

Research Article

Real-Time Invasion Monitoring using Integrated Motion Detection and Alert System

Sarafadeen A. Abdulwahab*¹ Akintomiwa J. Adedoyin² Usman B. Ibrahim³, Kehinde M. Adeleke⁴

^{1,2,3}Department of Electrical / Electronic Engineering, Federal Polytechnic, Ayede, Nigeria

⁴Department of Mechanical Engineering, Adeleke University, Ede, Nigeria

Article History:

Received: 11 March 2026 | **Accepted:** 17 March 2026 | **Published:** 29 March 2026

DOI: <https://doi.org/10.5281/zenodo.19303933>

*** Related declarations are provided in the final section of this article.*

Abstract

The research addresses the security issues which have been on the rise in residential, commercial, and governmental settings, hence leads to designing a multipurpose intelligent security system, which would entail sophisticated sensing, communication and control systems and technologies. It builds a versatile security system based on the use of pyroelectric infrared motion detector sensors, ESP camera module to display online digital images of trespassed areas, an alarm buzzer, the GSM module which is used to communicate with GSM telephones, and the Arduino Uno open-source micro-controller which will control the security system. The system seeks to provide solutions to the drawbacks of the common security systems like CCTV or alarm systems i.e. real time monitoring and control of actions like intruders. The security and display system is multipurpose which offers a comprehensive solution to the security of people and property, and the system is simple and convenient to use and make the required modifications as per the attacks and requirements. The study is accommodative to all the elements of designing, constructing and deploying the system, testing and analyzing the performance of the designed system. The system comprises PIR sensors of the movement, GSM modem to communicate with GSM phones, ESP camera to store and take pictures and Arduino Uno microcontroller. The system collects information about PIR sensors and operates with it to relay an image of the burglar to the cell phone of the house owner. The system is designed in such a way that there are units, which include controller, interfacing, GSM module and sensors. Hardware system testing

is a key factor in system design, to establish performance, functionality and compatibility with software applications. It was physically tested on PCB boards and tested with a continuity meter and sensory circuitry. It was designed in a mobile fashion and very precise in identifying intruders and notifying the user through emails and alarm notifications. The device is not only important in residential, business areas and government facilities since house burglary cases are increasing in the cities.

Keywords: PIR sensors, CCTV, GSM module, Remote sensing, Motion detection, Security alert

INTRODUCTION

The growing intricacy of contemporary society and the growing rate of security breaches have augmented the need of smart, receptive, and automated intrusion detectors. Conventional security systems, including single CCTV cameras, primitive alarm systems, and single technology motion sensors, are normally inadequate in offering real time identification, quick alerting, and proactive action. Most of these systems only capture what has occurred with no direct alerting of users whereas others can be hacked or work poorly in diverse environmental situations (Al-Hashemi et al., 2024; Teixeira et al., 2021). Consequently, integrated solutions based on a combination of a variety of sensing and alerting technologies are urgently required to ensure strong security of people and property.

The new technology of embedded systems and low power smart sensors has facilitated production of small systems that can sense the movement of an intruder, take pictures, trigger alarms and transmit warnings to authorized systems without human intervention (Hameed et al., 2022). Combining passive infrared (PIR) sensors with motion detection with real-time image modules like the ESP32-CAM has been useful in detecting human movement in an area being monitored (Kennedy et al., 2024). Combined with such devices communication modules as the GSM system or the wireless Internet, such devices are capable of sending notifications and evidence such as pictures of intruders to the homeowners or security staff on the spot (Kok et al., 2025).

Such responsive systems are also necessary as the incidence of burglary increases, human supervision needs decrease because of the busy schedules, and the security of homes and offices at a distance is expected to be managed more often. Batiha and Krömer (2020) reported that sensing, imaging and communication intelligent intrusion detection solutions offer continuous monitoring capability, quick response and flexibility to a diverse environment. They are also

easy to operate, centrally controlled and far more useful in providing situational awareness as opposed to traditional systems.

The current study is dedicated to the construction and installation of an Integrated Motion Detection and Alert System that will include the use of PIR sensors to detect the movement, the ESP32-CAM module to take a picture of an intruder, the buzzer to notify the users on-site, and the GSM-based communication module to provide the users with the notification remotely. The system will be designed using the Arduino microcontroller to provide real-time monitoring of intrusions and respond automatically (Kennedy et al., 2024). The combination of these technologies is a solution to the weaknesses of the previous systems, as it would guarantee increased accuracy, remote access, and automated distribution of alerts (Kennedy et al., 2024).

This research aimed at advancing the current development of smart security systems as it is a low cost, reliable and scalable intrusion detection system that can be used at homes, offices and government buildings. The system can be used independently, adjust to threats to security and furnish the user with prompt information needed to take preventive measures and quick action.

2.1 Materials

Development of an integrated intrusion detection and alert system utilized a combination of sensing, imaging, processing, and communication components. The major hardware materials are described as follows.

2.1.1 Arduino Uno Microcontroller

Arduino Uno microcontroller is the central processing and control device of the system, as it coordinates all the sensor data streams in and organizes the further alerting mechanisms. Continuous acquisition of data gathered by the PIR motion sensors, interpretation of detection events and initiation of corresponding responses, including triggering the ESP32-CAM to capture the image, turning on the buzzer to create an audible alarm, and sending alerts via the GSM module, is the responsibility of it (Akubude et al., 2020; Prakash et al., 2023).

This combination of digital and analog interfacing capabilities makes the Arduino Uno microcontroller highly suitable for prototyping and implementing embedded control systems. The microcontroller serves as a versatile and adaptable development platform, equipped with a flexible interface that supports a wide range of peripheral connections. The board provides six analog input channels, allowing it to measure and interpret varying analog signals with precision whenever such functionality is required (Adeleke et al., 2025). In addition, It features 14 digital input/output (I/O) pins that enable seamless integration with sensors, actuators, and communication modules for diverse control and monitoring tasks. Its in-built USB support enables it to be programmed and debugged easily and power may be connected either via the

USB or using an external connector giving it flexibility in deployment. The Arduino Uno plays the role of the decision - making point of the system and thus assures the effective coordination of all the modules and thus allows the intrusion detection system to respond to real time monitoring and triggering of alerts as shown in Figure 1.



Figure 1: Arduino uno Open-source Microcontroller

2.1.2 Passive Infrared (PIR) Motion Sensors

Two Passive Infrared (PIR) motion sensors were used in the system to enhance the accuracy and reliability of intrusion detection. These were used because they can work well within a voltage of 3 to 5 V range hence, they can be used with the regulated power supply of the system. The PIR sensors have a detection range of about 0.1 m to 6 m and a wide 120° viewing area (Chen et al., 2022; Pitafi et al., 2023), as Figure 2 shows, which allows a large area to be covered and has few blind spots. The sensors operate by sensing minute changes in the IR radiations emitted by hot objects, especially the human being, as it crosses the sensors. Once the sensor is disturbed by a moving heat source that alters the thermal pattern on the baseline the sensor produces an electrical signal that is transmitted to the Arduino where additional processing occurs. Using two PIR sensors at complementary postures, this system enjoys a high number of false alarm dismissals and it is more responsive to true motion events making it be more reliable in operation in various conditions.

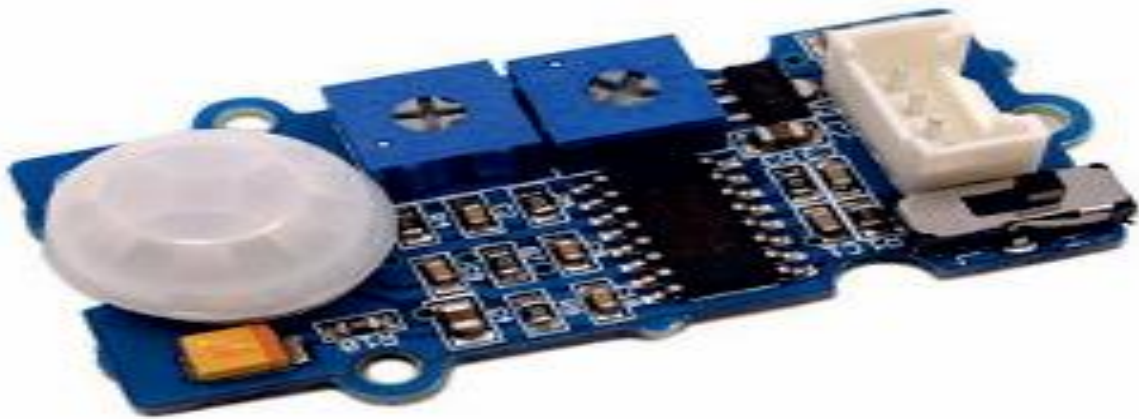


Figure 2: Passive Infra-Red Sensor

2.1.3 ESP32-CAM Module

The software development process was carried out using the Arduino IDE, where the system's control logic was programmed in C/C++. The program code used some functional routines that are necessary to monitor intrusion in real-time. The system launch procedure initially programmed all the digital I/O pins, created serial communication with the GSM module and turned on the ESP32-CAM interface as shown in Figure 3. An algorithm of continuous motion monitoring was subsequently used to scan the results of the PIR sensors in generating an interrupt, such as to process when motion was detected. This led to the process of capturing an image, where the Arduino would be used to send a message to the ESP32-CAM to retrieve and temporarily store an image. After this, the alert transmission process sent the AT commands required to send MMS/SMS notification, including the image taken, to a specified mobile number. At the same time, the buzzer was played to produce immediate warning on the site via an audible alarm.

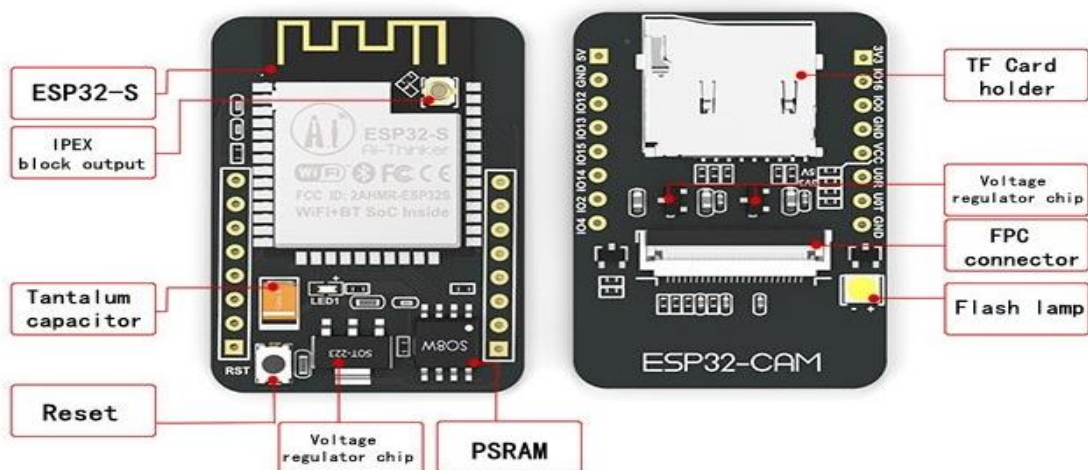


Figure 3: ESP32-CAM

Methods

2.2.1 System Architecture

This is developed around smooth combination of four fundamental functional modules motion sensing, image acquisition, alert triggering, and communication. These modules are functional in a way that they operate together to deliver real-time framework of intrusion detection and notification. The Arduino Uno is the central coordinating unit in the system that is used to coordinate the interactions of all the subsystems as shown in the system block diagram and flowchart contained in the source document. It constantly checks the results of the PIR motion detectors and directly triggers additional measures in case movement is observed. When these occur, the Arduino sends the ESP32-CAM through a series of commands and takes an image of the intruder at the same time sounding the buzzer, to produce a sound alert on-site. Simultaneously, the Arduino also sends a signal to the GSM module to send SMS or MMS notifications with attached images to a specified user cell phone number, generating the required AT commands. This closely coupled architecture guarantees timely detection, effective data collection and quick communications resulting in better responsiveness and reliability of intrusion monitoring system.

2.2.2 Hardware Integration

(a) Sensor Configuration

The layout was calculated so that the motion detectors would primarily cover the area and would not trigger too many false alarms. The Passive Infrared (PIR) sensors were deployed at angles and heights that would enable it to effectively observe the targeted area without interference with the non-relevant sources of heat like direct sunlight, heating vents or reflective surfaces. The location assisted in increasing detection accuracy and stability in situ. The digital input pin of each of the PIR sensors was connected directly to the digital output pin of an Arduino, using which motion signal could be continuously monitored in real-time. Also, the power and ground connections of the sensors were attached to a constant and controlled 5 V source to ensure the sensors operated reliably and do not produce voltage hikes that may affect sensor sensitivity. This intentional arrangement of the system delivered dependable motion sensing functionalities that were appropriate in an indoor setting and outdoor setting.

(b) Camera Interface

ESP32-CAM module was coded separately before system integration was done to verify that it can capture images well and be able to communicate. The module was connected to a USB-to-TTL serial converter, and the GPIO0 pin was deliberately grounded during the process of flashing the firmware in order to put the device in the flashing mode. This set up facilitated easy transfer of the necessary camera software and communication patterns. After the upload was done, the state of GPIO0 was returned to the normal state of operation, and the module was allowed to boot and perform the programmed functions. To have system-level communication, the ESP32-CAM was connected to the Arduino using the UART pins to provide assured data exchange in serial format whenever an image capture command was sent. This special purpose programming and communication arrangement made sure that the camera module ran effectively and in time with the rest of the intrusion detection system.

(c) Alert System Setup

This was done by connecting the buzzer using transistor interface that enabled the Arduino to turn the buzzer upon the intrusion being detected.

(d) GSM Communication Module

The GSM communications module, which is the SIM900, was added to the system to make it easier to send out notifications to the user remotely and forwarded images, thus making the intrusion detection system have a much larger scope than only the physical surroundings. The module was connected to the Arduino Uno through serial communication, and this allowed the smooth data transfer of the microcontroller with the GSM network. Upon detection and processing of a motion event by the Arduino, the microcontroller sends a sequence of standardized AT instructions to the SIM900 module, which is then instructed to make SMS or MMS notifications to a predefined mobile number. These notifications may use textual notifications and take the form of pictures taken by the ESP32-CAM and give the user real-time situational awareness. The GSM module has been set to guarantee the consistency of network enrollment, high message transmission speed, and minimum transmission error, which makes it a critical element to guarantee that the timely remote notification is delivered and that the overall performance and responsiveness of the intrusion monitoring module is improved.

(e) Power Supply

A stable and dependable source of energy to all parts of the microcontroller and peripheral devices of the system was developed as the power supply subsystem. A transformer to reduce the voltage to a lower safer level appropriate to electronic circuits was used to first step down the primary AC mains supply. This was lowered AC current which was then rectified into pulsating direct current. A stable supply of 5 V DC was obtained by rectifying the voltage and then filtering and regulating the voltage with voltage regulation circuitry. This controlled current drives the Arduino microcontroller, PIR sensors, ESP32-CAM module, GSM communication unit, and the buzzer to ensure every element functions within its designated current range. Ensuring the reliable power supply, the system ensures the stable functioning of the intrusion detection and alert system and avoids the malfunctions caused by the voltage.

2.2.3 Software Development

The software development was done with the Arduino IDE where the control logic of the system was written in C/C++. The firmware installed had a number of functional routines that were required to monitor intrusion in real time. Initially, the system start-up code programmed all of the digital I/O pins, connected to the GSM module, and turned on the ESP32-CAM interface. The outputs of the PIR sensors were then scanned using a continuous motion monitoring algorithm and an interrupt process was triggered, such as process at the point of motion being detected. This triggered the image capture process whereby the Arduino communicated with the ESP32-CAM to get and temporarily store an image. After this, the alert transmission routine sent the AT commands that were required to transmit MMS/SMS notifications, which included the image that was captured to a predetermined mobile number. At the same time audible alarm was offered with the help of the buzzer in order to be alerted instantly on-site. The operational logic is represented in the flowchart as shown in Figure 4.

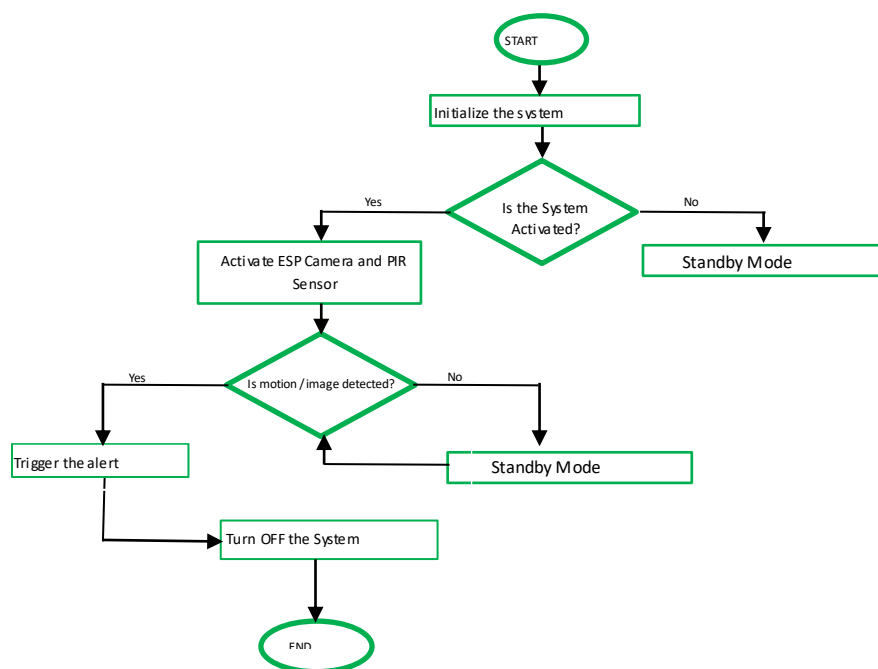


Figure 4: System Flow Algorithm

2.3 Testing and Validation

2.3.1 Hardware Testing

Hardware testing was a strategic inspection of all the physical parts and circuit connection and is done to ascertain the reliability and safety of the system prior to full integration. Primary continuity tests were done in the printed circuit board (PCB) to identify and remove any short circuits or open paths that might cause malfunction or breakage of the components. After verifying the PCB integrity, all hardware components such as the PIR sensors, buzzer, ESP32-CAM module and GSM communication module were individually tested to confirm they were functioning properly under typical electrical conditions. PIR sensors were tested on the functionality of the PIR detecting motion accurately and the buzzer was tested on the ability to generate sound on a regular basis, the camera module was tested on the stability of the image capture and the GSM tested on the ability to register to the network and respond to the commands. Their functioning once confirmed to be functioning correctly at the points where they assembled into the entire system in order to guarantee reliable operation at real - time level.

2.3.2 Experimental Evaluation

This was done in two separate stages in order to determine its performance in different environmental conditions. Early testing was conducted in an open outdoor space to determine the baseline functionality, sensor range and test the sensitivity of the motion detection and alert system without any interference. After successful outdoor performance, the system was implemented into a standard home setting, where lighting changes in the house, wall interference, human behavior, and external sound noise may affect the performance. During both stages, the system was evaluated in accordance with a number of major performance indicators, e.g. accuracy of motion detection, responsiveness between intrusion detection and issue a

notification, image capture and transmission reliability, GSM network resilience when receiving SMS/MMS, and performance of the audible alarm in providing real-time deterrence. This all-encompassing analysis made sure that the system could be used in a wide variety of real-world situations and still work well.

3 RESULTS AND DISCUSSION

3.1 Results

Hardware Functionality and Integration Testing Prelude Tests on the assembled PCB were performed by initial continuity testing to ensure that all connections were correct and clear of short-circuit faults. All the hardware was tested separately to ensure the proper functionality of the PIR sensors, ESP32-CAM module, GSM module, buzzer, and power unit. The sensory circuitry proved to be responsive to the anticipated sensitivity, and this showed that the PIR sensors would be able to respond reliably to changes in infrareds due to human movement and this in agreement with research conducted by Chen et al. (2022) and Purwanto et al. (2023).

Integration testing was done in an open space after the complete assembly of the system. The system was able to pass out of standby and into active monitoring and to sense motion within the sensing range. The ESP32-CAM took pictures in real-time and the buzzer played an immediate audible alarm when the ESP32-CAM spotted pictures. The GSM module then sent out notifications such as intrusion information to the relevant mobile device.

Experimental evaluation in an actual environment to test the applicability in the real world, the system was set up in a home environment. The PIR sensors and the camera module worked well in identifying the intruders into the area under watch. The system was able to constantly send an alarm and notification via email/SMS via the GSM module and this is in accordance with (Kok et al., 2025; Prakash et al., 2023).

Images captured were stored, transmitted and the alert system was reliable in notifying the user about the intrusion. The system also tested to be able to detect door-based intrusion accurately in the case of braking switches, showing that the system is versatile and applicable in various intrusion cases. All these are also supported by Wang et al. (2021) and Rajan et al. (2022).

In general, the performance outcomes reflected:

- PIR sensors have high accuracy in detecting motion.
- Quick picture taking and notification delivery.

- On-site warning reliable activation of buzzer.
- The email/SMS is delivered successfully and the image evidence is available in cloud services.
- Normal working in various lighting and environmental conditions.

The project as shown in Figure 5 demonstrates the complete prototype and test phases of the prototype working, which proves the practicality of the design.

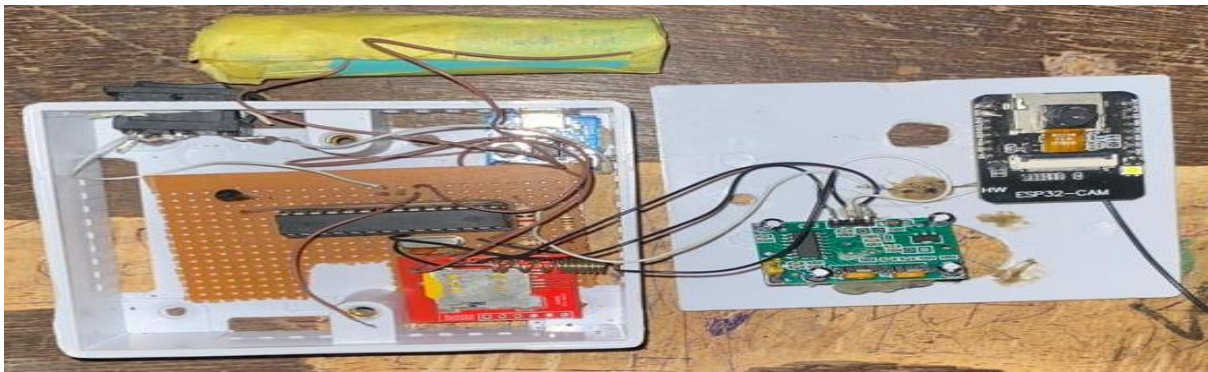


Figure 5: Components Assembly

3.2 DISCUSSION

The experience of the created intrusion detection and alert system proves that the combination of motion sensors, real-time imaging, and GSM-based communication is extremely effective to improve the value of security monitoring. False alarms were also minimized and the accuracy of detection was enhanced as the dual PIR detectors detected the motion within a greater field of view. This is consistent with the previous research (Pitafi et al., 2023; Zhuang et al., 2021) indicating a better reliability with the use of numerous sensors in intrusion detection.

The ESP32-CAM was found to be effective in giving real-time check of the threats as opposed to traditional CCTV systems that frequent record of the events without real-time responses. The integration of imaging and the GSM alerts provided the system with a quicker response to a possible danger by giving the user an audible alert and a remote alert.

The practicality of the system in the homes, offices, and small facilities is confirmed by the performance of the system in controlled and real-world testing environment. It was able to effectively achieve the fundamental goals of intruder detection, image capture and providing user

notification in time, thus it is an automated security system that can work without having human supervision on an ongoing basis.

Moreover, the small size of the system, its low price, and modularity increase the scalability of the system. The fact that it is integrated with the IoT has allowed its future development potential, such as remote access, cloud-based data storage, and compatibility with the smart home platform.

In general, the findings affirm that the suggested integrated system will offer an effective, real extremely efficient, and economical intrusion detection and response system, capable of offering significant enhancements to security devices in single technology.

Conclusion

The study offered the architecture and execution of a composite motion detection and alert system that can offer real-time intrusion surveillance and reaction. Using a combination of PIR motion sensing, ESP32-CAM image acquisition, GSM-based communication and an Arduino-based control architecture, the system was able to mitigate the major limitation of traditional single-use security technologies like the standalone CCTV systems or alarm systems. The experimental findings showed that the system was stable in identifying human movement, taking pictures of the intruder, raise an audible alarm, and send alerts, including pictures to the user via email and the GSM notification system. The two-sensing system enabled better detection precision, whereas the modular architecture of the hardware provided it with portability, low power use, and the ability to be adopted by a vast variety of residential and institutional purposes.

In general, the designed system met the main goal of providing a cost effective, automated and responsive security system that can be used in real time. The successes by which it has worked in the field test clearly shows its prospects to work effectively as a means of reducing the increasing security threats, particularly in homes and government buildings. The work is also the basis of the further improvements like the system of remote access using IoT, cloud-related alert management, and mass implementation as the wider applications of the smart-security.

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