PROJECT
ON

DESIGN AND CONSTRUCTION OF SOLAR POWERED CCTV CAMERA USING ESP32CAM MICROCONTROLLER WITH WEB APP VEIWING OVER WIFI

BY

AMOO KEHINDE MUHAMMED
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SUBMITTED TO THE

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MR. AGBOOLA A.O

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CERTIFICATION

This is to certify that this project work has been written by **AMOO KEHINDE MUHAMMED** with matric number **HND/23/SLT/FT/0898** 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.

______________________________ ____________________

MR. AGBOOLA A.O **DATE**

(Project Supervisor)

______________________________ ____________________

DR. USMAN A. **DATE**

(Head of Department)

______________________________ ____________________

MR. SALAHU BASHIR **DATE**

(Head of Unit)

______________________________ ____________________

DATE

(External Examiner)

DEDCATION

This project is dedicated to the memory of my beloved father, Mr. Amoo Ganiyu, whose guidance, love, and wisdom continue to inspire me even in his absence. Though you are no longer with us, your legacy lives on in all that I do.
May your soul continue to rest in perfect peace.

I also dedicate this work to my dear family—especially my mother, whose unwavering love and prayers have been my strength throughout this journey.

ACKNOWLEDGEMENT

First and foremost, I give all glory and thanks to the Almighty God for His grace, wisdom, and strength that sustained me throughout the course of this project.

My heartfelt gratitude goes to my project supervisor, whose valuable guidance, encouragement, and support played a vital role in the successful completion of this work. Your mentorship has greatly shaped my academic growth, and I am truly thankful.

I also wish to deeply appreciate my family for their constant support, patience, and understanding—especially during the challenging moments of this project. Your encouragement meant the world to me.

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Finally, to everyone who contributed in one way or another, directly or indirectly, to the success of this project—thank you.

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ABSTRACT

This project presents the design and construction of a solar-powered CCTV camera system using the ESP32-CAM microcontroller, integrated with a web-based interface for real-time video surveillance over WiFi. The primary objective is to develop a cost-effective, energy-efficient, and remotely accessible security solution suitable for off-grid or rural areas. The system harnesses solar energy to charge a battery, which powers the ESP32-CAM module. Video footage is captured and streamed via a WiFi connection to a web application accessible through any internet-enabled device. The ESP32-CAM serves as the core microcontroller, featuring both image capturing and wireless communication capabilities. This setup eliminates dependency on grid electricity, making it ideal for sustainable and low-cost security deployments. The prototype demonstrates stable video streaming, reliable solar power management, and effective remote surveillance through the web app.

CHAPTER ONE

1.1 PROJECT OVERVIEW

Closed-circuit television (CCTV) cameras play a crucial role in modern surveillance and security systems by enabling continuous monitoring and recording of activities in various environments, such as residential areas, commercial establishments, and public spaces. Traditional CCTV systems often rely on wired power connections and dedicated network infrastructure, which can be expensive and challenging to deploy in remote or off-grid locations. The emergence of wireless communication technologies and renewable energy solutions has led to the development of innovative, energy-efficient surveillance systems that can operate independently of conventional infrastructure.

This project aims to design and construct a solar-powered CCTV camera that integrates the ESP32CAM microcontroller for WiFi-based video streaming and remote access via a web application. The proposed system is designed to be a cost-effective, scalable, and eco-friendly surveillance solution that can be deployed in rural areas, construction sites, wildlife reserves, and other locations where grid power is unavailable or unreliable. By leveraging the capabilities of the ESP32CAM microcontroller, the system will support real-time video streaming, motion detection, and secure cloud storage, providing a robust and accessible security solution.

The integration of solar power ensures that the CCTV camera remains operational during power outages and in areas with limited access to electricity, making it an ideal solution for sustainable security applications. Additionally, the implementation of a web-based interface allows users to monitor and control the surveillance system remotely, enhancing convenience and usability. With increasing concerns over security and privacy, the development of a selfsufficient and intelligent surveillance system is crucial in modern security infrastructure.

1.2 AIM OF THE PROJECT

The aim of this project is to design and construct a solar-powered CCTV surveillance system utilizing the ESP32CAM microcontroller, capable of capturing and streaming real-time video footage over WiFi through a web-based interface. The system is intended to provide an energy-efficient, wireless, and remotely accessible security solution, particularly suitable for remote or off-grid locations where conventional power sources are unavailable.

1.3 OBJECTIVES OF THE PROJECT

The primary objectives of this project include:

Design and construct a solar-powered CCTV camera: Develop a system that utilizes solar panels and battery storage to provide uninterrupted power to the CCTV camera and ESP32CAM microcontroller.

To Integrate ESP32CAM microcontroller for WiFi connectivity: Implement the ESP32 to manage video streaming and network communication, ensuring efficient and low-latency data transmission.

To develop a web app for remote viewing: Create a user-friendly web application that allows authorized users to access live video streams from the CCTV camera over WiFi, enhancing accessibility and usability.
Enhance data security and storage capabilities: Implement secure data encryption and cloud-based storage solutions to ensure the integrity and confidentiality of surveillance footage.

To optimize energy efficiency: Design the system to effectively manage power consumption by incorporating energy-efficient hardware components and smart power management techniques.

To ensure scalability and remote management: Develop a system that can be expanded to support multiple cameras and remote access control, enabling large-scale deployment in various locations.

Improve image and video quality: Utilize high-resolution camera modules and image processing techniques to enhance clarity and detail in surveillance footage, ensuring reliable identification of objects and individuals.

Implement motion detection and alert mechanisms: Integrate motion sensors and AI-based recognition software to detect unusual activity and send real-time alerts to users, enhancing security responsiveness.

1.2 **BACKGROUND AND MOTIVATION**

Traditional CCTV systems often rely on wired connections and continuous grid power, limiting their deployment in areas lacking infrastructure. Recent developments in wireless communication and microcontroller technology, such as the ESP32, have enabled cost-effective, low-power, and high-performance surveillance systems. Solar power integration further enhances the system by making it independent of external power sources, reducing operational costs and promoting sustainability. This project is motivated by the need for a standalone, remote surveillance system that can function in off-grid areas while ensuring reliable video streaming and monitoring.

Additionally, growing security concerns and increasing crime rates have necessitated advanced surveillance solutions that are both cost-effective and efficient. The implementation of a solar-powered CCTV system using the ESP32 microcontroller offers a scalable approach to securing homes, offices, and other locations with minimal infrastructure requirements.By leveraging cloud-based storage and real-time monitoring, this system can provide enhanced security while reducing dependency on traditional power sources.

1.4 **SCOPE OF THE PROJECT**

This study focuses on the design, development, and testing of a low-cost, energyefficient CCTV surveillance system powered by solar energy and controlled via the ESP32 microcontroller. The project covers the integration of a camera module with the ESP32, implementation of real-time video streaming over WiFi, and development of a simple web-based user interface for remote access. The system is designed to operate autonomously using solar power, making it suitable for rural, remote, or off-grid locations.

The scope includes:

Selection and interfacing of appropriate hardware components (ESP32, camera module, solar panel, battery, and voltage regulation circuitry).

Design of a compact and efficient power management system for continuous operation.

Development of web-based video streaming using ESP32's built-in WiFi capabilities.

Basic implementation of security features for remote access to the video feed.

Testing of system performance under various lighting and connectivity conditions.

1.5. **LIMITATIONS OF THE PROJECT**

Limited Processing Power

The ESP32 microcontroller has restricted processing capabilities, which can limit image resolution, frame rate, and advanced features like motion detection or AI-based processing.

Power Constraints

Solar power availability depends on sunlight, which can be inconsistent due to weather conditions or location. Insufficient solar charging may lead to system shutdown, especially at night or during cloudy days.

Limited Storage

Without onboard storage (like an SD card) or external storage integration, the system may only support live streaming, not long-term video recording.

WiFi Dependency

The system relies on a stable WiFi connection for real-time viewing. Poor connectivity or range issues can interrupt video transmission.

Security Concerns

Without strong encryption and authentication, web-based access over WiFi can expose the system to hacking or unauthorized access.

Limited Night Vision

Unless equipped with infrared (IR) LEDs or low-light cameras, the system may not function effectively in the dark.

Component Durability

Outdoor installation exposes components to dust, moisture, and temperature extremes, which can affect reliability and lifespan unless weatherproofing is applied.

Data Bandwidth Limitations

Continuous video streaming can consume significant bandwidth, which may not be suitable for areas with limited internet data or speed.

CHAPTER TWO

LITERATURE REVIEW

2.1. Solar Power Systems

Solar power systems are widely used for off-grid applications, including CCTV camera installations, due to their sustainability and reliability (Sharma & Jain, 2021). A solar power system typically consists of photovoltaic (PV) panels, a charge controller, and a battery storage unit (Kalogirou, 2019). The efficiency of solar panels depends on factors such as panel orientation, shading, and temperature (Markvart & Castaner, 2018). Battery management systems play a crucial role in ensuring optimal charge and discharge cycles, thereby prolonging battery life and maintaining power reliability (Mohan & Undeland, 2020). Additionally, advancements in Maximum Power Point Tracking (MPPT) technology have improved energy harvesting efficiency, making solar-powered systems more viable for continuous CCTV operation (Gupta et al., 2022). The integration of smart energy management algorithms has further enhanced the efficiency of solar power systems, allowing for dynamic power distribution and improved storage capabilities (Hernandez et al., 2023).Us

Figure 2.1: image of a solar power system
https://www.amazon.sa/-/en/Security-Monitoring-Intrusion-Solar-Powered-Waterproof/dp/B0C8DJKGRS

TYPES OF SOLAR CCTV CAMERAS

I. Standalone Solar CCTV Cameras

These are self-contained systems that include the camera, solar panel, and battery in a single unit.
They are easy to install and require minimal setup since they don’t need additional wiring for power.
Ideal for small areas or where there is limited infrastructure.

Ii. Solar-Powered IP Cameras

These cameras are connected to a network via Wi-Fi and powered by solar energy.
They allow for remote monitoring via smartphones or computers.
They are typically more advanced, offering features such as high-definition video, motion detection, and cloud storage.

iii. Solar Trail Cameras

Solar trail cameras are commonly used for outdoor surveillance in remote locations, such as forests or farmlands.
They are designed to capture images or videos triggered by motion.
Solar trail cameras are equipped with high-capacity batteries to ensure longer usage periods.

Iv. Hybrid Solar CCTV Cameras

These systems combine solar power with traditional power sources like AC or DC electricity.
They are more reliable in areas with inconsistent sunlight, as they can switch to a backup power source when necessary.
These cameras provide enhanced flexibility and reliability.

2.2 **CCTV Camera Systems**

CCTV systems consist of several components, including cameras, storage devices, and network connectivity modules (Singh & Kumar, 2020). The type of camera used depends on application-specific requirements such as resolution, night vision, and motion detection capabilities (Smith & Brown, 2019). Image quality is influenced by factors like sensor size, lens type, and image compression methods (Patel & Shah, 2021). High-definition cameras with advanced features, such as infrared and AIpowered analytic, are increasingly being used for enhanced security (Zhang et al., 2022). Cloud-based video management systems have further streamlined remote monitoring, providing scalable and secure storage options (Williams & Chen, 2023). The emergence of deep learning-based video analytics has allowed for automated anomaly detection, improving response times and reducing false alarms (Nguyen et al., 2024).

2.3 **ESP32CAM Microcontroller**

The ESP32CAM micro controller, developed by Espressif Systems, is widely used in IoT applications due to its dual-core processor, low power consumption, and integrated WiFi and Bluetooth capabilities (Lee & Lee, 2022). This microcontroller supports various communication protocols, making it ideal for remote monitoring applications such as CCTV systems (Olivares et al., 2021). One of its key advantages is its ability to process real-time data efficiently while maintaining a stable wireless connection (Tang et al., 2023). Additionally, ESP32 provides multiple GPIOs, which facilitate interfacing with cameras, sensors, and other peripherals (Zhao et al., 2021). Recent developments have enabled the ESP32 to handle AI-powered image recognition, improving surveillance capabilities through edge computing (Fernandez et al., 2023). Further enhancements in firmware optimization and power-saving modes have increased the microcontroller’s efficiency, enabling longer operation periods on battery-powered systems (Rodriguez et al., 2024).

2.3. **CCTV Camera Systems**

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2.4. **Web App Development**

Developing a web application for remote CCTV viewing requires selecting an appropriate framework, such as React, Angular, or Vue.js, which offer responsive and scalable solutions (Johnson & Williams, 2021). Security is a major concern when transmitting video data over the internet, necessitating encryption techniques like SSL/TLS and authentication mechanisms such as OAuth (Kim & Park, 2020). Additionally, latency and bandwidth considerations must be optimized to ensure real-time video streaming without buffering (Chen et al., 2022). Cloud-based hosting solutions, including AWS and Firebase, can further enhance scalability and reliability (Gomez & Rivera, 2023). Recent advancements in WebRTC technology have enabled direct peer-to-peer streaming, reducing server load and improving real-time interaction (Martinez et al., 2024). The integration of AI-driven compression algorithms has further improved bandwidth efficiency, ensuring high-quality video streaming with minimal data usage (Alvarez et al., 2025).

CHAPTER THREE

3.0 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
x. Microprocessor
xi. Voltage regulator
Xii. Battery

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.

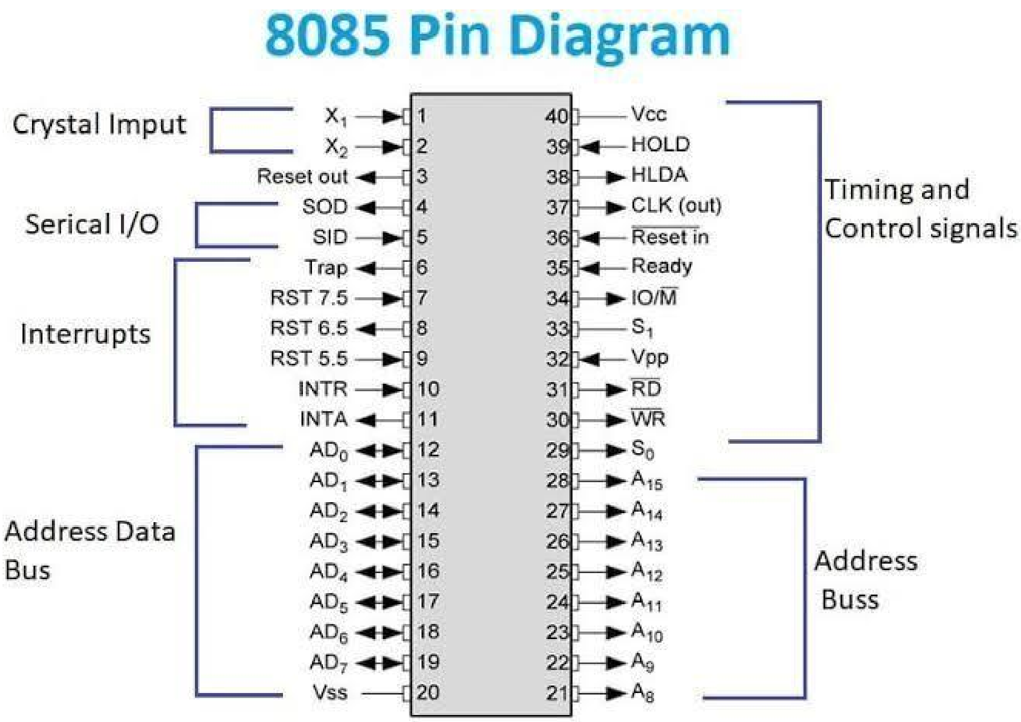

Figure 3.1: *IMAGE OF A MICRO CONTROLLER*
https://electronicsdesk.com/Roshni Y

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.
- Home Automation: Integrating cameras with smart home systems.
- Surveillance: Continuous observation in sensitive or vulnerable locations.

Figure 3.2 *ESP 32CAM IMAGE*

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

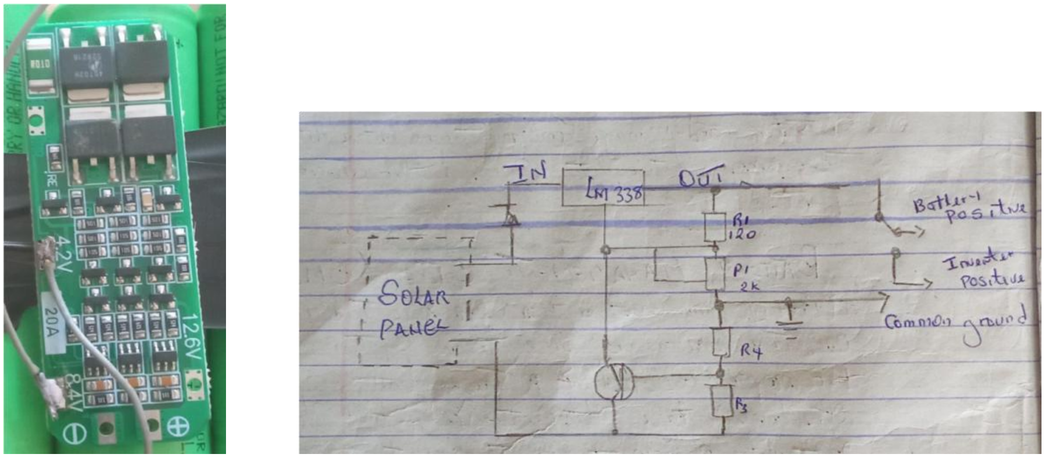

Figure 3.3 *BMS CIRCUIT DIAGRAM AND IMAGE*

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
Single phase.
3 - phase motor

DC motor
Brush 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.

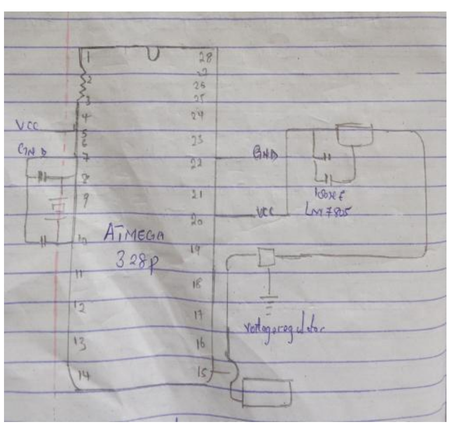

Figure 3.6 circuit diagram of a servo motor

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.

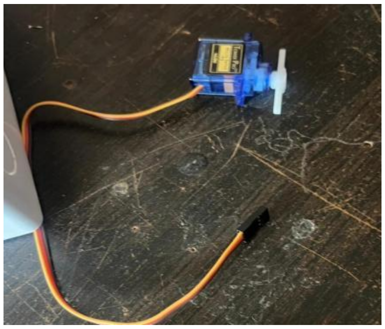

Figure 3.7 *IMAGE OF A SERVO MOTOR*

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.

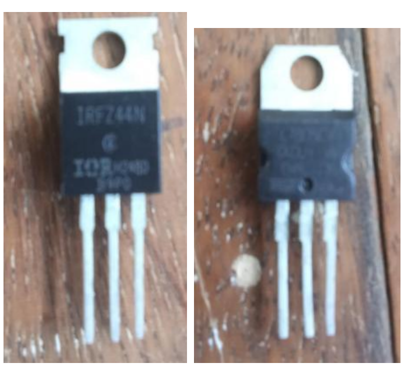

Figure 3.8 *IMAGE OF A VOLTAGE REGULATOR*

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.

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)

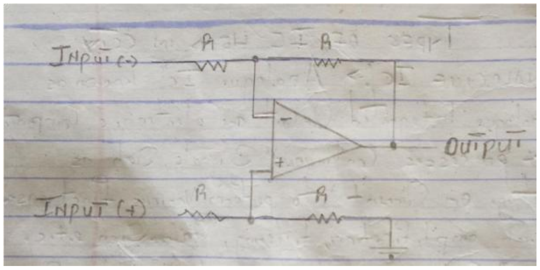

Figure 3.9 *A simple analogue circuit diagram*

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.

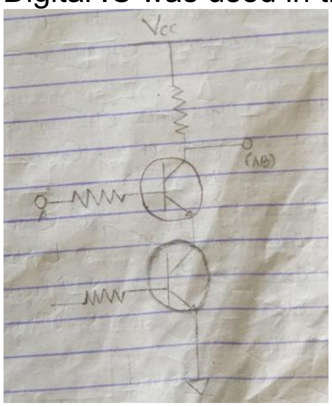

Figure 3.1.1. *A simple digital circuit diagram is shown above*

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
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.

3.2 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.

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/ghpages/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

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)

↓

[BUCK CONVERTER MODULE]
(Step-down to 5V + USB Output)

↓

[MICROCONTROLLER UNIT]

↓ ↓

[POTENTIOMETER]
(Input Control)

[SERVO MOTOR]
(Mechanical Output)

↓

(Camera)

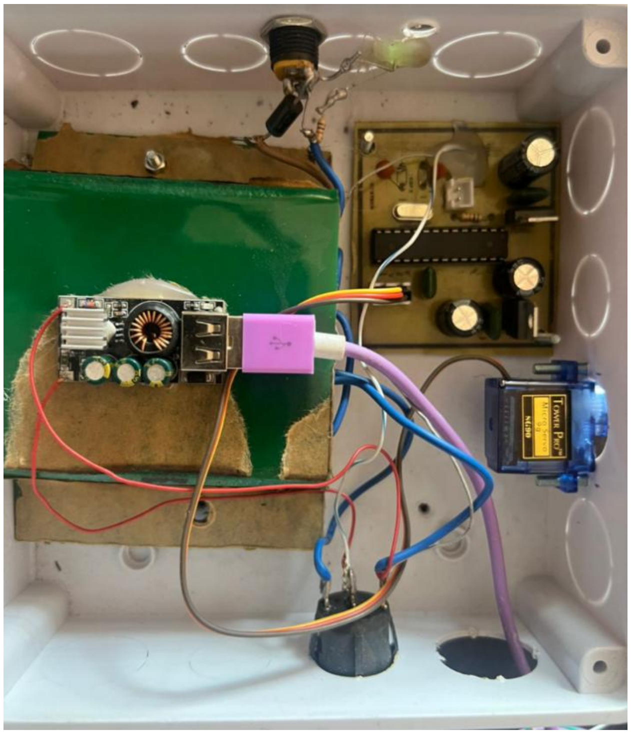

Figure 3.1.1 IMAGE OF THE OVERALL COMPONENTS

CHAPTER FOUR

4.0 TESTING AND EVALUATION

4.1 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.

4.2 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.

4.3 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.

4.4 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)

4.5 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

5.1 Summary of Achievements

The successful design and construction of the solar-powered CCTV camera system using the ESP32-CAM microcontroller demonstrate the viability of low-cost, energy-efficient surveillance solutions. The project achieved its core objectives, which include capturing real-time video, transmitting footage wirelessly over WiFi, and sustaining the system using renewable solar energy. The web application provided a user-friendly interface for remote monitoring, making the system ideal for use in areas without a stable electricity supply.

5.2 System Efficiency and Performance

The system performed reliably under sunlight, with the solar panel charging the battery adequately to keep the ESP32-CAM running. Wireless video transmission over WiFi was stable within its operating range, and the image quality was acceptable for basic surveillance needs. The use of a buck converter ensured efficient voltage regulation from the battery to the ESP32 module. Although the internal power system used wiring for connections, the video transmission remained completely wireless, offering convenience and ease of remote access.

5.3 Limitations of the Project

Despite its success, the project has a few limitations. The ESP32-CAM has limited onboard memory and does not support direct video storage unless extended with SD card capability or cloud integration. The system also lacks night vision, making surveillance at night less effective. Furthermore, the setup requires a stable WiFi connection for uninterrupted video streaming, limiting its use in areas without internet coverage. Weatherproofing and physical security of the components are additional concerns that need addressing for long-term outdoor use.

CHAPTER SIX

6.0 Recommendation

6.1 Suggested Improvements

To improve system functionality, it is recommended to integrate motion detection sensors to reduce power consumption and only record when activity is detected. Additionally, IR LEDs or night vision modules should be added to improve visibility during nighttime. An SD card can be used for local video storage, while integration with cloud services can enable access to archived footage from any location.

6.2 Opportunities for Future Development

Future versions of the project can benefit from mobile app development to offer real-time alerts, user-friendly controls, and push notifications. A GSM or LoRa module can also be incorporated for remote surveillance in locations without WiFi coverage. Moreover, optimizing the solar panel and battery capacity can ensure longer operation time during cloudy or rainy days.

6.3 Application in Broader Use Cases

This project has potential applications in rural security, farm monitoring, construction site surveillance, and wildlife observation. With further enhancements, it can serve as a scalable solution for low-income communities and areas with limited infrastructure, offering both environmental and economic benefits. The concept can also be extended to smart city solutions, eco-friendly IoT deployments, and emergency surveillance systems.

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