PROJECT

ON

DESIGN AND CONSTRUCTION OF SOLAR POWERED CCTV CAMERA USING ESP32 MICROCONTROLLER WITH WEB APP VEIWING OVER WIFI

BY

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CERTIFICATION

This is to certify that this project work has been written by **OYEWOLE AZEEZ ALABI** with matric number **HND/23/SLT/FT/0129** and has been read and approved as meeting the parts of the requirements for the award of Higher National Diploma (HND) in Science Laboratory technology Department, Institute of Applied Sciences, Kwara State Polytechnic.

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DEDCATION

This project work is sincerely dedicated to Almighty Allah for His mercy and blessings upon my life.

ACKNOWLEDGEMENT

All praise is due to Almighty Allah, the Beneficent and the Most Merciful, for His unending grace, guidance, and the gift of life. I sincerely thank Him for granting me the privilege, strength, and wisdom to begin and complete this project. Indeed, He is the source of knowledge, understanding, and success without His divine support, this achievement would not have been possible.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

With the growing concern for safety and security in both residential and commercial spaces, surveillance systems have become essential tools for monitoring activities and preventing crimes. Traditional closed-circuit television (CCTV) systems have been used extensively to capture video footage, but these systems often lack flexibility and are limited in terms of remote accessibility. In response to these limitations, the integration of modern microcontrollers such as the ESP32 has revolutionized the way CCTV cameras are designed and operated. The ESP32, which features both Wi-Fi and Bluetooth capabilities, is an ideal solution for creating a cost-effective, scalable, and user-friendly CCTV system that can transmit live video over Wi-Fi to web applications. This ability to view live footage remotely has enhanced the functionality of surveillance systems, making them more efficient and accessible for users. Additionally, the widespread availability of IoT (Internet of Things) technologies has further fueled the development of web-connected surveillance systems, opening new possibilities for real-time monitoring from virtually anywhere (Zhang & Li, 2020).

1.2 PROBLEM STATEMENT

Although CCTV cameras have become commonplace in many environments, many existing systems still face challenges when it comes to remote viewing and integration with modern web technologies. Traditional CCTV systems typically require dedicated hardware for video monitoring, which limits their usability and increases costs. Furthermore, these systems may require users to be physically present in a specific location to access video footage. The inability to easily monitor live video feeds from remote locations is a significant drawback in today's fast-paced, technology-driven world. Moreover, most CCTV systems do not integrate seamlessly with Wi-Fi networks, which limits their flexibility in terms of remote access. This project seeks to address these issues by developing a surveillance system based on the ESP32 microcontroller, enabling live video streaming to a web application over Wi-Fi. This will allow users to monitor their premises remotely and efficiently, without the need for additional, expensive infrastructure (Han & Lee, 2021)

Figure 1.1: A Micro-Controller CCTV Camera

1.3 OBJECTIVE OF THE PROJECT

The primary goal of this project is to design and construct a CCTV camera system using the ESP32 microcontroller that supports live video streaming over Wi-Fi, which can be accessed through a web application. The specific objectives of this project are:

- To design and develop a functional CCTV camera system utilizing the ESP32 microcontroller for video capture and Wi-Fi transmission.
- To build a web application interface that allows users to view live camera footage from any internet-enabled device.
- To ensure the system is affordable, scalable, and user-friendly for both personal and commercial use.
- To evaluate the system's performance under different conditions, ensuring reliable video streaming and ease of use.
- To implement necessary security protocols to ensure safe and encrypted video transmission (Ali & Zaman, 2022).

1.4 SIGNIFICANCE OF THE PROJECT

The significance of this project is reflected in its potential to enhance the flexibility and accessibility of surveillance systems. Traditional CCTV setups often require users to be present at the surveillance location or install additional hardware to achieve remote monitoring. By utilizing the ESP32, this project offers a simple yet effective solution for live video streaming over Wi-Fi, making it easy for users to access their CCTV footage remotely, whether on mobile devices or computers. The affordability of the ESP32 microcontroller further makes this system a viable option for individuals and small businesses looking for cost-effective security solutions. Additionally, the integration of IoT and web-based applications ensures that the system is adaptable to modern needs, offering convenience, scalability, and remote monitoring capabilities. This project contributes to the growing field of smart surveillance and provides a practical example of how IoT technology can be applied in real-world security applications (Kumar & Sharma, 2021).

1.5 SCOPE OF THE PROJECT

The scope of this project is limited to the design and construction of a CCTV camera system that uses the ESP32 microcontroller to capture video and stream it over Wi-Fi to a web application for remote viewing. The project focuses on the hardware design, web application development, and network configuration necessary for the system's functionality. It does not include advanced features such as artificial intelligence-based motion detection, facial recognition, or cloud storage integration. Additionally, the system will be tested for performance under different conditions, including varying network speeds and environmental factors. The project aims to provide a practical, low-cost solution that can be deployed for small-scale surveillance setups, suitable for residential or small business environments (Kumar & Sharma, 2021).

CHAPTER TWO

2.1 OVERVIEW OF CCTV CAMERAS

Closed-circuit television (CCTV) cameras are widely used for surveillance and security purposes. These systems transmit video signals to a specific set of monitors, making them a crucial component in monitoring and enhancing security in various environments. CCTV cameras operate using analog or digital signals, with digital systems offering superior image quality and network connectivity. Recent developments have focused on enhancing the efficiency and effectiveness of these systems through features such as remote monitoring, high-definition imaging, and night vision (Smith, 2020).

2.2 SOLAR POWER SYSTEMS: PRINCIPLES & APPLICATIONS

Solar power systems harness energy from the sun, converting it into electricity using photovoltaic (PV) cells. These systems are an eco-friendly alternative to traditional energy sources, often used in remote or off-grid locations. Solar power offers the advantages of sustainability and independence from the electrical grid. The efficiency of solar power systems depends on factors like solar panel placement, angle, and environmental conditions (Jones et al., 2019). With the growing demand for renewable energy, solar power has found applications in residential, commercial, and industrial sectors (Williams, 2021).

2.3 ESP32 MICROCONTROLLER: FEATURES & APPLICATIONS

The ESP32 is a popular microcontroller that integrates Wi-Fi and Bluetooth capabilities, making it ideal for Internet of Things (IoT) applications. It is widely recognized for its low power consumption, high performance, and versatility. The microcontroller's dual-core processor allows for efficient multi-tasking, enabling it to handle complex tasks such as real-time data processing in surveillance systems. Due to its affordability and scalability, the ESP32 has gained traction in developing smart devices, home automation, and remote monitoring systems (Liu & Zhang, 2021).

2.4 WIFI-TECHNOLOGY: PRINCIPLES & APPLICATION

Wi-Fi, or Wireless Fidelity, is a technology that uses radio waves to provide high-speed internet and network connections. Wi-Fi networks operate based on the IEEE 802.11 standards and are widely used for short- to medium-range wireless communication. Wi-Fi is essential for connecting devices such as computers, smartphones, and surveillance systems to the internet. The introduction of advanced Wi-Fi technologies, such as Wi-Fi 6, has improved connection speeds and the capacity for handling multiple devices simultaneously (Chen & Li, 2022).

2.5 WEB APP DEVELOPMENT: FRAMEWORKS & TOOLS

Web applications have become essential for providing remote access to various services, including monitoring systems. Modern web app development involves frameworks such as React, Angular, and Vue.js for front-end design, and Node.js or Django for back-end functionalities. These tools enable developers to build dynamic and responsive interfaces that enhance user experience. The integration of databases, such as MySQL or MongoDB, ensures that web apps can store and retrieve data efficiently. Web apps are increasingly used in security systems to allow users to monitor CCTV footage and control devices remotely (Taylor, 2023).

CHAPTER THREE

3.0 MATERIALS AND METHODOLOGY

The selection of materials and components is critical to the successful implementation of a solar-powered, WiFi-enabled CCTV surveillance system. The components chosen ensure energy efficiency, real-time wireless communication, environmental sustainability, and reliable performance in off-grid or remote areas. Each material is selected based on functionality, availability, cost-effectiveness, and compatibility with the ESP32-CAM platform. Hardware materials and software materials are used in the project.

HARDWARE MATERIALS - They are the physical components of our Camera System. These hardware materials include:

i. Pv (solar panel)

ii. Dc bulk converter

iii ESP32CAM

iv. Microcontroller

v. Printed Circuit Board

vi. Ic Socket

vii Capacitor (Electrolytic)

viii Non Electrolytic Capacitor

viii Electric motor (Servo Motor)

ix. BMS(Battery Management System)

x. Microprocessor

xi. Voltage regulator

Xii. Baterry

SOFTWARE MATERIALS: These are referred to the program, algorithm and firmware that enables the camera to function and provide various features. The software materials include:

1. Arduino IDE

2. Web App

3.1 HARDWARE MATERIALS

i. MICROPROCESSOR AND MICRO CONTROLLER

MICROPROCESSOR: Microprocessor in our CCTV camera refers to a small chip that acts as the brain of the camera. It executes instructions, manages video processing.

The microprocessor act as the camera brain, enabling it to capture,process and transmit video signals. It's a crucial components that determine the camera performance, feature and functionality.

For our CCTV camera project work, we are provided with 8085. The image below shows a Microprocessor PIN Configuration.

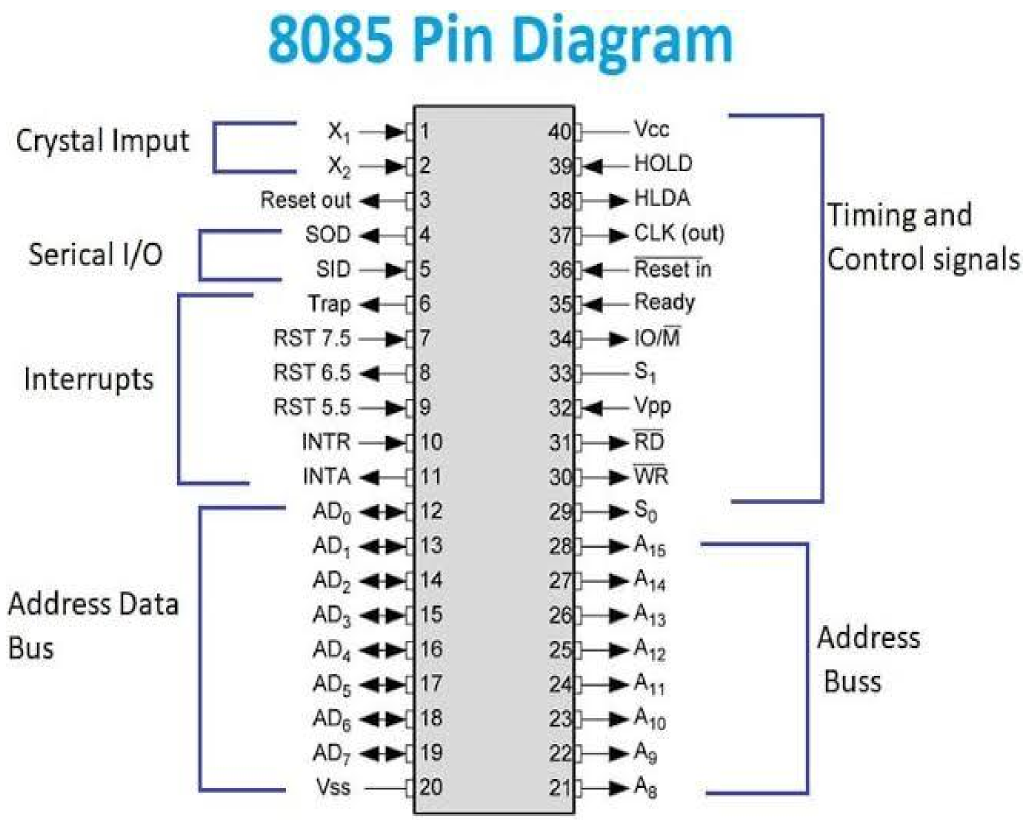

Figure 3.1: Diagram of a Microcontroller

MICROCONTROLLER: In CCTV Camera, a microcontroller is a small computer chip that controls camera functions (emg exposure, focus etc), interface with sensors(handles data from sensor like motion detector and manage communication).

ii. ESP32-CAM

ESP32-CAM is a small development board that combines the ESP32 microcontroller with a camera module, enabling Wi-Fi and Bluetooth connectivity along with image capture and video streaming capabilities. Here's a breakdown of the term:

ESP32: A powerful microcontroller developed by Espressif Systems with built-in Wi-Fi and Bluetooth. It has dual-core processing capabilities, various GPIOs, and supports IoT applications.

CAM: Short for "camera", indicating that the board includes a camera module (usually the OV2640 sensor).

ESP32-CAM features typically include:

ESP32-S chip

OV2640 camera

MicroSD card slot (for storage)

GPIO pins (limited, as many are used by the camera)

Support for video streaming over Wi-Fi

Low cost and compact design

Remote monitoring devicesThe ESP32-CAM is a compact camera module that integrates a camera with Wi-Fi and Bluetooth capabilities.

It is used in various projects such as:

• Security Cameras: For remote monitoring and motion detection.

Figure 3.2: ESP32 Camera Module

• Home Automation: Integrating cameras with smart home systems.

• Surveillance: Continuous observation in sensitive or vulnerable locations.

iii. BATTERY MANAGEMENT SYSTEM (BMS)

A battery management system (BMS) as used in our CCTV camera is an electronic system that monitor battery health (Tracks battery state of charge, voltage and temperature), controls charging (Regulates charging process to prevent overcharging or undercharging) and also provides power management. BMS in CCTV camera ensure:

1. Reliable operation

2. Extended battery life

3. Safe operation

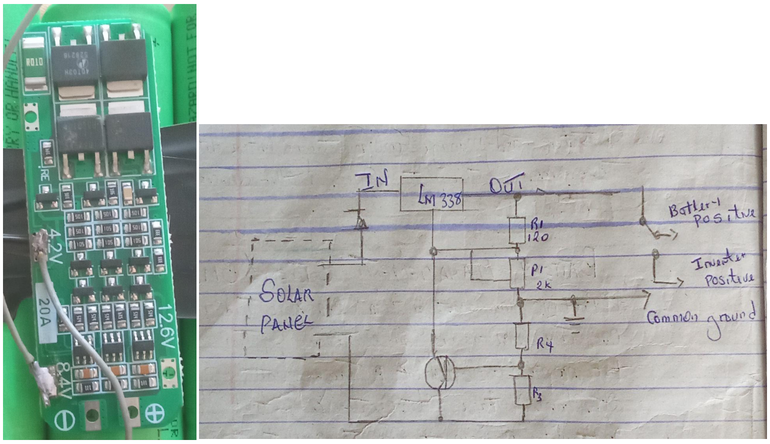

Figure 3.3: BMS Circuit Diagram AND Image

iv. PRINTED CIRCUIT BOARD (PCB)

Printed Circuit Board (PCB) is a flat board that connects and support electronic components such as chips resistor and capacitor using a conducive pathway printed omto the board In our CCTV camera, the Printed Circuit Board (PCB) is a crucial components that is:

1. Connect and supports various electronic components such as image sensors, amplifier and video processing chips.

2. Enable functionality: The PCB allow the camera to capture, process and transmit video signals.

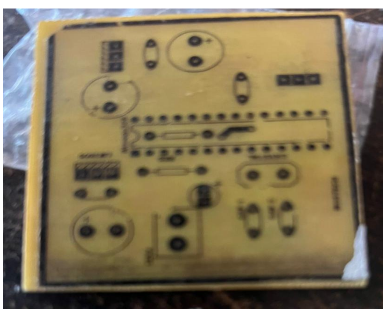

Figure 3.4: Image of a Printed Circuit Board

v. IC SOCKET

IC Socket is an electronic components attached or place on our printed Circuit Board to serve or aid the plugging and unplugging our microcontroller.

The micro-controller can be plug on the IC Socket and be unplug also from the IC Socket attached to our PCB Board

Figure 3.5: Image of an IC Socket

Vi. ELECTRIC MOTOR

ELECTRIC MOTOR

Ac motor	DC motor
Single phase.	Brush motor
3 - phase motor	brushless motor
	Servo motor
	Stepper motor

In our solar CCTV camera, the type of motor we will be needing a SERVO MOTOR to rotate the camera.

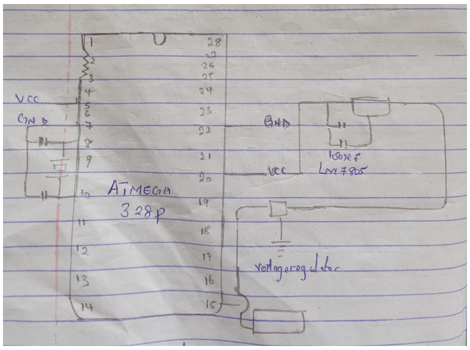

Figure 3.6: Diagram of a Servo Motor

Servo Motor is a type of motor that precisely control movement allowing for accurate positioning, rotation or movement. It uses feedback to adjust it's position or speed ensuring precise control. In our CCTV camera, the servo motor help to rotate the camera and change the position of the camera in other to have the streaming at one particular angle for sometime and streaming in another particular angle for sometimes.

Figure 3.7: Diagram of a signal wire and GND wires

Our servo motor will come with 3- wires, which are:

1. Signal wire: which provides direction

2. Vcc wire : The VCC wires refers to our positive power supply to power the motor

3. The GND wires: refers to the negative power supply to power the motor.

From the circuit diagram, the microcontroller will control the signal of the SERVO MOTOR and voltage regulator to regulate voltage from 12v to 5v.

vii. VOLTAGE REGULATOR

In the CCTV camera, the voltage regulator helps to regulate the voltage coming from the battery in the project. Two voltage regulator was used. The first voltage regulator helps to regulate voltage from the battery to the servo motor and the second voltage regulator regulates voltage from the battery to the microcontroller and the microcontroller only needs 5v.

ix. SOLAR PANEL

A photovoltaic (PV) solar panel is a device that converts sunlight into electricity using semiconducting materials and it's used to generate electrical energy from sunlight, making the system energy-independent. A 6V or 12V, 3W to 10W panel is typically used depending on the power consumption profile and expected solar irradiance in the region.

Considerations for Selection:

Output voltage range: 6V to 18V

Power output: minimum 3W for daylight operation

In our CCTV camera setup, the solar cell is vital to:

• Power the Camera: Harnesses sunlight to generate electricity, reducing reliance on wired power or replaceable batteries.

• Enable Wireless, Battery-Free Operation: Ideal for remote or hard-to-reach locations without access to a stable power grid.

• This makes solar-powered CCTV cameras suitable for:

• Outdoor Surveillance: Monitoring parking lots, building perimeters, or public spaces.

• Remote Areas: Securing locations where conventional electrical infrastructure is unavailable.

1. Solar CCTV Camera

CCTV → "CCTV" meaning Closed Circuit Television Camera also known as Video Surveillance. It’s a system using cameras to transmit signals to specific monitors, often for security and surveillance purposes.

3.2 TYPES OF IC USED IN CCTV

1) Analogue IC: Analogue IC is known as Analogue Integrated Circuit. ICs are electronic components that process continuous signals such as voltage or current to perform various functions such as amplification, filtering, conversion etc.

“CCTV” cameras operating in analogue mode of signal transmit video signal using composite video cable (e.g. BNC connections).

Examples of analogue ICs include:

I. Operational Amplifier (Op-Amps)

Ii. Voltage Regulators

Iii.Analogue-to-Digital Converters (ADC)

Iv.Digital-to-Analogue Converters (DAC)

(A circuit diagram is shown here, labeled with Inputs, Output, resistors, and an op-amp symbol)

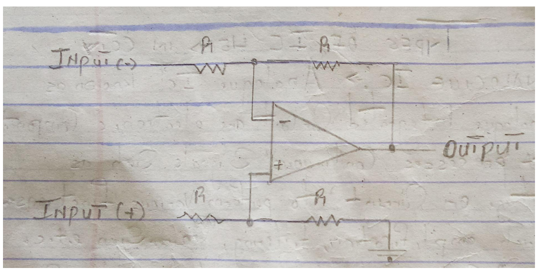

Figure 3.8: A simple analogue circuit diagram is shown below

DIGITAL IC: A Digital Integrated Circuit (Digital IC) is an electronic chip that processes digital signals—signals that use only two states: ON (1) and OFF (0). Unlike analog ICs that work with continuous signals (like varying voltages), digital ICs work with binary logic. Digital IC was used in the project.

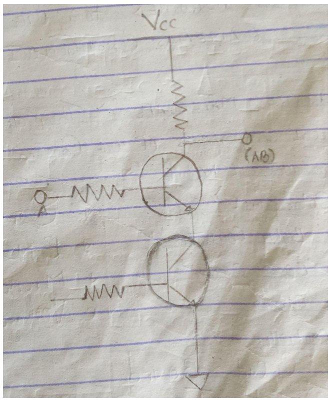

Figure 3.9: A simple digital circuit diagram is shown above

3.3 ROLE OF DIGITAL ICS IN CCTV CAMERAS

I. Video Processing:

Ii. The raw signal from the camera sensor is often in analog form.

Iii. A Digital Signal Processor (DSP) converts it into a digital format.

Iv. It enhances image quality, reduces noise, and applies corrections (like brightness/contrast adjustment).

v. Image Processing:

Vi. Motion detection

These functions help in smart surveillance

Camera Settings Control

Digital ICs manage

Exposure control

White balance

Zoom/focus

They also handle automation based on lighting and scene detection.

Common Digital ICs Used in CCTV:

Microcontrollers / Microprocessors – Control camera functions.

FPGA (Field Programmable Gate Array) – For high-speed parallel processing.

DSP (Digital Signal Processor) – Handles video encoding/decoding.

Memory ICs – Store firmware or captured images/videos.

Simple Digital Circuit Diagram (from image):

X. BULK CONVERTER: The Buck converter is a type of a DC-DC converter that steps down the voltage from a higher level to a lower level while maintaining the efficiency.

Xi. BATTERY:The battery helps to store electricity generated by the solar panel during the day,provide power at night and also ensure continous operation even without sunlight when charged.

3.4 SOFTWARE MATERIALS

Software Materials for Programming ESP32-CAM and Web Application Development

This project involves the development of a wireless surveillance system using the ESP32-CAM module, which is capable of capturing and streaming real-time video over Wi-Fi. A web application is also developed to view and control the live video feed from a browser on any connected device.

Programming the Microcontroller

To operate our ESP32-CAM, we use embedded system programming. This includes:

Software: Instructions programmed into the microcontroller using a low-level software system called firmware.

LED Indicators: Light Emitting Diodes (LEDs) are used for feedback, responding to signals from the microcontroller.

3.5 MICROCONTROLLER & LED FUNCTIONALITY

The microcontroller sends instructions to the LED to:

Blink

Stay on or off for a specific time

Respond to programmed sequences

The instructions are written using environments such as the Arduino IDE, which supports ESP32-CAM development.

1. **Programming Environment for ESP32-CAM**

1.1 Arduino Integrated Development Environment (IDE)

The Arduino IDE is used as the primary programming environment for the ESP32-CAM module. It supports the C/C++ language and provides access to essential hardware abstraction libraries.

Setup Steps:

Install the Arduino IDE from https://www.arduino.cc/en/software.

Add ESP32 board support using the URL:

https://raw.githubusercontent.com/espressif/arduino-esp32/gh-pages/package_esp32_index.json

Use the Board Manager to install the ESP32 package.

Select AI Thinker ESP32-CAM

Write and upload the code using a USB-to-Serial converter (CP2102 or CH340G).

1.2 Required Libraries

The following libraries are included in the sketch to enable core functionalities:

WiFi.h – Manages wireless connections.

WebServer.h – Handles HTTP communication.

esp_camera.h – Provides camera initialization and frame capture.

FS.h and SD.h – For microSD card access (optional).

ESPAsyncWebServer.h – Optional for asynchronous web server performance.

2. USB-to-Serial Driver Installation

To upload code, a USB-to-Serial converter is required. Proper drivers must be installed for communication:

CP2102 Driver: https://www.silabs.com/developers/usb-to-uart-bridge-vcp-drivers

CH340G Driver: http://www.wch.cn/download/CH341SER_EXE.html

3. Web Application for Video Streaming

A lightweight web application is embedded directly within the ESP32-CAM firmware. Once the ESP32-CAM connects to a Wi-Fi network, it hosts a web server that streams live video and optionally provides control buttons (e.g., for switching on/off LEDs or triggering image capture).

3.1 Features of the Web Application

Live video feed from the ESP32-CAM (JPEG or MJPEG stream)

User interface accessible from any device on the same network

Optional controls for GPIO functions (e.g., flash control)

HTML and JavaScript-based front end served from ESP32's onboard storage

The camera stream is served from the /stream endpoint, while other endpoints (e.g., /flash) can be used for control.

3.6 CONSTRUCTION AND MODE OF OPERATION OF SOLAR POWERED CCTV CAMERA

The system operates as an autonomous, solar-powered surveillance unit. It integrates a camera module, solar power system, ESP32 microcontroller, and a web-based viewing platform. The mode of operation is explained in sequential stages:

1. Power Supply via Solar Energy

A solar panel charges a rechargeable battery (e.g., 12V or 7.4V Li-ion) during daylight.

The battery powers the system through a voltage regulation circuit (e.g., buck converter or LM7805 for 5V).

This ensures uninterrupted operation even at night or during cloudy weather.

2. Image and Video Capture

The ESP32-CAM module has an onboard camera (OV2640) that captures real-time video or still images.

It is programmed using Arduino IDE or ESP-IDF to operate in web server mode.

3. WiFi Connectivity and Web Server

The ESP32-CAM connects to a WiFi network (e.g., home router or mobile hotspot).

It sets up an HTTP web server and hosts a local webpage containing the camera feed.

The web page can be accessed on any device (PC/smartphone) connected to the same network using the ESP32's IP address.

4. Web App Viewing Interface

The web interface displays:

Live video stream

Optional controls (e.g., LED flash ON/OFF, camera resolution)

The user accesses the feed by entering the ESP32's IP address in a browser.

Authentication or password protection can be implemented for security

SOLAR CCTV BLOCK DIAGRAM

SOLAR PANEL

↓

BATTERY (12V DC)

↓

BULK CONVERTER MODULE

(Step down to 5V + USB output)

↓

MICROCONTROLLER UNIT

↓

SERVOMOTOR

↓

CAMERA

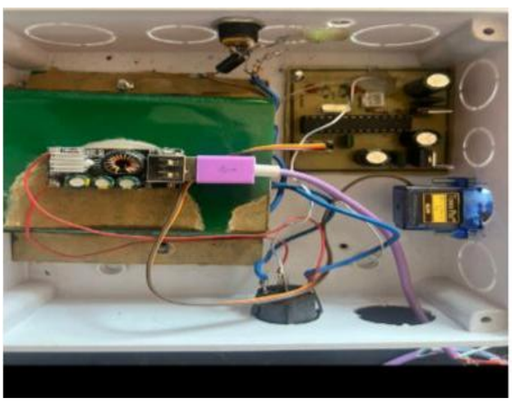

Figure 3.1.1: Image of the Overall Components

CHAPTER FOUR

4.1 TESTING AND EVALUATION

4.1.1 Power System Test

- The solar panel was tested under different sunlight conditions.
- The TP4056 charger correctly charged the 18650 battery during daytime.
- Voltage output remained stable at ~3.3V (regulated) for the ESP32-CAM.

4.1.2 Camera and Streaming Test

- The camera delivered a video feed of 15–20 fps at VGA resolution (depending on WiFi strength).
- Image quality was acceptable for surveillance purposes.
- Live streaming over WiFi was successful at a distance of up to 30 meters.

4.1.3 Web Interface Test

- Users could connect to the ESP32 IP and view live feed using smartphones or laptops.
- Response time was minimal, with less than 1-second delay on average.
- Interface remained stable for extended periods.

4.2 RESULTS

- The system successfully achieved solar-powered surveillance with real-time streaming.
- ESP32-CAM maintained connectivity and performance under standard operation.
- The battery lasted through the night on a full charge, supporting 24/7 surveillance.

Test Parameter	Result
Streaming Range	Up to 30 meters (WiFi)
Battery Duration	8 – 12 hours (overnight)

Charging Time (Full Sun)	3 – 4 hours
Web App Access Delay	Less than 1 second
Resolution	VGA (640x480) to SVGA (800x600)

4.3 CHALLENGES ENCOUNTERED

- Limited Night Vision: The ESP32-CAM lacks built-in IR; additional IR LEDs may be required.
- WiFi Coverage Limitations: Coverage was restricted to local network range.
- Power Regulation: Needed efficient regulation to avoid under-voltage issues.
- Overheating: Prolonged use in direct sun required additional cooling considerations.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY OF THE STUDY

This project focused on the design and construction of a solar-powered CCTV surveillance system using an ESP32 microcontroller with the capability to stream video over WiFi through a web interface. The motivation behind the project was to develop a low-cost, energy-efficient security solution that can be deployed in areas with limited or no access to electricity.

The ESP32-CAM module served as the core component for image capturing and streaming. A solar energy system, consisting of a solar panel, rechargeable lithium-ion battery, and a charging circuit (TP4056), was used to ensure uninterrupted power supply. A minimalistic web interface hosted by the ESP32 enabled real-time monitoring from any device connected to the same WiFi network.

Key stages of the project included:

- Hardware selection and system design.
- Software development using Arduino IDE.
- Integration of the solar system with ESP32-CAM.
- Deployment and performance testing of the system.

5.2 CONCLUSION

The project successfully demonstrated a working prototype of a self-sustaining CCTV camera system. Key outcomes include:

- Effective Surveillance: The ESP32-CAM provided clear image capture and live video streaming within local network range.

- Energy Autonomy: The use of solar power eliminated the need for constant grid power or frequent charging.
- Web-based Monitoring: A user-friendly interface allowed users to view live feeds via any browser-enabled device.
- Cost-Effective Design: The system used readily available and affordable components, making it scalable and replicable for rural and urban applications.

This system is well-suited for residential security, farm monitoring, remote area surveillance, and similar applications where wired power infrastructure is unavailable or impractical.

5.3 CONTRIBUTIONS TO KNOWLEDGE

This project has contributed to the following:

- Demonstrated how renewable energy can be effectively combined with IoT-based security systems.
- Showcased the potential of the ESP32-CAM for low-budget video surveillance applications.
- Provided a foundation for future expansion into cloud-based surveillance, motion detection, and mobile app integration.

5.4 LIMITATIONS OF THE STUDY

Despite its success, the project had a few limitations:

- Lack of Night Vision: The ESP32-CAM lacks built-in infrared support; external IR LEDs would be needed for night surveillance.
- WiFi Range: The system depends on local WiFi; remote access requires additional configuration or internet-connected networks.

- Battery Capacity: The runtime is limited to the size and number of lithium batteries used.

5.5 RECOMMENDATIONS

Based on the observations and limitations, the following are recommended:

1. Integration of Infrared (IR) LEDs: For night-time monitoring.
2. Use of External WiFi Antenna: To improve signal strength and extend coverage.
3. Motion Detection Feature: Add PIR sensor and configure alerts to conserve power and improve security responsiveness.
4. Cloud Streaming Option: Use cloud platforms (e.g., Firebase, Blynk) for real-time access from any location.
5. Mobile App Integration: For enhanced user experience, push notifications, and device control.
6. Larger Solar Panels and Batteries: For longer operational periods and to accommodate future upgrades.

5.6 FUTURE WORK

For further development, the following can be explored:

- Implementation of AI-based object detection using ESP32-compatible ML models.
- Adding SD card support for local video recording.
- Developing a custom Android/iOS app for remote access.
- Use of LoRa or GSM modules for rural locations without WiFi coverage.

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