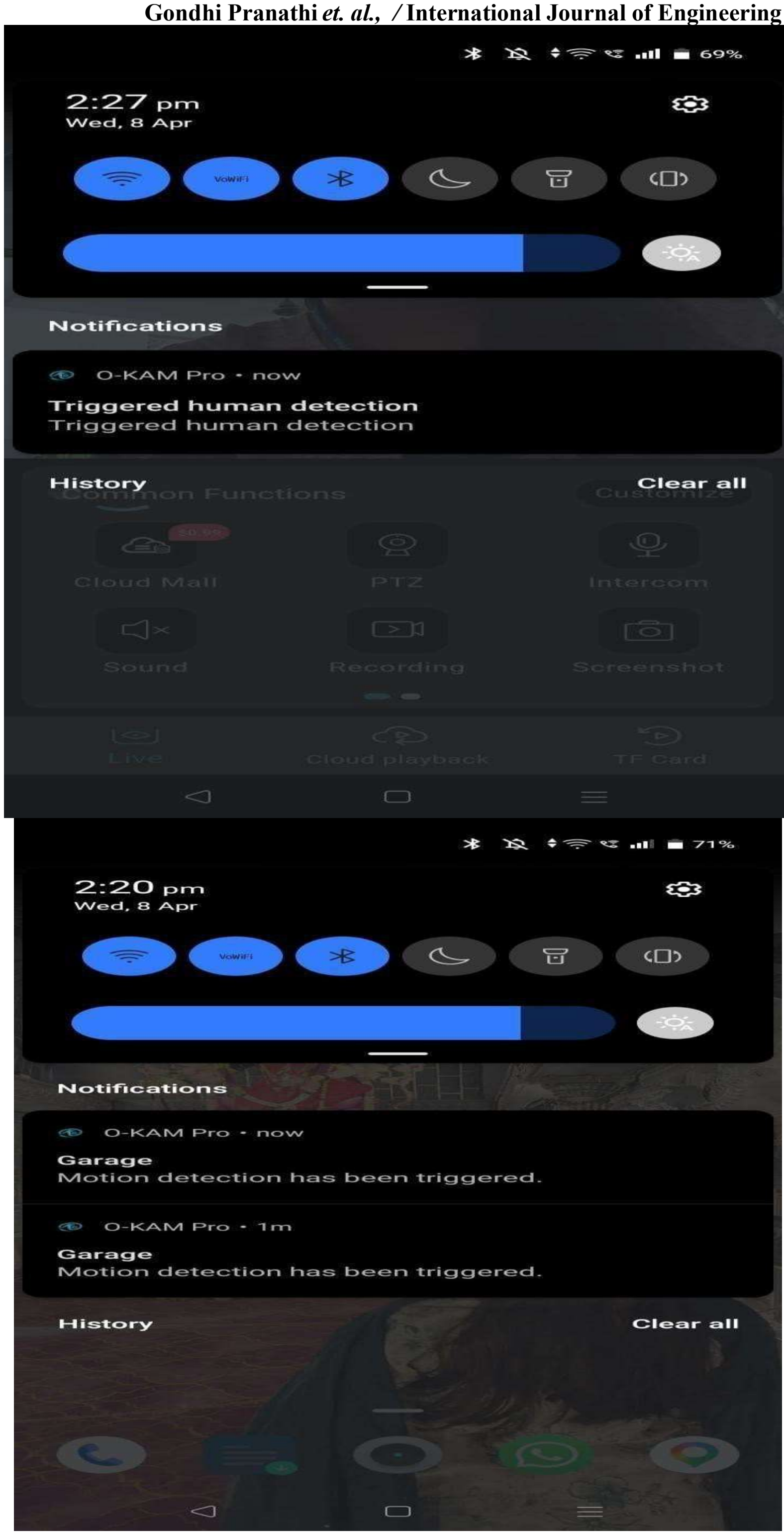

Figure 4; Mobile Notification Alerts For Motion And Human Detection

Discussion

The experimental results demonstrate that the proposed intrusion detection robot provides a practical and economical alternative to conventional fixed surveillance systems. The combination of wireless communication, embedded intelligence, and robotic mobility significantly improves monitoring flexibility while reducing dependence on continuous human supervision. The ESP32-CAM-based architecture successfully delivered stable video streaming and responsive remote control without requiring dedicated monitoring software.

Although the developed prototype achieved reliable performance, the overall effectiveness can be further improved by incorporating artificial intelligence-based object recognition, autonomous path planning, cloud-based data storage, and advanced sensor fusion techniques. Nevertheless, the present implementation validates the feasibility of developing an affordable IoT-enabled surveillance robot capable of performing continuous real-time monitoring.

Conclusion and Future Scope

Conclusion

This work presented the design and implementation of a Wi-Fi-controlled intrusion detection system using a regulated patrolling robot. The proposed system integrates the ESP32-CAM module, ultrasonic sensing, motor control, wireless communication, and a browser-based monitoring interface into a unified surveillance platform. Experimental evaluation confirmed that the robot successfully performed continuous patrolling, obstacle avoidance, live video streaming, and real-time intrusion detection while maintaining reliable wireless communication.

The developed prototype effectively generated motion and human detection alerts, enabling users to monitor protected areas remotely with minimal human intervention. The integration of embedded systems, IoT communication, and robotic mobility resulted in a low-cost, portable, and scalable surveillance solution suitable for indoor security, industrial inspection, warehouse monitoring, institutional campuses, and hazardous environments. The obtained results demonstrate that the proposed system provides an efficient and practical approach for modern intelligent surveillance applications.

Future Scope

Several enhancements can further improve the capability and applicability of the proposed surveillance robot. Future work may incorporate artificial intelligence and deep learning techniques for automatic human recognition, suspicious activity analysis, and object classification. The integration of cloud computing and IoT platforms would enable remote data storage, centralized monitoring, and real-time analytics from any geographical location.

Further improvements may include autonomous path planning using simultaneous localization and mapping (SLAM), GPS-assisted outdoor navigation, multi-robot cooperative surveillance, and 5G-enabled communication for lower latency and higher data throughput. Additional environmental sensors such as gas, smoke, flame, and thermal imaging sensors can expand the system's functionality for industrial safety, disaster management, and emergency response. These advancements would significantly enhance the intelligence, scalability, and operational efficiency of the proposed intrusion detection system while extending its applicability to next-generation smart security infrastructures.

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