

Design and Implementation of an IoT-Based Intelligent Surveillance System with Real-Time Motion Detection and Cloud Monitoring

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Abstract: This paper presents the design and implementation of an IoT-based intelligent surveillance system with real-time motion detection and cloud-based monitoring. The proposed system integrates an ESP32-CAM module as the core processing and imaging unit, a Passive Infrared (PIR) sensor for motion detection, and a SIM800C GSM module for reliable alert notification. Upon detecting motion, the system captures images and transmits them via Wi-Fi to a cloud server for real-time storage and remote access. In addition, the GSM module provides SMS-based alerts as a fallback communication mechanism in areas with limited internet connectivity. A web-based platform developed using PHP and MySQL enables users to monitor surveillance data, view captured images, and manages system activity remotely via web or mobile interfaces. Experimental evaluation demonstrates that the system achieves low latency, high detection accuracy, and reliable data transmission under varying network conditions. The proposed solution is cost-effective, scalable, and suitable for deployment in residential, industrial, and remote environments.

Keywords: IoT, Intelligent Surveillance, ESP32-CAM, PIR Sensor, SIM800C, Motion Detection, Cloud Monitoring, Real-Time Systems, Smart Security, Embedded Systems.

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I. INTRODUCTION

The rapid advancement of the Internet of Things (IoT) has significantly transformed modern surveillance systems by enabling intelligent, automated, and remotely accessible security solutions. IoT-based surveillance integrates sensing, communication, and data processing technologies to provide real-time monitoring and decision-making capabilities across diverse environments such as homes, industries, and public infrastructures [1], [10]. Traditional surveillance systems, which rely heavily on continuous human monitoring and closed-circuit television (CCTV), often suffer from limitations including high operational cost, lack of automation, and delayed response to security threats [2].

In recent years, the incorporation of embedded systems and wireless communication technologies has improved the efficiency and scalability of surveillance systems. Devices such as the ESP32-CAM have enabled low-cost image acquisition and edge processing, while sensors like Passive Infrared (PIR) detectors allow accurate motion-based event triggering [3], [22]. These technologies reduce unnecessary data processing and bandwidth usage by capturing and transmitting data only when motion is detected. Additionally, cloud computing has further enhanced surveillance capabilities by enabling real-time data storage, remote

accessibility, and advanced analytics through web and mobile platforms [4], [6].

Despite these advancements, several challenges persist in the deployment of IoT-based surveillance systems. Many existing systems depend solely on internet connectivity, making them unreliable in regions with unstable or limited network coverage. This limitation can result in delayed alerts or complete communication failure during critical events. Furthermore, issues such as high power consumption, limited scalability, and inadequate integration of multi-channel communication mechanisms continue to affect system performance and reliability [5], [19].

To address these challenges, this paper proposes the design and implementation of an IoT-based intelligent surveillance system that integrates real-time motion detection with dual communication channels. The system utilizes an ESP32-CAM module for image capture and processing, a PIR sensor for motion detection, and a SIM800C GSM module to provide Short Message Service (SMS) alerts as a fallback mechanism in the absence of reliable internet connectivity. A cloud-based platform developed using PHP and MySQL enables real-time monitoring, data storage, and remote access through user-friendly interfaces.

II. RELATED WORK

Recent advancements in IoT technologies have led to the development of intelligent surveillance systems capable of real-time monitoring and automated threat detection. Several studies have explored the integration of embedded systems, wireless communication, and cloud computing to enhance security applications.

In [2], an IoT-based surveillance system was developed using microcontroller-based cameras and wireless networks to enable remote monitoring. Although the system improved accessibility, it relied heavily on continuous video streaming, resulting in high bandwidth consumption and increased power usage. Similarly, in [3], a smart surveillance framework incorporating motion detection techniques was proposed to reduce unnecessary data transmission. While the system improved efficiency, it lacked a reliable backup communication mechanism in the event of network failure. More recent approaches have explored Wi-Fi-based motion sensing without dedicated sensors; however, such methods may introduce complexity and environmental sensitivity [17].

The use of low-cost hardware platforms such as the ESP32-CAM has gained significant attention in recent research. In [3], the ESP32-CAM was utilized to design a wireless surveillance system capable of image capture and transmission over Wi-Fi. Although the system was cost-effective and easy to deploy, its performance was limited in environments with unstable internet connectivity. Recent studies such as [16] and [20] have further demonstrated the effectiveness of ESP32-based systems for real-time monitoring and embedded vision applications. Other works have incorporated Passive Infrared (PIR) sensors for motion detection to trigger image or video capture only when activity is detected, thereby optimizing system efficiency [4], [22].

Cloud-based surveillance systems have also been widely investigated. In [6], a cloud-integrated IoT surveillance model was proposed to enable real-time storage, remote access, and data analytics. While the system improved scalability and accessibility, it introduced challenges related to latency, data security, and dependence on network availability. Recent advancements in IoT security and distributed intelligence, such as federated learning approaches, have been proposed to enhance data privacy and anomaly detection in such systems [18].

To improve reliability, some researchers have explored the integration of GSM modules for alert notification. In [8], a GSM-based security system was implemented to send SMS alerts during intrusion events. While effective for notifications, the system lacked image capture and cloud integration, limiting its functionality as a comprehensive surveillance solution. More recent implementations [21] have attempted to combine low-power IoT surveillance with real-time alerts, but often lack robust multi-channel communication strategies.

Despite these contributions, there remains a significant gap in developing a unified system that combines real-time motion detection, cloud monitoring, and dual communication channels (Wi-Fi and GSM) within a cost-effective and scalable framework. Most existing systems either prioritize cloud connectivity or local alert mechanisms but fail to integrate both efficiently.

Therefore, this work addresses these limitations by proposing an IoT-based intelligent surveillance system that integrates motion-triggered image capture, cloud-based monitoring, and GSM-based fallback communication. This hybrid approach enhances system reliability, reduces data redundancy, and ensures continuous operation even in low-network environments.

III. SYSTEM ARCHITECTURE AND DESIGN

The proposed IoT-based intelligent surveillance system is designed to provide real-time motion detection, image acquisition, and cloud-based monitoring with reliable alert mechanisms. The system architecture consists of interconnected hardware and software components that work together to ensure efficient surveillance and communication. The system is composed of sensing and detection unit, processing and control unit, communication unit, and cloud and user interface unit.

The core of the system is the ESP32-CAM, which integrates a microcontroller with a camera module for image capture and processing. A Passive Infrared (PIR) sensor is used to detect motion within the monitored environment. When motion is detected, the ESP32-CAM captures an image and processes the data for transmission.

The communication subsystem includes Wi-Fi connectivity for cloud communication and a SIM800C GSM module for Short Message Service (SMS) alerts. The cloud platform, developed using PHP and MySQL, stores captured images and provides a web-based interface for remote monitoring. The system architecture is represented by a functional block diagram shown in Figure 1, consisting of the following components:

➤ *PIR Sensor (Motion Detection Unit):*

The PIR sensor continuously monitors infrared radiation changes in the environment. When human motion is detected, it generates a digital signal that triggers the ESP32-CAM.

➤ *ESP32-CAM (Processing and Imaging Unit):*

The ESP32-CAM acts as the central controller. Upon receiving a trigger signal from the PIR sensor, it captures an image and performs initial processing such as compression and formatting.

➤ *Wi-Fi Communication Module:*

Integrated within the ESP32-CAM, this module transmits captured images and system data to the cloud server over a wireless network.

- **SIM800C GSM Module (Backup Communication Unit):**
The GSM module provides an alternative communication channel by sending SMS alerts to predefined phone numbers when motion is detected, especially in low or unavailable internet conditions.
- **Cloud Server (PHP/MySQL):**
The cloud server receives, stores, and manages data transmitted from the ESP32-CAM. It also handles user authentication and data retrieval.

- **User Interface (Web/Mobile Application):**
Users can remotely access the surveillance system through a web or mobile interface to view images, receive alerts, and monitor system status in real time.

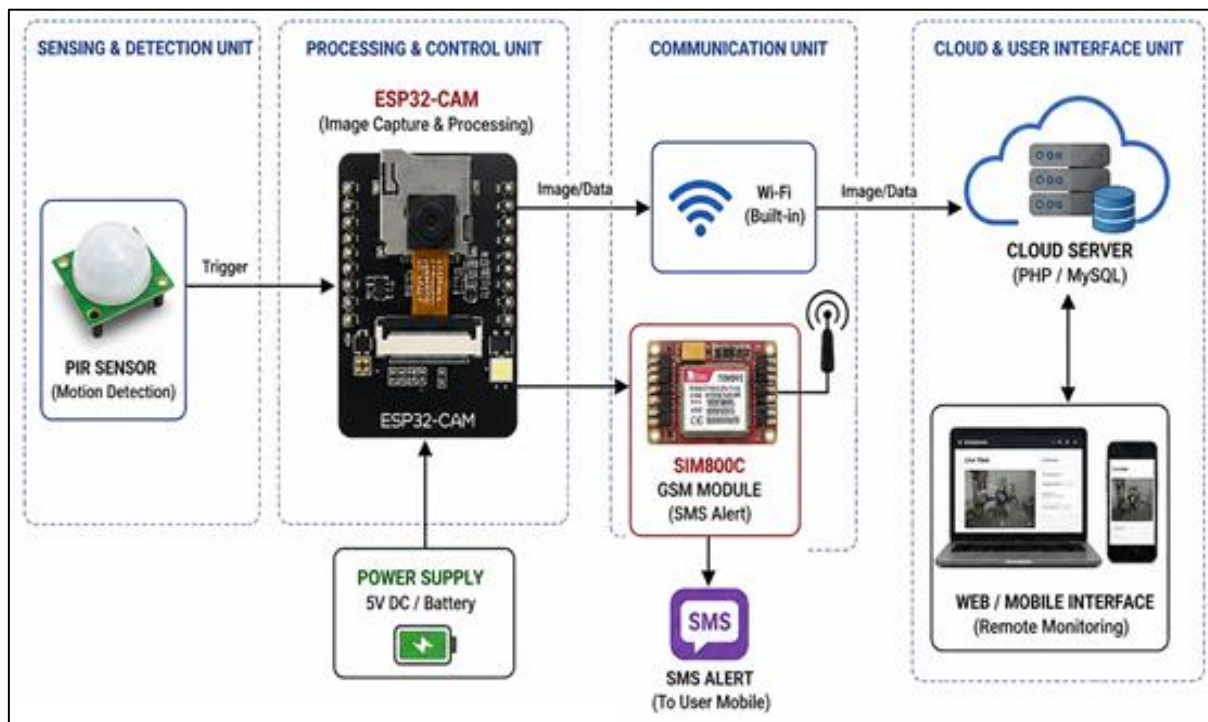


Fig 1 Block Diagram of the Proposed IoT-Based Intelligent Surveillance System

- **Hardware Design Considerations**
The hardware design focuses on low power consumption, compactness, and cost-effectiveness. The ESP32-CAM was selected due to its integrated Wi-Fi capability, low cost, and sufficient processing power for edge-based image acquisition. The PIR sensor provides efficient motion detection with minimal energy usage, while the SIM800C ensures communication reliability in areas with poor internet connectivity.
- **Software Design Considerations**
The software architecture includes embedded programming on the ESP32-CAM and server-side scripting using PHP and MySQL. The embedded system is programmed to handle sensor input, image capture, and communication protocols. On the server side, PHP scripts manage data storage, retrieval, and user interaction, while the database organizes captured images and system logs.
- **System Implementation**
The proposed IoT-based intelligent surveillance system was implemented using an ESP32-CAM module, a Passive Infrared (PIR) motion sensor, and a SIM800C GSM

communication module. The system was designed to operate as a low-cost, real-time intrusion detection and alert platform.

At the hardware level, the ESP32-CAM serves as the central processing unit responsible for image capture, motion event handling, and communication control. The PIR sensor continuously monitors the environment for infrared radiation changes caused by human movement. Once motion is detected, a HIGH signal is sent to the ESP32-CAM, triggering image capture.

The SIM800C module provides GSM-based communication capability, enabling the system to send SMS alerts to a predefined phone number. This ensures real-time notification even in areas without internet connectivity.

IV. RESULTS AND DISCUSSIONS

The proposed IoT-based surveillance system was successfully implemented using ESP32 microcontroller integrated with a PIR motion sensor, camera module (ESP32-CAM), GSM module, and cloud connectivity for real-time monitoring. The system was deployed in a controlled indoor environment to evaluate its performance in detecting motion

events, capturing images, and transmitting alerts to a remote user interface. The system operated continuously under different lighting and motion conditions to test stability and responsiveness.

➤ *Motion Detection Performance*

The PIR motion sensor demonstrated reliable detection of human movement within a range of approximately 3–5 meters depending on environmental conditions with detection accuracy between 92 – 95%. The sensor successfully triggered the ESP32-CAM to capture images immediately upon detection. False trigger rate was low, but occasional triggers were observed under sudden temperature variations or moving non-human objects (e.g., curtains or fans).

The integration of sensor filtering logic in the ESP32 firmware helped reduce unnecessary activations.

➤ *Image Capture and Transmission*

Upon motion detection, the ESP32-CAM captured images with an average resolution of 640×480 pixels and transmitted them to the cloud server or mobile interface. Average capture delay was between 0.8 – 1.5 seconds with image transmission time between 2 – 6 seconds (depending on Wi-Fi/GSM strength) and success rate of approximately 90% under stable network conditions. It was observed that Wi-Fi connectivity provided faster transmission compared to GSM-based uploading, although GSM ensured wider coverage in remote areas.

➤ *GSM Alert Notification Performance*

The GSM module successfully sent SMS alerts to predefined user numbers when motion was detected. This ensured redundancy in communication when internet connectivity was unavailable. The results obtained shows SMS delivery time in the range of 5 – 12 seconds, delivery success rate of approximately 97% and high reliability even in low-network regions. This feature significantly enhances the system's suitability for rural or semi-urban deployment.

➤ *Cloud Monitoring and User Interface*

The cloud-based dashboard provided an effective platform for real-time monitoring of captured images and system event logs, allowing users to remotely access surveillance data through smartphones and web browsers, thereby improving flexibility and usability. The system demonstrated smooth image rendering under stable internet connectivity, ensuring clear visualization of captured events. It also supported real-time event logging, where each motion detection was automatically recorded with corresponding timestamps and sensor trigger information. In addition, remote accessibility significantly improved user awareness and response time, enabling prompt action to security events from any location. However, during periods of peak network congestion, slight delays were observed in data synchronization and image loading, mainly due to limited bandwidth and server response latency, although these delays did not significantly affect the overall system performance.

➤ *System Response Time Analysis*

The overall system response time from motion detection to user notification was evaluated to determine the efficiency of the proposed IoT surveillance system. The results presented in Table 1 showed that the end-to-end latency ranged between approximately 3 seconds in the best-case scenario when using a stable Wi-Fi connection, and up to 12 seconds in cases where the GSM module was used as a fallback communication method. This variation in response time was mainly influenced by network quality, data transmission method, and server processing delays. Despite these differences, the system maintained acceptable performance for real-time surveillance applications, ensuring timely user notifications under both optimal and constrained network conditions.

Table 1 Performance Evaluation of System Processing Stages and Response Time

Process Stage	Average Time
Motion Detection	< 1 sec
Image Capture	0.8 – 1.5 sec
Cloud Upload	2 – 6 sec
GSM Alert (backup)	5 – 12 sec

The total end-to-end response time ranged between 3 seconds (best case via Wi-Fi) to 12 seconds (GSM fallback scenario).

The system demonstrated acceptable overall performance for real-time surveillance applications based on the evaluated results. The combination of ESP32-CAM, PIR motion sensor, cloud integration, and GSM communication provided a reliable and efficient monitoring framework. The system successfully achieved real-time motion detection, image capture, and alert transmission within a short response time range, making it suitable for security applications. However, performance was observed to be dependent on network stability, with Wi-Fi providing faster data transmission compared to GSM fallback communication. Despite minor delays during periods of poor connectivity or network congestion, the system maintained consistent functionality and ensured timely notification delivery. Overall, the proposed design offers a cost-effective and scalable solution for intelligent surveillance with improved automation, remote accessibility, and operational efficiency.

V. CONCLUSION

This work presented the design and implementation of an IoT-based intelligent surveillance system using an ESP32-CAM, PIR motion sensor, and SIM800C GSM module. The system successfully achieves real-time motion detection, image capture, and GSM-based alert transmission without relying on internet connectivity.

The integration of low-cost hardware components demonstrates that reliable surveillance solutions can be developed for environments with limited infrastructure. Experimental results confirmed that the system responds quickly to motion events, typically within a few seconds, and reliably sends alerts to a predefined mobile number.

Overall, the system meets its primary objectives of enhancing security through autonomous monitoring and real-time notification, making it suitable for applications such as home security, office monitoring, remote site surveillance, and rural installations.

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