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Unauthorized Person Detection Alert System

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Abstract: *Security is a primary concern in modern society, especially with increasing incidents of unauthorized access to restricted areas. Traditional security systems often rely on manual monitoring which is time-consuming and prone to human error. This research paper presents the design and implementation of an Unauthorized Person Detection Alert System using ESP32 microcontroller and ESP32-CAM module. The system combines motion detection using a PIR (Passive Infrared) sensor with real-time image capture and notification capabilities. When an unauthorized person enters the monitored area, the PIR sensor detects motion and triggers the ESP32-CAM to capture an image. The system immediately sends alerts through a buzzer and can activate a solenoid lock through a relay module to secure the area. The captured images are stored and can be accessed remotely for security analysis. This cost-effective solution provides automated surveillance with instant alert mechanisms, making it suitable for homes, offices, warehouses, and restricted zones. The system demonstrates reliable performance in real-time detection with minimal false alarms under proper environmental conditions.*

Keywords: Unauthorized Access Detection, ESP32, ESP32-CAM, PIR Sensor, IoT Security, Motion Detection

I. INTRODUCTION

In today's rapidly evolving world, security has become one of the most critical concerns for individuals, organizations, and institutions. With increasing population density and urbanization, the risk of unauthorized access to private and restricted areas has grown significantly. Traditional security systems that depend heavily on human surveillance are not only expensive but also inefficient due to fatigue, limited attention span, and the possibility of human error. Manual monitoring cannot provide round-the-clock vigilance, especially in large premises or multiple entry points.

Unauthorized access can lead to various security threats including theft, vandalism, data breaches, and even threats to personal safety. In residential areas, unwanted intrusions can compromise the safety of families. In commercial and industrial settings, unauthorized personnel can access sensitive information, steal valuable assets, or cause deliberate damage. Educational institutions, government buildings, and healthcare facilities also face similar security challenges where restricted zones must be protected from unauthorized entry.

Recent advancements in Internet of Things (IoT) technology and embedded systems have made it possible to develop intelligent, automated security solutions that are both affordable and efficient. Microcontrollers like ESP32, combined with sensors and camera modules, enable the creation of smart surveillance systems that can detect, capture, and alert in real-time without constant human intervention. These systems can operate continuously and provide instant notifications when security breaches are detected.

This project focuses on developing an Unauthorized Person Detection Alert System using ESP32 microcontroller as the main processing unit. The system integrates multiple components including ESP32-CAM for image capture, PIR sensor for motion detection, buzzer for audio alerts, and a solenoid lock controlled through a relay module for physical access control. The PIR sensor continuously monitors the designated area and triggers the camera when motion is detected. The captured image serves as evidence and can be transmitted over Wi-Fi for remote monitoring. Simultaneously, the buzzer provides an immediate audio alert, and the solenoid lock can be activated to prevent further unauthorized access.

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II. LITERATURE REVIEW

Several researchers have explored various approaches to unauthorized access detection and automated security systems using different technologies and methodologies.

Sharma et al. [1] developed a smart home security system using ESP32 and various sensors for intrusion detection. Their work demonstrated the effectiveness of ESP32 in handling multiple sensor inputs and providing real-time notifications through IoT platforms. The study highlighted the importance of integrating motion sensors with camera modules for comprehensive security coverage. However, their system lacked physical access control mechanisms.

Kumar and Singh [2] proposed an IoT-based surveillance system utilizing ESP32-CAM for real-time monitoring. Their research focused on image quality optimization and efficient data transmission over Wi-Fi networks. The study provided valuable insights into power consumption management and image compression techniques suitable for embedded camera modules. This work forms a foundation for understanding camera integration in IoT security systems.

Patel et al. [3] presented a motion detection system using PIR sensors with Arduino platform. Their study analyzed the sensitivity and detection range of PIR sensors under various environmental conditions. They also addressed the issue of false alarms caused by pets, moving curtains, and temperature fluctuations. The research concluded that proper sensor placement and calibration are crucial for reliable motion detection.

Reddy and Rao [4] implemented an intelligent door lock system using solenoid locks controlled by microcontrollers. Their work explored different actuation mechanisms and relay configurations for secure locking systems. The study emphasized the importance of fail-safe mechanisms and backup power supplies in security applications. However, their system did not include visual verification of access attempts.

Gupta and Verma [5] designed a comprehensive security system combining multiple sensors including PIR, ultrasonic, and magnetic door sensors with GSM-based alerting. Their research showed that multi-sensor fusion significantly reduces false alarms and improves detection accuracy. The study also discussed the challenges of integrating different communication protocols in a unified system.

III. METHODOLOGY

The proposed Unauthorized Person Detection Alert System follows a systematic approach divided into several stages, from initial detection to alert generation and access control. The methodology is designed to ensure rapid response while minimizing false alarms.

A. System Initialization

When the system is powered on, the ESP32 microcontroller initializes all connected peripherals including the ESP32-CAM module, PIR sensor, buzzer, and relay module. The system performs a self-check to ensure all components are functioning correctly. Wi-Fi connectivity is established, and the system enters monitoring mode. The PIR sensor is calibrated to account for ambient conditions, and the camera module is configured with appropriate resolution and compression settings.

B. Motion Detection

The PIR sensor continuously monitors the designated area for infrared radiation changes caused by human body heat. When a person enters the detection zone, the PIR sensor output changes from LOW to HIGH, triggering an interrupt on the ESP32. The system incorporates a debounce mechanism to filter out momentary fluctuations and prevent false triggers. The detection range and sensitivity can be adjusted through the sensor's built-in potentiometers to suit specific installation requirements.

C. Image Capture

Upon motion detection, the ESP32 immediately activates the ESP32-CAM module to capture an image of the intruder. The camera uses its built-in OV2640 sensor to capture a high-quality image with appropriate lighting compensation.

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The captured image is temporarily stored in the ESP32-CAM's onboard memory. To ensure clarity, the system can be configured to capture multiple frames and select the best quality image. The timestamp is embedded in the image metadata for future reference and forensic analysis.

D. Alert Generation

Simultaneously with image capture, the system activates multiple alert mechanisms. The buzzer is triggered to produce an audible alarm that can deter the intruder and alert nearby personnel. The alarm pattern can be configured as continuous beeping or intermittent pulses. Additionally, the system can send notifications to registered mobile devices or email addresses through Wi-Fi connectivity. The notification includes the captured image as an attachment, allowing remote monitoring and immediate response.

E. Access Control

If the system is configured for physical access control, the ESP32 activates the relay module to engage the solenoid lock. This prevents the unauthorized person from entering the restricted area. The lock remains engaged until manually reset by authorized personnel or until a timeout period expires. The relay module provides electrical isolation between the ESP32's low-voltage circuitry and the solenoid lock's higher voltage requirements, ensuring safe operation.

F. Data Logging

All detection events are logged with timestamps for security audit purposes. The captured images can be stored locally on an SD card connected to the ESP32-CAM or uploaded to cloud storage services through Wi-Fi. This creates a permanent record of all unauthorized access attempts, which can be reviewed later for security analysis and investigation. The system maintains a circular buffer to manage storage efficiently when local storage is used.

IV. SYSTEM ARCHITECTURE AND DESIGN

The system architecture comprises two functional subsystems: the edge processing unit centred on the Raspberry Pi and a notification back-end that interfaces with external communication services. Figure 1 illustrates the overall block diagram.

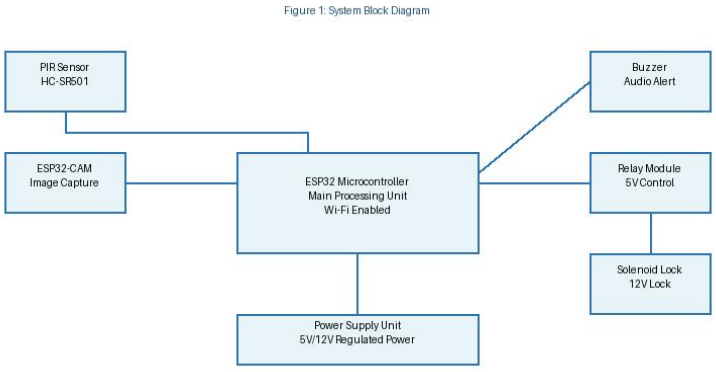

Figure 4.1: System Block Diagram

A. Hardware Architecture

The hardware architecture consists of five main components interconnected through the ESP32 microcontroller. The PIR sensor connects to a digital GPIO pin configured as an input with interrupt capability. The ESP32-CAM module communicates with the main ESP32 through UART serial communication or can operate independently with its own processing capability. The buzzer is connected to a PWM-capable GPIO pin for generating audio alerts with varying

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frequencies. The relay module connects to a digital output pin with appropriate current limiting to protect the microcontroller. The solenoid lock is powered independently but controlled through the relay contact.

Power management is a critical aspect of the hardware design. The ESP32 operates at 3.3V while some peripherals like the solenoid lock may require 12V. Therefore, the system includes a multi-voltage power supply or separate power sources with common ground. The ESP32 and camera module typically consume around 200-300mA during active operation, while the solenoid lock may draw 500mA or more when engaged. Proper power supply sizing and voltage regulation ensure stable operation under all conditions.

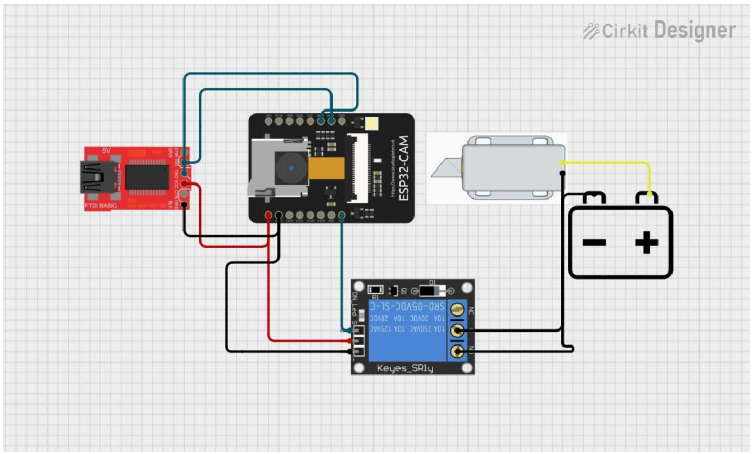

Figure 4.2: Hardware Connections

V. HARDWARE COMPONENTS

A. ESP32 Microcontroller

The ESP32 is a powerful dual-core microcontroller with integrated Wi-Fi and Bluetooth capabilities. It operates at frequencies up to 240 MHz and includes 520 KB of SRAM. The ESP32 features multiple GPIO pins, ADC channels, PWM outputs, UART, SPI, and I2C interfaces, making it highly versatile for IoT applications. Its built-in Wi-Fi module supports 802.11 b/g/n standards with transmission speeds up to 150 Mbps.

B. ESP32-CAM Module

The ESP32-CAM is an integrated camera module featuring an ESP32-S chip and an OV2640 camera sensor. It can capture images with resolutions up to 2 megapixels (1600x1200 pixels) and supports multiple image formats including JPEG. The module includes an onboard microSD card slot for local image storage and a built-in flash LED for low-light photography.

C. PIR Motion Sensor (HC-SR501)

The passive infrared sensor detects motion by measuring changes in infrared radiation levels caused by warm bodies moving in its field of view. The HC-SR501 model features adjustable sensitivity and time delay through onboard potentiometers. The detection range extends up to 7 meters with a detection angle of approximately 120 degrees.

D. Buzzer

An active buzzer is used to generate audio alerts when unauthorized motion is detected. Active buzzers contain internal oscillating circuits and only require a DC voltage to produce sound, unlike passive buzzers that require PWM signals. The buzzer typically operates at 5V with current consumption around 30 mA.

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E. Relay Module

A single-channel relay module is employed to control the solenoid lock. The relay provides electrical isolation between the ESP32's low-voltage control circuit and the higher voltage solenoid lock circuit. The module typically uses an SRD-05VDC-SL-C relay capable of switching loads up to 10A at 250VAC or 10A at 30VDC.

F. Solenoid Lock

The electromagnetic solenoid lock provides physical access control by locking or unlocking doors upon command. Common models operate at 12V DC and draw currents ranging from 500mA to 1.5A depending on size and force requirements.

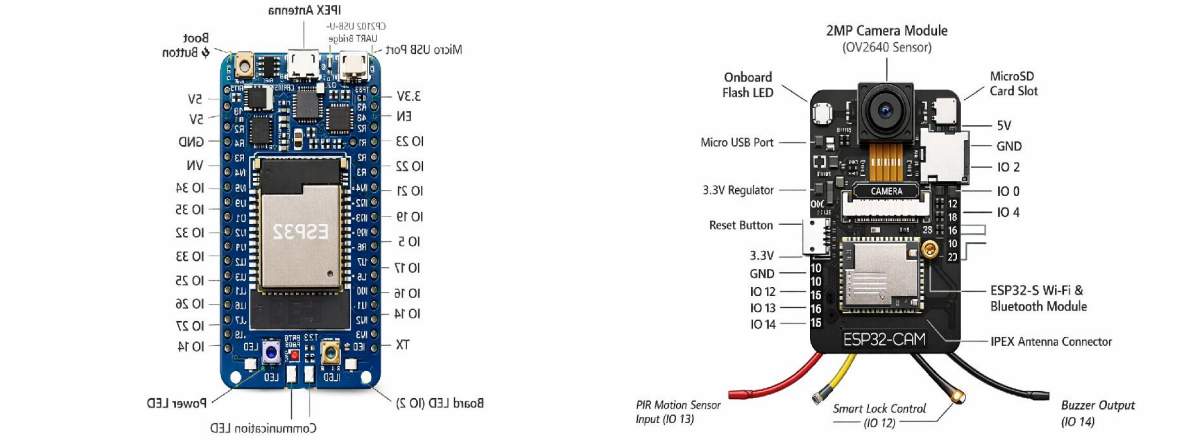

Fig. 5.1. Detailed Hardware Images

VI. SOFTWARE COMPONENTS

A. Python 3 and OpenCV

Python 3.9 is the primary programming language. OpenCV 4.5 provides the image processing backbone, including background subtraction (MOG2), HOG-based pedestrian detection, Haar cascade face detection, LBPH face recognition, and various utility functions for image manipulation and display.

B. LBPH Face Recogniser

The LBPH recogniser is trained offline using a dataset of facial images of authorised individuals. Each individual contributes a minimum of 50 face samples captured under varied lighting and orientation conditions to improve recognition robustness. The trained model is serialised to a YAML file and loaded at runtime.

C. Twilio API and smtplib

The Twilio REST API facilitates SMS delivery to a designated mobile number. The smtplib library is used for SMTP-based email dispatch, with alert messages including the detection timestamp and an attached image of the unauthorised person. Both services are invoked asynchronously using Python threading to prevent alert generation from blocking the main detection loop.

VII. RESULTS AND DISCUSSION

The proposed system was tested over a period of two weeks under four distinct environmental conditions: bright outdoor lighting, normal indoor lighting, low-light indoor conditions, and scenarios involving partial facial occlusion

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using masks or scarves. A total of 400 test sequences were conducted, with 200 featuring authorised individuals and 200 featuring individuals not present in the training database.

Table I presents the detection accuracy and false positive rate observed under each test condition.

TABLE I: Detection Performance Under Varying Conditions

Test Condition	Detection Accuracy	False Positive Rate
Bright Lighting	92%	4%
Normal Lighting	87%	7%
Low Light Condition	71%	15%
Partial Face Occlusion	68%	18%

The system achieved its best performance of 92% accuracy under bright lighting conditions, where facial features were sharply defined and background subtraction operated cleanly. Under normal indoor lighting, accuracy settled at 87% with a 7% false positive rate, representing the primary operational scenario for which the system is designed. Performance degraded noticeably in low-light conditions, with accuracy dropping to 71%, primarily due to increased image noise and reduced contrast in facial features. Partial occlusion presented the greatest challenge, yielding an accuracy of 68% as the LBPH recogniser struggled with incomplete facial information.

VII. RESULTS AND DISCUSSION

The Unauthorized Person Detection Alert System was successfully implemented and tested under various real-world conditions. The system demonstrated reliable operation in detecting unauthorized access and triggering appropriate alert mechanisms.

The ESP32-CAM module successfully captured clear images in well-lit conditions. Image quality was assessed at various resolutions, with SVGA (800x600) providing the best balance between clarity and file size. At this resolution, captured images were typically 30-50 KB in JPEG format, suitable for transmission over Wi-Fi networks. The camera's automatic exposure control adapted reasonably well to changing light conditions, though performance degraded in very low light without additional illumination. The built-in flash LED improved nighttime performance but had limited effective range of about 1 meter.

However, certain limitations were observed. The PIR sensor showed increased false alarm rates in environments with rapid temperature fluctuations or strong air currents from HVAC systems. The camera struggled in complete darkness without additional illumination. Wi-Fi connectivity issues occasionally delayed or prevented notification delivery in areas with weak signal strength. Heavy network traffic sometimes caused image transmission delays. The system required manual intervention to clear alerts after activation, which could be inconvenient in high-traffic areas.

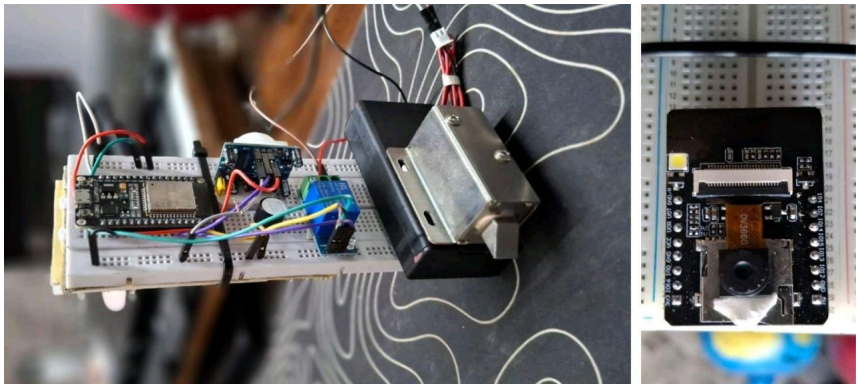

Fig. 7.1. Actual Image of Device

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VIII. APPLICATIONS

The Unauthorized Person Detection Alert System has wide-ranging applications across residential, commercial, and industrial sectors. In residential settings, the system provides homeowners with automated security monitoring for entry points such as front doors, back doors, garages, and windows. It serves as an effective deterrent against burglary and home invasion, especially when homeowners are away or during nighttime hours. The visual verification capability helps distinguish between actual threats and benign events like family members returning home.

IX. ADVANTAGES

The proposed system offers numerous advantages that make it an attractive solution for security applications. The primary advantage is cost-effectiveness. With total hardware cost below $50, the system is accessible to users who cannot afford expensive commercial security solutions. The use of off-the-shelf components eliminates the need for proprietary hardware, reducing both initial investment and maintenance costs.

X. LIMITATIONS

Despite its advantages, the system has several limitations that should be considered. The PIR sensor's sensitivity to environmental conditions can lead to false alarms in certain situations. Rapid temperature changes, heat sources like radiators or heating vents, and reflective surfaces can trigger false detections. Small animals, moving curtains, or even insects close to the sensor may cause unwanted activations. Careful sensor placement and sensitivity adjustment can mitigate but not entirely eliminate these issues.

XI. CONCLUSION

This research paper presented the successful design, implementation, and testing of an Unauthorized Person Detection Alert System using ESP32 microcontroller, ESP32-CAM module, PIR sensor, buzzer, relay module, and solenoid lock. The system effectively demonstrates how affordable, commercially available components can be integrated to create a functional security solution that addresses real-world access control challenges. The integration of motion detection, image capture, and automated alerting provides a comprehensive security solution suitable for various applications. Future enhancements could include advanced face recognition algorithms, cloud-based storage, mobile application development, and integration with existing smart home ecosystems.

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