PROJECT

ON

DESIGN AND CONSTRUCTION OF SOLAR POWERED CCTV CAMERA USING ESP32CAM 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 **AGBEDE DAMILARE MUYIS** with matric number **HND/23/SLT/FT/0838** 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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I wholeheartedly dedicate this project to my beloved parents, whose unwavering love, sacrifices, and encouragement have been the backbone of my journey.

ACKNOWLEDGEMENT

My sincere appreciation goes to my supervisor Mr. Agboola A.O for their invaluable guidance, feedback, and encouragement throughout the course of this work.

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ABSTRACT

This project presents the design and construction of a solar-powered CCTV surveillance system utilizing the ESP32-CAM microcontroller. The system is engineered to operate independently of grid power by harnessing solar energy stored in lithium-ion batteries. The ESP32-CAM enables live video streaming and remote image capture over Wi-Fi, making the setup ideal for rural and remote monitoring applications. The design prioritizes energy efficiency, affordability, and wireless functionality. By combining IoT technology and renewable energy, the system offers a sustainable, scalable solution for enhancing security in off-grid environments.

CHAPTER ONE

1.0 INTRODUCTION

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.

1.1 AIMS OF THE PROJECT

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.

1.3 **OBJECTIVES OF THE PROJECT**

The primary objectives of this project include:

Design and construct a solar-powered CCTV camera with ESP32-based WiFi streaming. The system will utilize solar energy to power the camera, allowing for remote monitoring and surveillance in areas with limited access to electricity.

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.

1.4 SCOPE OF THE PROJECT

The scope of work for this project includes:

- Solar-Powered Cctv systems that can send digital video 100 metres over twisted-pair Ethernet cable and unlimited distances over IP networks.
- solar-powered system that can efficiently charge a battery using solar energy.
- Integrate an ESP32-based WiFi streaming module into the CCTV camera, allowing for remote monitoring and surveillance.
- CCTV camera that can capture high-quality video and images.
- User-friendly interface for remote monitoring and surveillance, allowing users to access live video feeds.
- A rotating CCTV camera to capture other angles

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

2.0 LITERATURE REVIEW

This chapter provides a comprehensive review of existing literature on the design and construction of a solar-powered CCTV system using the ESP32-CAM microcontroller. The review includes discussions on the application of solar energy in IoT (Internet of Things) and surveillance systems, the functionalities and relevance of the ESP32-CAM in CCTV, wireless data transmission technologies, and power management in embedded systems.

Wireless CCTV systems have replaced traditional wired networks due to flexibility and ease of deployment. (Sharma and Bansal, 2018) identified the main factors in wireless surveillance design as video compression, bandwidth optimization, and signal reliability. (Tuhin et al. 2022) demonstrated the ESP32-CAM's ability to stream video over Wi-Fi with acceptable performance within a range of 10 to 15 meters, noting that the use of external antennas could enhance the signal strength.

2.1 Types of CCTV

- Bullet cameras
- Ptz (Pan-tilt-zoom) Cameras
- Wireless cameras
- IP CCTV
- Dome cameras
- H d cctv
- C mount CCTV Camera
- Dome Bullet CCTV Camera
- Infrared camera
- Day/night CCTV camera
- PTZ cameras

2.2 IP CCTV

The most preferable CCTV system generally considered is an IP (Internet Protocol) based CCTV system due to its high image quality, flexibility, scalability, and ability to be easily integrated with other security systems and accessed remotely over a network; making it suitable for a wide range of applications and security needs.

Figure 1: image of a camera

Key points about IP CCTV systems:

High resolution: Delivers clear, detailed footage in high definition.

Network accessibility: View footage from anywhere with an internet connection.

Multiple camera types: Supports a variety of camera types like dome, bullet, PTZ (pan-tilt-zoom) to suit different monitoring needs.

Advanced features: Can include motion detection, facial recognition, license plate recognition, and analytics.

Scalability: Easily add new cameras to the system as needed.

The scope of IP CCTV encompasses the design, installation, and management of a network-based video surveillance system using internet protocol (IP) cameras, allowing for remote access, high-definition video quality, advanced analytics features like motion detection and facial recognition, and the ability to view live footage or recorded video from anywhere with an internet connection, often through a dedicated software interface on computers, smartphones, or tablets; essentially providing a comprehensive security solution with greater flexibility and functionality compared to traditional analog CCTV systems.

Key aspects of IP CCTV scope include:

Camera selection and placement:

Choosing appropriate IP cameras based on desired viewing angles, resolution, low-light capabilities, weatherproofing needs, and specific application requirements.

Network infrastructure:

Setting up a robust network with sufficient bandwidth to support video streaming from multiple cameras simultaneously.

Video recording and storage:

Selecting a network video recorder (NVR) to store and manage video footage, with options for cloud storage for remote access and redundancy.

Video analytics:

Implementing advanced features like motion detection, intrusion detection, license plate recognition, and facial recognition to identify potential security threats.

Access control integration:

Linking IP CCTV with other security systems like access control panels for coordinated security management.

Remote monitoring and management:

Enabling users to view live video feeds, access recorded footage, and configure camera settings from any location with internet access.

System maintenance and updates:

Regularly checking camera functionality, network connectivity, and software updates to ensure optimal performance.

2.3 Factors to consider when choosing a CCTV system:

Application: What areas need to be monitored (indoors, outdoors, specific locations).

Camera resolution: Required image quality for clear identification.

Night vision: Important for monitoring in low-light conditions.

Storage capacity: How much footage needs to be recorded and for how long.

Budget: Cost of cameras, recorder, installation, and maintenance.

2.4 Mode of Power

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).

Solar energy is widely adopted in powering IoT and surveillance systems, especially in remote and off-grid locations. According to (Abdulkareem, 2020), solar-powered surveillance systems ensure continuous power supply for low-energy IoT devices, eliminating the dependence on grid electricity. Olaniyi et al. (2019) emphasized that coupling solar panels with lithium-ion batteries provides reliability and autonomy for night-time operations.

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 self-sufficient and intelligent surveillance system is crucial in modern security infrastructure.

Efficient power management is critical in solar-powered surveillance systems to ensure longevity and reliability. (Ahmed, 2020) discussed implementing MPPT (Maximum Power Point Tracking) and low-dropout voltage regulators to enhance solar power efficiency. (Musa, 2019) recommended using deep-cycle lithium batteries for their energy density and lifecycle performance.

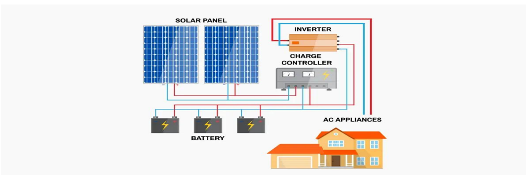

Figure 2: image of a solar power system

2.5 ESP32 Microcontroller

The ESP32-CAM is a development board based on the ESP32 microcontroller, integrated with an OV2640 camera, Wi-Fi, and Bluetooth. It offers a low-cost and compact solution for video surveillance. (García, 2020) demonstrated its use in home automation and remote image capturing. (Kumar and Thomas, 2021) also utilized ESP32-CAM in a smart doorbell project, highlighting its capability for real-time image transmission and cloud integration.

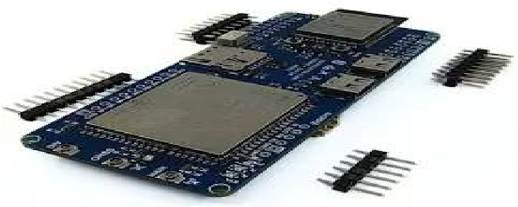

Figure 3: image of a ESP32

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.

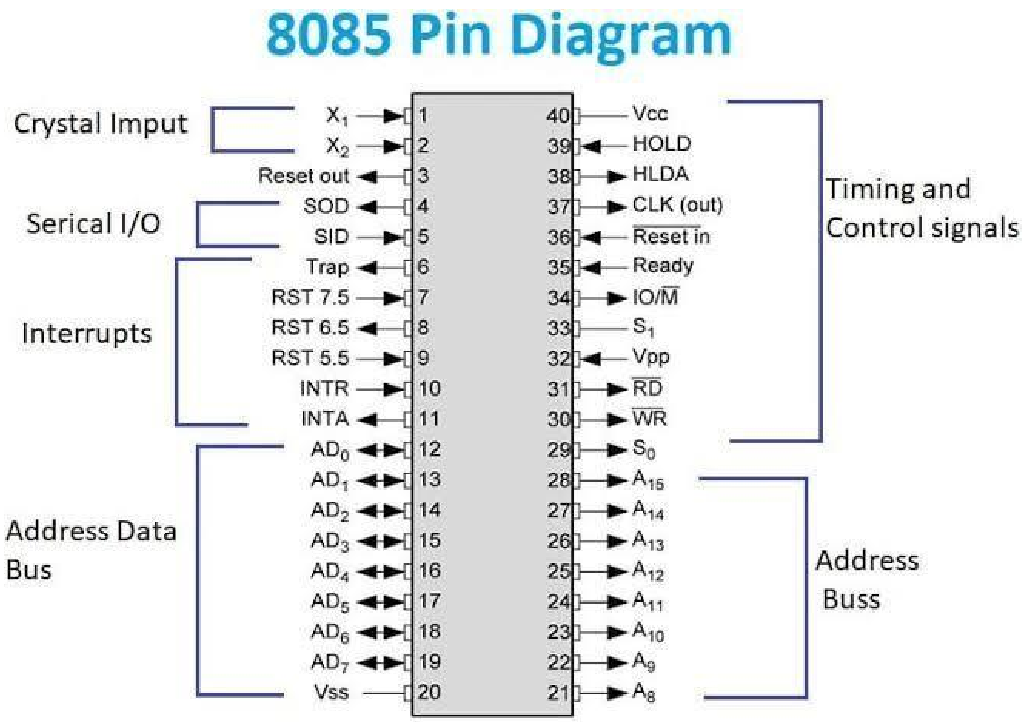

Figure 3.1: *IMAGE OF A MICRO CONTROLLER*
https://electronicsdesk.com/Roshni Y

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 3.1 *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

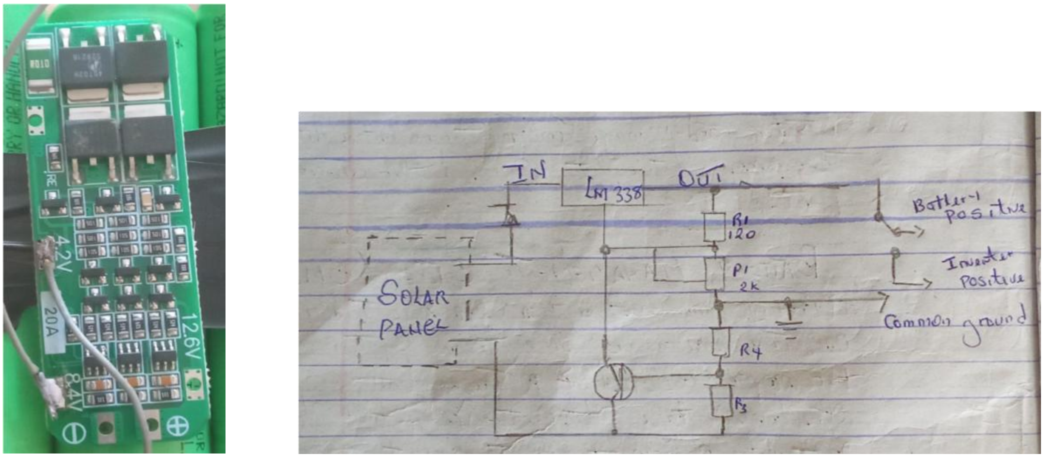

Figure 3.2 *BMS CIRCUIT DIAGRAM AND IMAGE*

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 3.3 *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 3.4 *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.

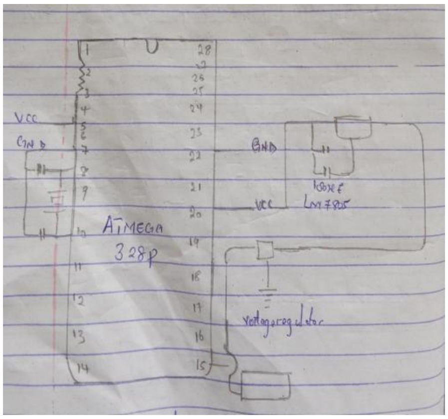

Figure 3.5 circuit diagram of a servo motor

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.

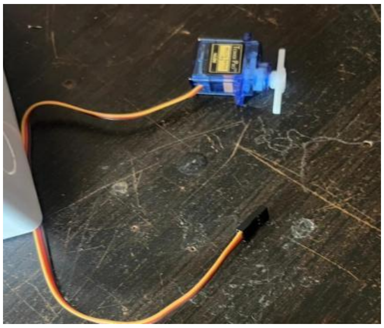

Figure 3.6 *IMAGE OF A SERVO MOTOR*

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.

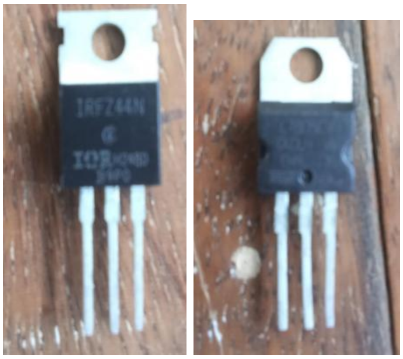

Figure 3.7 *IMAGE OF A VOLTAGE REGULATOR*

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)

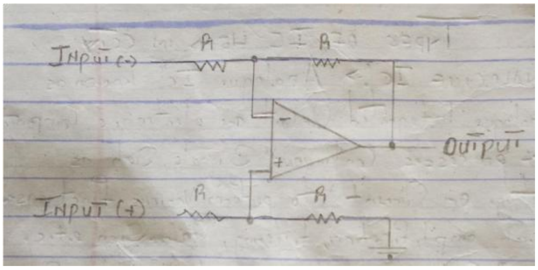

Figure 3.8 *A simple analogue circuit diagram*

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.

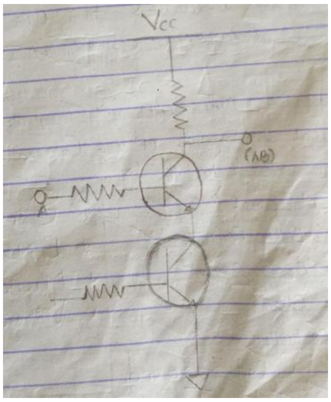

Figure 3.9. *A simple digital circuit diagram is shown above*

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 ]     [ SERVO MOTOR ]
     (Input Control)   (Mechanical Output)
                               |
                               ▼
                           (Camera)
```

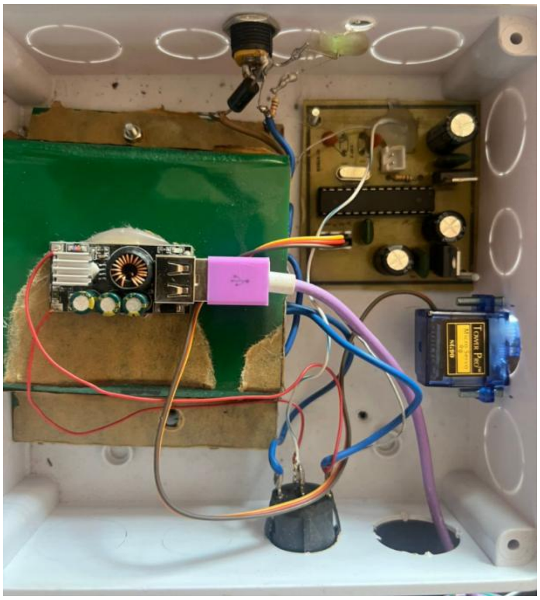

Figure 3.2.1 IMAGE OF THE OVERALL COMPONENTS

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

SUMMARY

This project work focused on developing a low-cost, solar-powered CCTV surveillance system using the ESP32-CAM microcontroller. The system integrates solar energy, battery storage, and wireless data transmission to provide real-time monitoring without relying on grid electricity. Key components include a solar panel, TP4056 charge controller, lithium-ion battery, and ESP32-CAM with Wi-Fi connectivity. The methodology involved calculating power requirements, designing the circuit, programming the camera module using Arduino IDE, and testing under varying conditions. The result is a functional, self-sustaining surveillance unit suitable for both urban and rural security needs.

CONCLUSION

The development of a solar-powered CCTV using the ESP32-CAM microcontroller successfully demonstrates how embedded systems and renewable energy can be integrated for real-world surveillance applications. The system achieves its goal of remote monitoring without dependence on the electrical grid, making it especially suitable for security in inaccessible or off-grid areas. Despite limitations in bandwidth and processing power, the solution is scalable and adaptable for further improvements such as cloud integration or GSM communication. This project contributes meaningfully to the advancement of energy-efficient, IoT-based surveillance systems.

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