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ENHANCING COVERT INTRUDER DETECTION IN SMART HOMES: AN OPTIMIZED LOW-POWER ESP32-CAM PIR SYSTEM

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Abstract

The current home security systems in Nigeria are frequently insufficient and susceptible to being bypassed by criminals, leading to a decline in individuals' perception of safety. This work aims to tackle this urgent matter by creating a home security system that utilizes a microcontroller and incorporates image capturing functionality using an ESP32-CAM module and passive infrared (PIR) sensors. The system identifies trespassers using passive infrared (PIR) sensors, takes their photographs using the camera, and saves the images on an SD card and web server for evidential purposes and remote surveillance. The system's performance and functionality were validated by comprehensive testing, which involved software simulations, hardware simulations, and post-implementation assessments. The proposed approach provides a cost-effective and reliable alternative to traditional manual surveillance, minimizing the likelihood of human errors and providing real-time monitoring with visual evidence to aid law enforcement. While the system shows promising results, further research is recommended to integrate cloud computing, machine learning, advanced computer vision algorithms for facial recognition and behavior analysis, and smart home technologies to provide a comprehensive and intelligent security solution. In order to enhance the system's ability to withstand challenges and be effectively used in practical situations, it is advisable to enhance energy efficiency, enhance user experience, and do thorough testing of scalability and dependability in many circumstances.

Keywords: Home security, Microcontroller, Image capturing, Intruder detection,ESP32-CAM, Passive infrared sensors

1.1 Introduction

Intrusion detection systems have been the subject of extensive research and significant advancements since the late 1970s. The way individuals anticipate home automation and security systems to function has undergone a significant transformation because of the rapid advancement of technology. In the past, most security systems were founded on mechanical locks and manual controls, which were frequently inadequate to deter professional intruders. However, the security landscape has undergone a substantial transformation because of the proliferation of internet-connected devices, which has resulted in the pervasive adoption and implementation of advanced security protocols. Currently, intrusion detection systems employ wireless sensor and actor networks in conjunction with commonly employed computational methods. The Internet of Things (IoT) and the proliferation of wireless sensor networks have made advanced home security systems accessible. These systems utilize computer vision and image processing techniques to improve the detection of intruders and increase the capacity for monitoring. These systems employ state-of-the-art technology to promptly notify homeowners, evaluate facial characteristics, and identify and monitor illegal individuals, as per Yavuz et al. (2020). The development of identification and reaction mechanisms that are both efficient and accurate is facilitated by computer vision techniques (Ganesh and Gunavathi, 2019). The utilization of cloud computing and machine learning technologies has significantly improved home security systems, including intelligent decision-making, remote monitoring, and comprehensive data analysis. Cloud-based systems are capable of securely storing and monitoring substantial quantities of surveillance data, as per Alam et al. (2021). As a result, this data can be employed to construct prediction models, analyze behavior, and identify patterns. Recent advancements in these fields have established a solid foundation for the construction of a home security system that includes microcontrollers and photography capabilities. This objective is the principal motivation for this investigation.

1.2 Statement of the Problem

The government is dealing with major security problems because of persistent criminals and those who commit various crimes by getting around the present security protocols. People are less confident about the safety of their own houses and localities because of the general insecurity. Human mistake is one of the expensive and insufficient conventional security measures to save and review video recordings. These limitations aggravate the issue of insecurity by making it more difficult to keep an eye on and capture criminals. To overcome these obstacles, a very safe and effective monitoring system must be established. A good strategy is to use a microcontroller-based video surveillance system to collect and analyze images. The primary objectives of this system are to use real-time monitoring, reduce the possibility of human mistakes, and provide an affordable way to store and analyze video data. Nigeria's security may be greatly enhanced by this approach, which strengthens the capacity to identify and stop criminal activity by the application of contemporary technology.

1.3 Aim and Objectives

The aim of this research is to develop a microcontroller-based home security system with image capturing capabilities. The specific objectives of this study are:

1. To design a Microcontroller-Based Home Security System with Image Capturing
2. To Simulate the Designed System with Proteus Professional Software
3. To Implement the Home Security System with Image Capturing

1.4 Scope of the Study

This project consists of hardware and software parts to create and put into use an image-capture home security system based on microcontrollers. One hardware component is using a passive infrared (PIR) sensor to identify an intruder in a confined space. The microcontroller triggers the sensor, which then instructs a connected camera to take and save pictures of the invader, therefore offering tangible proof of the security breach (Rghioui et al 2017).

Software-side, the microcontroller, sensor data management, and picture taking are all handled by source code written in the Micro C Pro programming language. The work takes use of current developments in wireless sensor networks and the Internet of Things to provide advanced home security capabilities including remote access and real-time monitoring (Yavuz et al., 2020). Furthermore, investigated is the possibility of future integration with machine learning and cloud computing to improve the intelligence, scalability, and functionality of the system. Further enhancing the efficacy and flexibility of the system are these technologies, which enable remote monitoring, data analysis, and intelligent decision-making (Singh et al., 2020).

1.5 Rationale for the Study

This study was inspired by the pressing need to address the significant security challenges that Nigeria is currently confronting. The inherent simplicity with which criminals can bypass existing security protocols leads to an elevated degree of unpredictability that poses a threat to the safety of the general public. Conventional security solutions, such human monitoring, are expensive, ineffective, and prone to human mistake, especially when it comes to recording and reviewing video.

A more safe and effective solution is sought to be offered by the suggested picture acquiring and processing capabilities of the microcontroller-based video surveillance system. Human mistake will be lessened by this technology, which will also improve real-time monitoring and lower the price of surveillance. The system achieves accurate intruder identification, quick alarms, and intelligent decision-making based on pattern recognition and behavior analysis by using cutting edge technologies including computer vision, cloud computing, and machine learning.

In the end, this paper discusses how urgently Nigerian security has to be strengthened. This project seeks to improve people's living conditions by creating a cutting-edge home security system that uses the newest technology developments.

1.6 Significance of the Study

The importance of this work is in its capacity to transform the domain of home security by tackling the fundamental constraints of conventional systems. The study presents an advanced home security system that utilizes a microcontroller and is capable of recording images. This system provides improved protection and safety by enabling real-time surveillance and quick response to security breaches. This innovation enhances the security of residential properties and offers a cost-effective solution by utilizing affordable microcontrollers and readily accessible components. As a result, it reduces the expensive installation and maintenance expenses typically associated with traditional systems. Through automation of the detection and alarm processes, the implemented solution guarantees consistent and reliable security alerts, so reducing the likelihood of human error that is sometimes encountered in manual surveillance. Law enforcement agencies greatly benefit from the capacity to gather and save high-resolution images of intruders. It acts as a powerful deterrence for possible wrongdoers and significantly streamlines the procedure of finding and punishing offenders. The modular architecture of microcontroller-based systems facilitates seamless scalability and customization, empowering homeowners to tailor the system to suit evolving security requirements by incorporating additional sensors or cameras as necessary.

Moreover, the system's capacity to effortlessly communicate with pre-existing smart home gadgets builds a cohesive and comprehensive network for home automation and security. Offering centralized control and monitoring, this enhances the user experience. The Internet of Things (IoT), computer vision, and machine learning technologies are integrated into home security systems in this work to enhance both theoretical and practical understanding. This prepares the ground for next research and advancements in this field. It

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encourages creativity and technical development, which leads to the creation of ever more complex and intelligent home security systems.

2.0 Literature Review

An electronic version of a burglar alarm is essentially a home security system. The primary objective of this system is to issue a warning in the event that an unauthorized individual violates your security measures and gains entrance to your residence, subsequently stealing valuable items.

The identification of intruders is a vital component of access control. The fundamental basis for access control is centered around ensuring home security. In the absence of it, the credibility of a facility is doubtful. A home security system, as described in this thesis on physical security, is a configuration of electrical equipment designed to detect the presence or attempted entry of an intruder and trigger an alert. A Home Security system may entail the replacement of human observation with technological surveillance. Professionally designed, planned, installed, and routinely serviced home security systems are long-lasting and efficient. In the absence of these essential criteria, a home security system may be susceptible to being bypassed, experiencing malfunctions, and generating false alerts. Babiuch and Postulka (2020) propose an IoT-based home security system using ESP32 microcontrollers. It can detect intruders, trigger alarms, capture images, and send data to smartphones. The system also monitors temperature and offers cost analysis for deployment. While effective, it doesn't explore facial recognition, behavior analysis, or cloud-based machine learning for future improvements.

Oyebola (2017) suggests a cost-effective residential security system that employs a motion-activated picture recording configuration regulated by a microcontroller. The hardware consists of an infrared motion detector and an OV7076 camera. An SD card is used for image storage. The microcontroller manages and synchronizes system functions. Testing serves to verify the efficacy of motion detection and image capture. Future study should investigate the scalability of the system and identify and solve any potential weaknesses to improve the overall robustness of the system.

Arumsari Earth Housing's security is improved with a Smart Home system that Setiawan et al. (2019) introduces. It integrates an ESP32 microcontroller, camera, and MC-38 door magnetic switch sensor. Image transmission is activated by the MC-38 sensor when it detects probable intrusion angles ranging from 60 to 180 degrees. This feature serves as an early warning system for homes. However, additional investigation is necessary to tackle the issue of scalability and potential weaknesses, guaranteeing the system's resilience and wider suitability in diverse residential contexts.

Ragu and colleagues (2023) demonstrate a home automation solution that uses Wi-Fi and ESP-32 to control appliances from cellphones. The system improves accessibility and energy efficiency, especially helping those who are physically challenged, by embracing the Blynk framework and Internet of Things concepts. Showing efficient monitoring and control capabilities, it meets the increasing need for smart home solutions. Scalability and security issues could be the main topics of future study to guarantee wider applicability and protect user privacy in practical implementations.

The research conducted by Babiuch et al. (2020) employed ESP32 microcontrollers to create a home security and monitoring system based on the Internet of Things (IoT). The system employs intrusion detection, alarm activation, image capture, data transmission to mobile devices, and object temperature monitoring over a web server. Although the study shows a workable implementation, it is devoid of information regarding energy efficiency, privacy concerns, scalability, performance assessment, and comparison with other alternatives.

The studies implement home security systems using IoT modules, ESP32/ESP8266 microcontrollers, and sensors like PIR for motion detection. Babiuch et al. (2020) use camera imaging and web servers, while Sahoo et al. (2017) employ ZigBee networks and GSM for alerts. Both propose affordable solutions but lack evaluation of performance, scalability, privacy, energy efficiency, and comparisons with existing systems.

The studies implement affordable home security systems using microcontrollers (ESP32/ESP8266), sensors (PIR for motion detection), and communication modules (ZigBee, GSM). They integrate features like image capture, alarms, temperature monitoring, and mobile notifications. However, they lack comprehensive evaluations of performance, scalability, privacy, energy efficiency, and comparisons with existing solutions, limiting their practical applicability.

The studies implement affordable home security systems using microcontrollers (ESP32/ESP8266), sensors (PIR for motion detection), and communication modules (ZigBee, GSM). They integrate features like image capture, alarms, temperature monitoring, and mobile notifications. Teja et al. (2021) propose a system using ESP32-CAM, PIR sensor, and cloud storage for captured images. While demonstrating functional prototypes, the studies lack comprehensive evaluations of performance metrics, scalability, privacy concerns regarding data transmission and storage, energy efficiency for long-term deployment, and comparative analyses with existing commercial or research-based solutions.

Ali et al. (2018) designed a smart home security system utilizing a Raspberry Pi, incorporating sensors, cameras, and a web interface for remote monitoring and control. The system proved reliable and user-friendly, enhancing home security through real-time alerts and surveillance. However, further research is needed to improve system scalability, advanced threat detection capabilities, and integration with wider smart home technologies.

Malini et al. (2022) proposed a PIR-based security system that optimizes energy use and memory requirements. The system uses PIR sensors to detect motion, triggering voltage changes that activate a lighting system and webcam through a relay. Software on a computer records video only when the webcam is active, conserving memory and power. However, future research should focus on improving detection accuracy, integrating with additional security systems, and exploring alternative energy-efficient components to enhance overall system performance.

METHODOLOGY

3.1 Design Analysis

The design of the hardware part of the system is presented in this section. The choice of components, the justification for such choice and the circuit design is also presented therein.This project was tested and simulated through the use of electronic software. It was built around ESP 32 Cam microcontroller which provided the low signal output to the buffer to increase the signal needed for the camera to be fully operated.

3.2 System Overview

The ESP 32 Cam was programmed and all the codes were compiled and ran to the memory of the ESP 32 Cam microchip to send signals to the buffer. Buffer consists of transistor and resistor to amplify the weak signal from ESP 32 Cam microchip to make the IP camera perform its functions. Microchip uses +5v as an input voltage and an external oscillator which is made up of 4 MHz crystal capacitor and two 100nf capacitor connected in parallel across it. The esp 32 camera was connected to the collector of the buffer transistor.

This project was built on a printed circuit board and Vero board. They are mounted and soldered. It was monitored on mobile phone through the provided Application Interface. The Application was launched successfully via internet or hotspot Wi-Fi connection.

3.3 Components Required

3.3.1 Microcontroller (ATMEGA 328p)

ATmega 328 has 1KB Electrically Erasable Programmable Read Only Memory (EEPROM). This property shows if the electric supply supplied to the microcontroller is removed, even then it can store the data and can provide results after providing it with the electric supply. Moreover, ATmega-328 has 2KB Static Random Access Memory (SRAM). Other characteristics will be explained later. ATmega 328 has several different features which make it the most popular device in today‟s market.

3.3.2 ESP32-CAM

The ESP32-CAM provides an inexpensive way to build more advanced home automation projects that feature video, taking photos, and face recognition.

In this Project, we‟ve tested the Camera Web Server example to test the camera functionalities. Now, the idea is to modify the Functions or write a completely new code to complement the desired system. For example, take photos and save them to the micro SD card when motion is detected, integrate video streaming in your home automation platform (like Node RED or Home Assistant), and much more.

Figure 3.1: Pin configuration of an ESP 32 Camera

3.3.3 Crystal Oscillator

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A microprocessor, PIC, or microcontroller with a clock speed of 1MHz can internally process data one million times per second at each clock cycle, which determines how quickly the processor can run and process data. A series crystal network made up of two capacitors with the same value is placed across the oscillator input of each MCU to obtain this frequency.

Fig. 3.5 clearly shows how an OSC1 and OSC2 input pin connect a network made up of a crystal and two capacitors to a microcontroller or central processing unit. These two pins are typically found on all microcontrollers and processors. There are occasionally two different kinds of OSC pins available. One is for the primary oscillator, which makes the clock, and the other is for the secondary oscillator, which makes the secondary clock frequency for various secondary tasks. The capacitor used in the crystal oscillator are rated at 20pf, anything in between but 15pF, 22pF, 33pF is used widely. The image in Fig. 3.2 explain the circuit of Crystal Oscillator

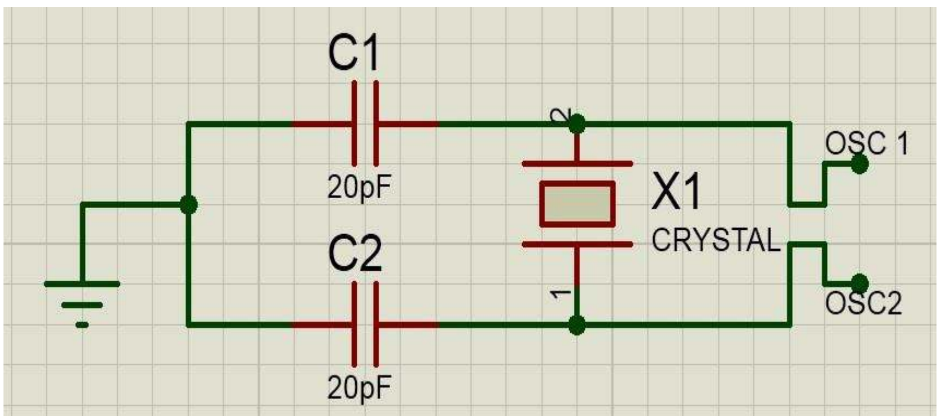

FIG 3.2: Crystal Oscillator

3.3.4 PIR Sensor

Passive Infrared (PIR) sensor is the foundation of the security system. The sensor's functionality is based on infrared radiations emitted from the human body. It is a useful tool for the detection of human movement as it detects a change in infrared radiations as a result of moving warm blooded objects within their range. All objects, including human beings, produce electromagnetic radiation. The wavelengths of these radiations are dependent on the temperature of objects.

The device has three pins (gate, drain and source). The image below shows a PIR sensor and its typical pin configuration which is quite simple to understand the pin-outs configuration. The PIR sensors consist of three pins and a functional description of each of these pins is as described hereunder:

Pin1 correlates with the drain terminal of the device and was connected to the positive supply of 5V DC.

Pin2 correlates with the device’s source terminal and was connected to the ground terminal using 100K resistor. The pin is the sensor’s output pin and it carries the Infrared signal detected to the amplifier. The third pin of the PIR sensor is connected to the ground.

3.3.5 Working Principle of a Buffer Transistor

A transistor circuit known as an emitter follower is one in which the voltage at the emitter tracks the input voltage. In a sense, it is the input voltage's mirror image. As a result, the voltage at the output and input are identical. The emitter follower serves as a buffer since the output voltage is a mirror image of the input voltage, the input impedance is high, and the output impedance is low. As a result, the load that needs to be powered connects to the circuit's output, and if a voltage line

needs to be buffered, it can be connected to the circuit's input. This is excellent if you don't have access to a buffer chip or a logic chip that can be modified to function as a buffer.

3.4 System Build and Design

This Section details the process involve in the design and development of the Microcontroller Based Home Security System with Image Capturing.

3.4.1 Programming the ESP32 Cam Board

The esp32 cam board Is a stand-alone camera that is programmed with Arduino environment. The board is installed in Arduino development environment. This enable the Arduino environment to be able to upload codes on the board. The board is programmed with FTDI connector which is an hardware protocol used in uploading code on the board. The pin configuration between the ESP 32 Cam and the FTDI Connector is Shown in the Figure below.

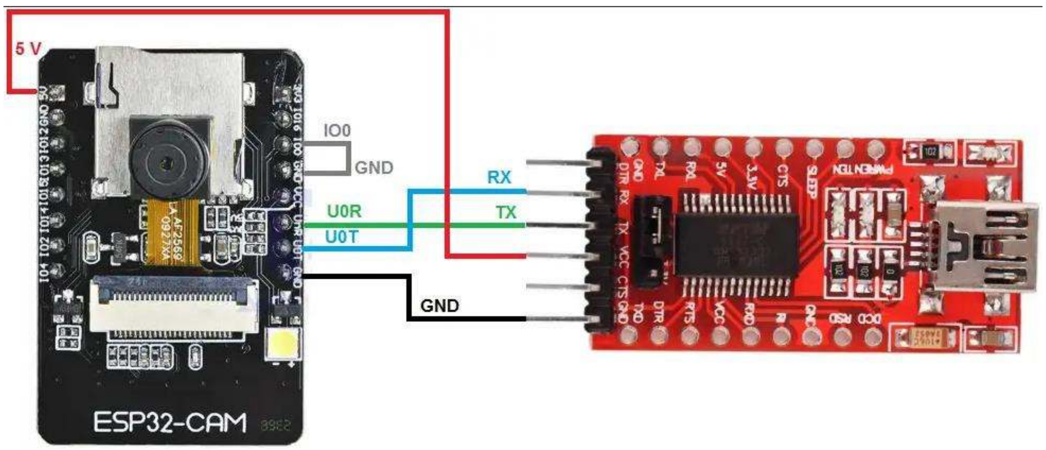

FIG 3.3: Integrating the ESP 32 cam with FTDI Connector

3.4.2 Programing the Camera

The camera is an OV2640 2MP camera module. It has a ¼ inch sensor with an array of 1600 x 1200 elements. At max speed, it can stream 1600 x 1200 video at 15 FPS. The camera is connected internally to the ESP32 GPIO (General Purpose Input Output). The pin definitions are included within our code. To work with the camera, we defined those GPIO pinouts, and then configure a number of camera parameters. we created a frame buffer, after which you can read the camera data from the frame buffer. The esp_camera.h library handled most of the work here, it was included in our code. We created an integer to represent the number of milliseconds we want in between each image. we set the value to 5,000, which is a 5-second delay.

The three functions we used in this setup are:

1) configESPCamera – Configures and initializes the camera module.
2) initMicroSDCard – Initializes the MicroSD card.
3) takeNewPhoto – Takes a photo and stores it on the MicroSD card.

We initialize the camera and MicroSD card, as well as set up the serial monitor, during the setup phase. We also provide our delay time in paper. To take an image, we first construct a filename for the new image in the Loop and provide it to the takeNewPhoto function.

3.4.3 Motion Activation with the Camera

PIR motion sensor is a passive infrared sensor It sense human infrared emissions thus sense passage of human. The digital output it gives creates an input for the GPIO pin 13 of the ESP 32 cam. The ESP 32 cam read high from the PIR motion sensor if the sensor sense passage of human.

The ESP 32 cam takes pictures anytime it reads input from the PIR motion sensor. The picture is saved on an SD card.

The PIR sensor will output HIGH when it detects someone, which is the opposite of how our switch worked, so we woke up the ESP32 on a HIGH, instead of a LOW. We can do that by changing this statement in the coding section.

3.4.4 IP Address (Access Point Mode)

Basically, we linked our Wi-Fi devices (stations) to the ESP32-CAM's own Wi-Fi network by setting it up as an access point (like your smartphone or your computer) which enables it to create its own hotspot. The ESP 32 cam also create a local hotspot in access point mode. The ESP 32 cam gives an IP address.192.168.4.1. This is an 1pv6 address that is inputed by the user on a web browser to Livestream with the ESP 32 cam.

3.4.5 Power Supply Unit

To make the system as minute as possible, we had to adopt a minimalist design which prompts us to use a mini-battery to supply power across the entire system. To ensure the optimal performance of the system. The 7.4v lithium batteries was used. It's reduced to 5v using lm7805 which is a 5v regulator.

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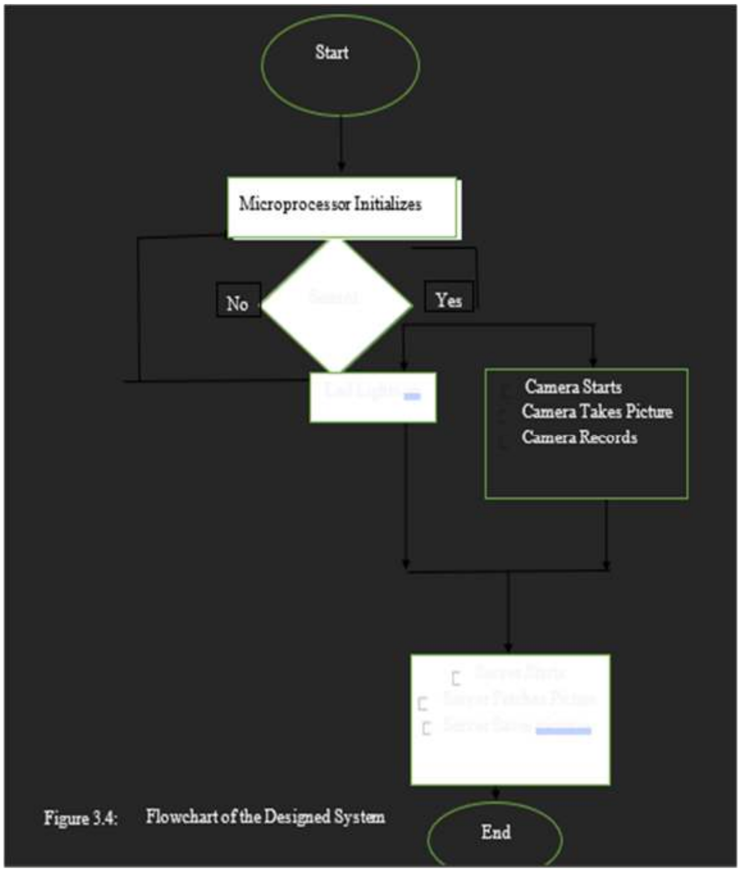

Figure 3.4: Flowchart of the Designed System

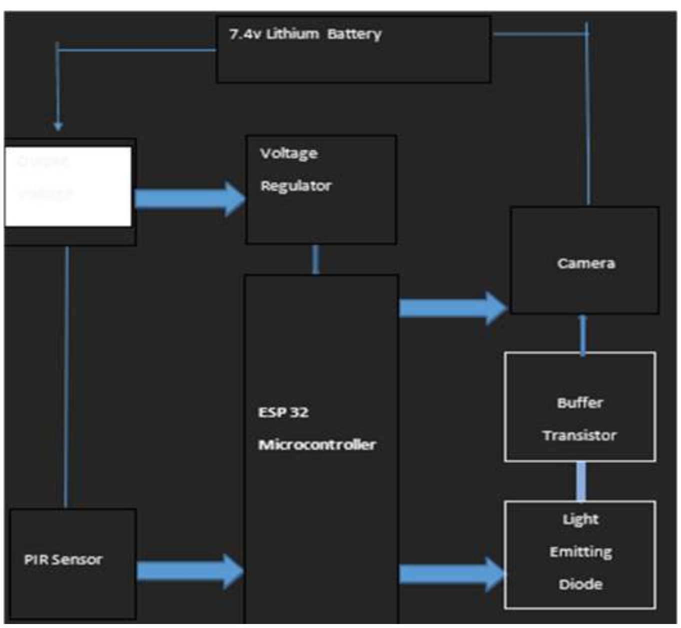

Figure3.5: Block Diagram of the Home Security System

RESULTS AND DISCUSSION

4.1 Performance Test
The system underwent extensive testing on various platforms to ensure expected performance. Individual module tests confirmed that each component produced the intended results. The overall performance test validated the system's design goals, demonstrating its ability to achieve the anticipated outcomes. The system captures an intruder's face using a camera and sends the image to a web server and SD card. Additionally, users can live stream the camera feed.

4.2 Results and Testing
Implementation followed a block diagram, detailed in figure 3.4. The ESP32 microcontroller was programmed in C and assembled on a Vero board. Testing was crucial for proper stage integration and included both software and hardware testing.

4.2.1 Software Testing
Software testing involved simulating components and devices to analyze performance, divided into code and hardware simulations.

4.2.1.1 Code Simulation
The ESP32 microcontroller's code was written in C, compiled to a hex file using Arduino interface v1.6.7, and tested with the Real PIC simulator. The simulator, utilizing USART, replicated the ES232 Camera's operation, showing successful communication between the microcontroller and the camera.

4.2.1.2 Hardware Simulation
Hardware simulation involved setting a short time delay to test camera functionality. After collecting images, the ESP32-Cam module was powered off, and the SD card images were reviewed on a computer. Configuration parameters were adjusted to refine camera settings.

4.3 Post-Implementation Testing

Post-implementation testing was conducted after soldering the circuit on a Vero board. This ensured proper circuit performance and interaction between components, with deviations and accuracy noted.

FIG 4.1: Exterior View of the Design

FIG 4.2: Result from the Webserver

5.1 Conclusion

This study effectively developed and executed a home security system utilizing a microcontroller and the ESP32-CAM module, which is capable of recording images. The system utilizes passive infrared (PIR) sensors to detect the presence of intruders and activate the camera to collect photographs. These images are then saved on an SD card and may be accessed using a web server interface. The system underwent extensive testing, which included software simulations, hardware simulations, and post-implementation testing, in order to verify its performance and functionality. The proposed system caters to the demand for enhanced home security solutions in Nigeria by offering a cost-efficient, effective, and dependable substitute to conventional manual surveillance systems. It reduces the likelihood of mistakes made by humans, allows for monitoring in real-time, and supplies visual proof of security breaches by capturing photographs, which helps law enforcement agencies in detecting and prosecuting crimes.

5.2 Recommendations

Although the developed system shows promising results, there is potential for further improvements and future research to enhance its capabilities and make it more robust. The utilization of cloud computing and machine learning technologies can improve scalability, data management, and intelligent decision-making by employing advanced pattern recognition and behavior analysis. By incorporating advanced computer vision algorithms for facial recognition and suspicious behavior detection, the system's capability to effectively identify and monitor possible threats will be enhanced. In addition, the integration of the system with other smart home technologies, such as door and window sensors, smoke detectors, and automated lighting systems, can result in a more comprehensive home security solution.

Optimizing energy efficiency and enhancing user experience are both crucial. Exploring energy-efficient components and implementing power management systems can prolong the operating lifespan of the system and lower expenses, thereby making it acceptable for long-term deployment. Improving the user interface and accessibility features will enhance usability and expand the system's appeal, especially for users with disabilities. Ultimately, doing thorough scalability and reliability testing in many scenarios will enable the detection of possible limitations and weaknesses, facilitating additional enhancements to guarantee the system's strength and ability to withstand real-life situations.

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