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Implementation of a Smart Home Intruder Detection System using a Vibrometer and ESP 32 CAM

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Abstract: *Nigeria today is rife with occurrences of intruders breaking into homes at every slight opportunity. The topic of security is quite important; hence this paper presents the development and implementation of a Smart Intruder Detection System utilizing the ESP32-CAM board, the Vibrometer and the ATMega328P microcontroller to enhance lighting, security, and surveillance functionalities. The ESP32-CAM serves as the central control unit, leveraging its built-in Wi-Fi and camera capabilities, while communicating with the ATMega328P microcontroller responsible for managing lighting, security, and surveillance components. The Vibrometer adds a vital layer of security by detecting vibrations associated with forced entry attempts. Upon sensing significant vibrations, the Vibrometer triggers the ESP32-CAM to start an immediate recording of potential intrusions. In the realm of lighting control, the ATMega328P regulates diverse light sources such as LEDs and smart bulbs. The ESP32-CAM facilitates a user-friendly experience, enabling seamless control and automation of the lighting system through a dedicated mobile application or voice commands. For surveillance purposes, the ESP32-CAM captures real-time video, streaming it to the user's mobile device or a centralized monitoring station. The ATMega328P contributes to the system's intelligence by supporting motion detection algorithms, which, in turn, trigger automated alerts and activate lighting or alarm systems in response to detected movement. The precision performance of the components was carried out and the average precision for all the components was 95%. The synergistic integration of the ESP32-CAM board and ATMega328P microcontroller results in a cohesive and intelligent smart home automation solution.*

Keywords: *ESP-32 Cam, Home Security, Intruder Detection, Smart Home, Vibrometer*

1. INTRODUCTION

The escalating demand for smart home technologies underscores the need for innovative solutions that seamlessly integrate convenience, energy efficiency, and security. This project addresses this demand by introducing a Smart Home Intruder Detection System, utilizing the ESP32-CAM board, ATMega328P microcontroller and a vibrometer. Smart home technologies have become integral to modern living, offering enhanced control and automation. The integration of the ESP32-CAM and ATMega328P presents an opportunity to create a comprehensive system capable of advanced lighting, security, and surveillance. A critical component of this system is the vibrometer, a device that senses vibrations caused by potential intruders attempting to break into the home. When the vibrometer detects high-intensity vibrations, it sends a signal to the ESP32-CAM to initiate video recording, thereby enhancing the system's real-time monitoring and response capabilities. This project aims to explore the synergies between these components and their collective impact on user experience, energy efficiency, and home security. The advancement of automation technology makes human life easier, more comfortable, and less demanding in all sectors [1, 2]. Smart home automation systems play a crucial role in enhancing the quality of life by supervising and managing the household environment [3]. In today's world, automated systems are favoured over manual ones [1, 4]. The Internet of Things (IoT) is a promising technology utilized for linking and controlling household devices through the Internet [5]. The field of communications technology has garnered significant interest in smart home automation systems. Sayenduzzaman *et al.* [6] developed a smart home automation system that replaces traditional systems with IoT technologies. It is important to highlight that a significant number of researchers have primarily concentrated on the integration of the Internet of Things (IoT) within residential settings, often utilizing expensive microcontrollers. However, the security dimension concerning unauthorized access to homes remains inadequately explored. This project seeks to fill this gap by creating an affordable smart home solution that employs the economical ESP 32 CAM, alongside the development of a vibrometry system designed to identify potential forced breakins. This system employs an Android application to regulate and supervise appliances, temperature, motion, and gases within the household environment, facilitated through a satellite station and a radio frequency transceiver.

2. MATERIALS AND METHODS

In IoT automated systems, there are two levels of design: hardware architecture and software architecture. The hardware architecture plays a crucial role in the system, as it needs to be properly configured for software applications to seamlessly integrate. The software applications are designed to initiate requests, with the hardware module being responsible for the main output. Both levels must be synchronized for optimal functionality.

2.1 Hardware Architecture

The smart home automation system's hardware architecture includes an ATMEGA328P microcontroller, vibrometer, buzzer, relay module, ESP32 Cam, LED/Bulbs, servo motor, and casing.

2.1.1. ATMEGA328P microcontroller

The ATMEGA328P microcontroller is an 8-bit microcontroller based on the AVR architecture. It is renowned for its flexible design and advanced capabilities, as shown in Table 1 [7].

Table 1 - Features of ATMega328P Controller

Feature	**Description**
CPU Architecture	AVR RISC
Flash Memory	32KB
SRAM	2KB
EEPROM	1024B
I/O Pins	23 General-Purpose
ADC Channels	6 (PDIP), 8 (TQFP/QFN/MLF)
Timers/Counters	3
Communication Interfaces	USART, SPI, I2C
Other Features	Temperature Sensor, Watchdog Timer, Power-Saving Modes
Voltage Range	1.8V - 5.5V

The ATmega328P's design incorporates power management capabilities that are essential for its operation. These capabilities include various sleep modes that allow the microcontroller to conserve power during periods of inactivity or low activity. This feature makes the ATmega328P well-suited for energy-efficient applications and battery-powered systems. In this particular design, a 18050 Li-Ion Battery was utilized to supply the necessary power to the ATMEGA328P microcontroller and other system components. Additionally, a power adapter is employed to convert 220/240V AC into 5V and 12V DC. This adapter provides two DC outputs.

2.1.2 TP4056 module

The module shown in Figure 1 is designed specifically to charge rechargeable lithium batteries. It utilizes the constant-current/constant-voltage (CC/CV) charging method, ensuring a safe and efficient charging process. Moreover, this module incorporates the essential overcharging protection mechanism that is crucial for lithium batteries. Notably, it offers the convenience of charging batteries directly from a USB port, as it operates within a working input voltage range of 4V to 8V.

Figure 1: TP4056 Module

2.1.3 ESP32 cam

The ESP32-CAM as shown in Figure 2 is a small-size, low-power consumption camera module based on ESP32 [8]. Table 2 lists the features of the ESP 32 CAM, which includes an OV2640 camera and an onboard TF card slot.

2.1.4 Servo motor

As shown in Figure 3, a servo motor is a rotary or linear actuator that enables accurate control over acceleration, velocity, and linear or angular position [9]. It is made composed of a motor and a position-feedback sensor. It also needs a reasonably complex controller, which is frequently a specialized module made just for servomotor applications.

Table 2: Features of ESP32 CAM

Feature	Description
Function	Microcontroller with Wi-Fi, Bluetooth, and camera
Processor	ESP32
Connectivity	Wi-Fi, Bluetooth
Camera	Built-in OV2640 sensor
Storage	MicroSD card slot
Power Consumption	Low-power design

Figure 2: ESP32 CAM

Figure 3: Servo motor

2.1.5 16MHZ Crystal oscillator

A 16 MHz crystal functions as a resonator that generates an oscillating signal at a frequency of 16 million hertz. This signal is commonly utilized for timekeeping purposes or to provide a stable clock signal for digital devices. Crystal oscillators are integral components in a diverse range of electronic gadgets, such as computers, smartphones, and radios. Crystals possess a highly ordered structure, characterized by atoms arranged in a lattice formation. This orderly arrangement enables crystals to vibrate at extremely precise frequencies. When an electric current is introduced to a crystal, it vibrates at its inherent frequency. By carefully selecting a crystal with the appropriate natural frequency, it becomes feasible to produce an oscillating signal at any desired frequency.

2.1.6 Vibrometer

The SW-420 Vibrometer sensor as shown in Figure 4 operates on the principle of piezoelectricity. When subjected to mechanical vibrations, its piezoelectric element deforms or compresses, generating an electric charge. This charge is amplified and converted into a measurable voltage signal. By attaching the sensor to the surface or structure under analysis, vibrations are detected and translated into electrical signals. These signals can be further processed and analyzed to determine key vibration characteristics. The sensor's output can be interfaced with external devices for comprehensive analysis. The SW-420 Vibrometer sensor harnesses piezoelectric properties to accurately measure and interpret mechanical vibrations for maintenance and performance optimization purposes.

Figure 4: Vibrometer sensor

2.2 Software Infrastructure

The software design of this project consists of writing codes to implement the desired smart home intruder detection system. This includes the code that would be used to control the microcontrollers, the alert system and the web-based application. The program code is written in CSS (for the microcontrollers and alert system) and HTML for the web-based app. The intelligent homes project has introduced the concept of accommodating multiple home automation devices. In a smart home, there exists a correlation between wireless connectivity, sensors, monitoring, and tracking. Smart homes are comprehensive systems that incorporate various technologies and applications, enabling convenient control and enhanced security for the household. A microcontroller-based smart home automation system is designed. Figures 5 and 6 show the complete circuit and the block diagram for the research respectively.

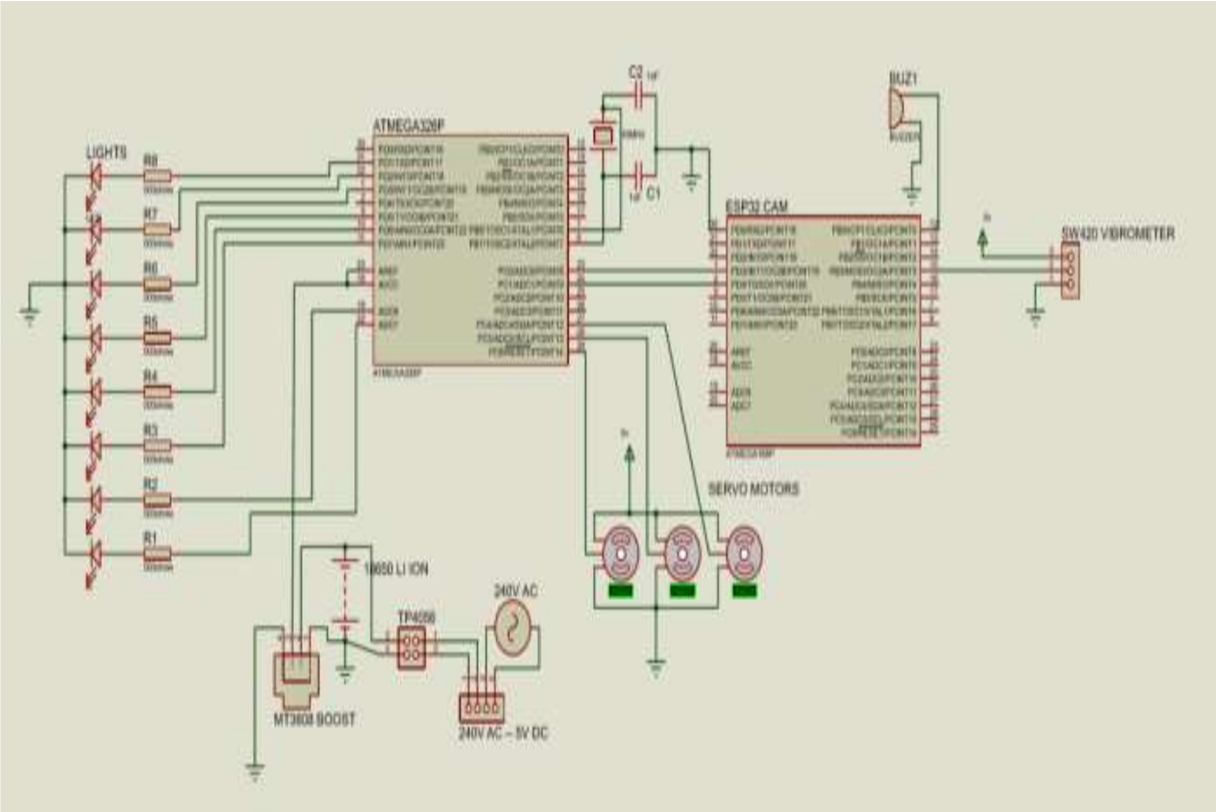

Figure 5: Circuit diagram of the developed system

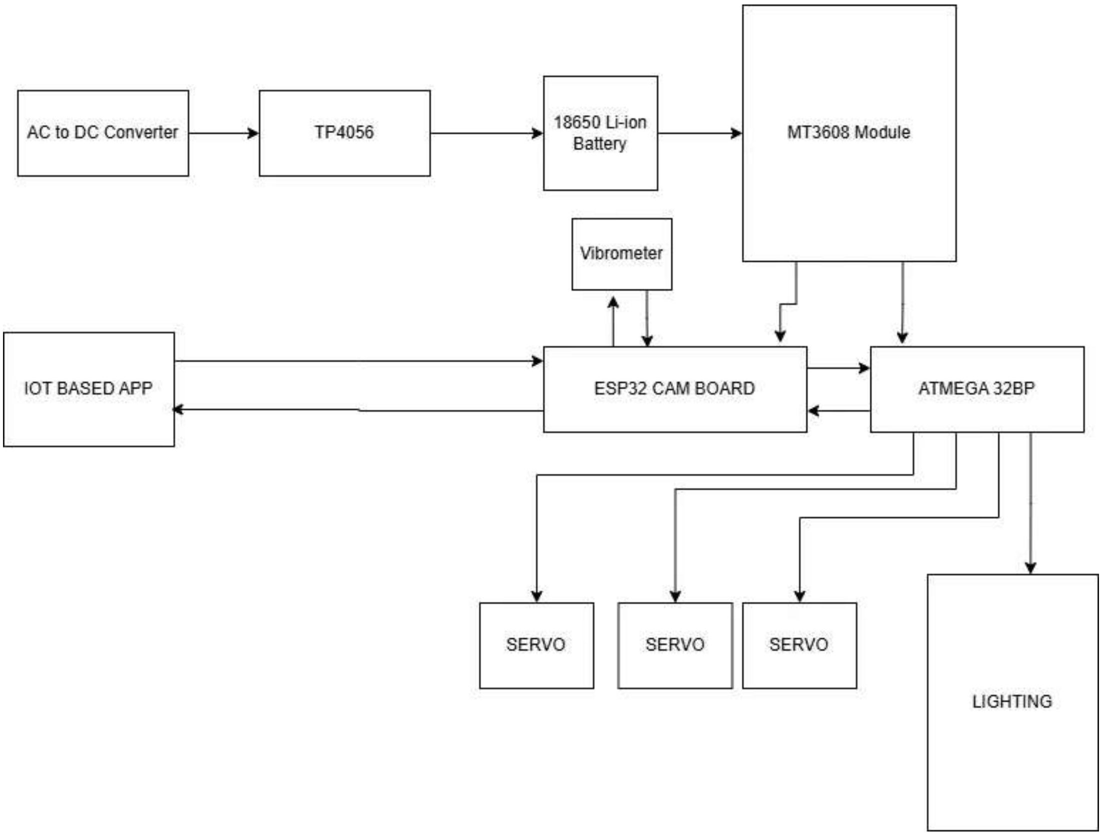

Figure 6: Block diagram of the developed system

The primary responsibility of the client software operating on the server is to oversee the lighting and security units integrated within the home automation system. To connect to the system, users require a personal computer, tablet, or mobile device with internet access. The control software is stored on the server, which facilitates all communications within the home automation system. The server operates bidirectional, recording instructions received from the home automation system into the database and transmitting recorded control instructions from the stored database to the smart home.

A compound containing a two-bedroom flat was modelled using a wooden frame as shown in Figure 8 and the lights and the vibrometer were connected as proposed. The control panel was designed and housed into a plastic frame and then placed beside the wooden structure as shown in Figure 7.

Figure 7: Construction of wooden frame model

The system was linked to an AC power source which was subsequently converted to a DC voltage source using an MT3054. This source was connected to our TP4056 module to help charge the Li-Ion batteries in the control panel. Before testing the system as a whole, each component underwent individual testing to ensure its functionality. Upon connecting the system to a power source, it was checked to see if it was charging the batteries. LEDs were used to indicate status. RED indicated that the batteries were recharging. BLUE indicated that the batteries were full. A Standalone code was run on the SW420 Vibrometer sensor to ascertain the right sensitivity specifications to use in the model. The sensitivity measurement was set to medium to not send false alarms.

A web-based IoT application is created which would primarily be responsible for our input and output. The Web-based IoT application as shown in Figure 8 consists of 7 buttons; four to control the lights and three to control the doors.

Figure 8: The system's web app interface

The server is hosted directly on the ESP32 cam board and receives live camera feed for the compound. A vibrometer sensor and a GSM module are also connected to the ESP32 cam board, with the vibrometer triggering the buzzer and the GSM module when it senses a vibration. The buzzer then goes off and an SMS alert is sent to notify the User of possible break-in. The Peripheral parts of the System (the room lights, the servomotors) are all connected to the ATMega 328P which receives signals from the ESP32 Cam board to control them.

3. RESULTS AND DISCUSSION

The entire system underwent rigorous integration and testing to evaluate the attainment of its intended objectives within real-life conditions. In this model, a web application was integrated into the system to facilitate communication and control of various components as well as to serve as an output for the User (Operator). The web application interface is accessible through the internet, providing seamless communication with the ESP-32 cam board and the ATMega 328P controller equipped with a WiFi module. Within this user-friendly interface, Users can ON and OFF each light in every room, view the activities in the compound via the ESP-32 Cam and control all doors in the model. After successful integration, a performance evaluation of the Smart Home Model was conducted. We tested to see at what threshold the buzzer would go off when the door is rattled. The camera feed of the ESP32 cam was also tested as well as the lights. Three scenarios were tested as well as four different points namely the door (behind which the vibrometer is attached); the front part of the building; the sides of the building (both left and right) and then the back. Scenario 1 details the response gotten from the Alert System when a gentle tap/knock is applied to all four points, and Scenario 2 details the response gotten when medium force is applied to all four points (simulated using a mallet), while the third Scenario details the response gotten when a huge force is applied to all four points (simulated using a hammer). Table 3 shows the results obtained from different scenarios. It can be seen from the table that the alert system doesn't sense vibration at every instance that a force is applied. It also shows that the vibration is felt and an alert is recorded and sent to the user's phone once a certain threshold has been passed. The door remains the most sensitive point of vibration as the vibrometer is stationed there. When vibration is sensed, an alert is sent to the buzzer which gives off an immediate sound as well as the GSM Module which sends an SMS to the user's phone to indicate that an intruder has been detected as shown in Figure 9.

Table 3: Results from the vibrometric sensing

Scenarios	The position where Force is Applied	Was Vibration Detected?
Scenario 1: Gentle tap/knock	Door	No
	Front Wall	No
	Sides + Back	No
Scenario 2: Medium Force applied	Door	Yes
	Front Wall	Yes
	Sides + Back	No
Scenario 3: Huge Force Applied	Door	Yes
	Front Wall	Yes
	Sides + Back	Yes

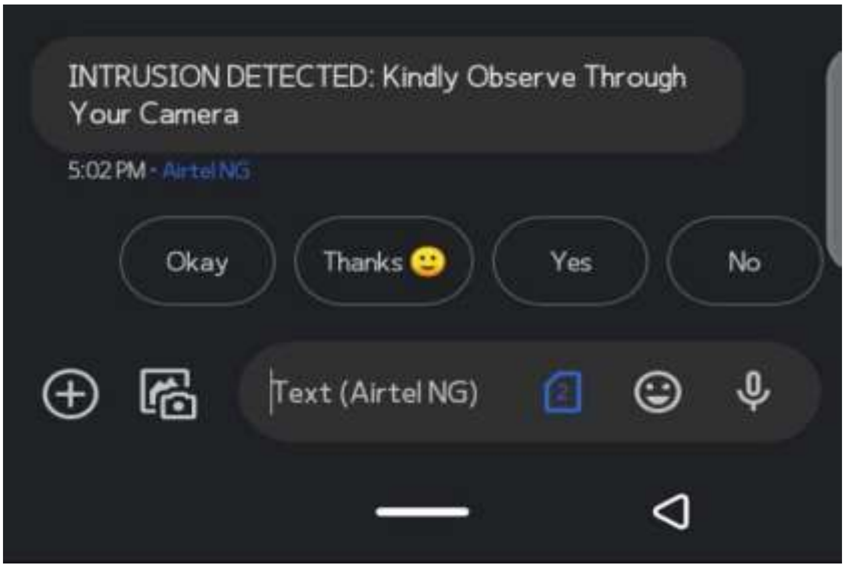

Figure 9: Screenshot of SMS alert

The performance of each core feature was evaluated after 20 trials, as presented in Table 4. The smart home system under consideration demonstrated an average precision of 95% across all components.

Table 4: Performance of the components of the developed system

Component	Total number of Attempts	Number of Successful Attempts	Precision (%)
ATMega 328P	20	16	95
ESP32 CAM	20	17	95
Vibrometer	20	18	90
GSM Module	20	20	100
		Average	**95**

4. CONCLUSION

The development of a smart home intruder detection system using a vibrometer and ESP32 CAM represents a significant advancement in home security technology. By leveraging the sensitivity of vibrometer sensors to detect unusual vibrations and the ESP32 CAM's capabilities for real-time video streaming, homeowners can achieve enhanced surveillance and immediate alerting mechanisms.

This methodology provides a structured framework for the design, implementation, and testing of the system. Key components such as hardware setup, software development, and testing protocols ensure that the system operates effectively in real-world conditions. Furthermore, the inclusion of future enhancements, such as machine learning and additional sensors, opens pathways for continuous improvement and adaptability to evolving security challenges.

Ultimately, this project not only bolsters home security but also empowers homeowners with the tools to monitor their environment, fostering peace of mind and proactive safety measures. Through careful planning and execution, this smart home intruder detection system can serve as a reliable guardian for residential spaces.

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