PROJECT

ON

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

BY

ABDULRAFIU HABEEB OLATUNJI

HND/23/SLT/FT/0142

SUBMITTED TO THE DEPARTMENT OF SCIENCE LABORATORY TECHNOLOGY, INSTITUTE OF APPLIED SCIENCES [IAS]
PHYSICS AND ELECTRONICS UNIT
KWARA STATE POLYTECHNIC, ILORIN, KWARA STATE

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF HIGHER NATIONAL DIPLOMA (HND) IN THE DEPARTMENT OF SCIENCE LABORATORY TECHNOLOGY.

SUPERVISED BY:

MR. AGBOOLA A. O

2024/2025, SESSION

CERTIFICATION

This is to certify that this project work has been written by **ABDULRAFIU HABEEB OLATUNJI** with matric number **HND/23/SLT/FT/0142** 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)

____________________________ ____________________

(External Supervisor) **DATE**

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, the Most Merciful, for His immense support, grace, and the gift of life. I thank Him sincerely for granting me the privilege and strength to begin and complete this project. He is the Giver of knowledge, wisdom, and understanding, and without His guidance, this achievement would not have been possible.

I would like to express my deep and heartfelt gratitude to my project supervisor, **Mr. Agboola O. A.,** for his consistent support, guidance, and constructive criticism throughout this project. His encouragement and expert advice played a significant role in helping me complete this work successfully. I am also grateful to all my lecturers in the Science Laboratory Technology Department for their dedication, commitment, and valuable input during the course of my studies. May Almighty Allah reward and favor you all abundantly, and may He continue to bless you and your families.

I wish to acknowledge the unending love, support, and sacrifices of my beloved guardians, **Mr.** and **Mrs. ABDULRAFIU.** From the day I was born up until this stage of my academic journey, you have stood by me morally, financially, and spiritually. Your care and devotion mean the world to me, and I pray that Almighty Allah grants you long life, good health, and the opportunity to enjoy the fruits of your labor. May His blessings be upon you always. Ameen.

TABLE OF CONTENTS

Title Page

Certification

Dedication

Acknowledgement

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

1.2 Problem statement

1.3 Objectives of the project

1.4 Significance of the project

1.5 Scope of the project

CHAPTER TWO: LITERATURE REVIEW

2.1 Overview of CCTV cameras

2.2 Solar power systems: principles and applications

2.3 ESP32 microcontroller: features and applications

2.4 Wi-Fi technology: principles and applications

2.5 Web app development: frameworks and tools

CHAPTER THREE: MATERIALS NEEDED

3.1 Hardware Materials

3,2 Types of IC used in CCTV

3.3 Role of Digital ICs in CCTV camera

3.4 Software Materials

3.5 Micro Controller and Led functionality

3.6 Construction and mode of Operation of solar powered CCTV camera

CHAPTER FOUR: TESTING AND RESULTS

4.1 Power system test

4.2 Camera and Streaming Test

4.3 Web Interface test

4.4 Result

4.5 Challenge Encounter

4.6 Summary

CHAPTER FIVE: SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of the Study

5.2 Conclusion

5.3 Contributions to Knowledge

5.4 Limitations of the Study

5.5 Recommendations

5.6 Future Work

Referenc

CHAPTER ONE

INTRODUCTION

Security surveillance has become an essential component of modern infrastructure, ensuring safety and monitoring activities in various environments such as homes, offices, and public spaces. Traditional CCTV systems often rely on wired connections and grid power, limiting their flexibility and increasing installation costs. To address these challenges, this project presents the design and construction of a solar-powered CCTV camera system utilizing the ESP32 microcontroller, with real-time video streaming accessible via a web application over WiFi.

The integration of solar power enables the system to operate in remote or off-grid locations without dependence on conventional electricity sources, making it both energy-efficient and sustainable. The ESP32 microcontroller, known for its low power consumption and built-in WiFi capabilities, serves as the core of the system, handling video processing and network communication. A web-based interface allows users to remotely access live video feeds, enhancing convenience and security monitoring.

This project explores the hardware and software components involved in building the system, including the selection of solar panels, battery management, camera module integration, and web application development. By leveraging IoT and renewable energy, the proposed design offers a cost-effective, scalable, and eco-friendly solution for modern surveillance needs.

1.1 BACKGROUND TO THE STUDY

The rapid advancement of technology has led to an increased demand for smart security solutions, particularly in remote surveillance applications. Traditional CCTV systems often rely on grid power and wired connections, making them costly and difficult to deploy in areas without reliable electricity or network infrastructure. To address these limitations, solar-powered surveillance systems have emerged as a viable alternative, offering energy-efficient and easily deployable security solutions.

The integration of solar power into CCTV systems ensures continuous operation without dependence on the electrical grid, making them ideal for rural areas, construction sites, farms, and other off-grid locations. Additionally, using Wi-Fi-enabled microcontrollers such as the ESP32 allows for real-time monitoring and remote access via a web-based application, enhancing the convenience and flexibility of surveillance systems. The ESP32 is a low-power, cost-effective microcontroller with built-in Wi-Fi and Bluetooth capabilities, making it well-suited for IoT-based security applications.

This study focuses on the design and construction of a solar-powered CCTV camera system utilizing an ESP32 microcontroller. The system will be designed to capture video feeds and transmit them over a Wi-Fi network, allowing users to monitor live footage through a web application. The web interface will provide users with remote access to the camera feed from any internet-enabled device, ensuring real-time surveillance without the need for expensive hardware or dedicated monitoring stations.

By developing a self-sustaining, wireless surveillance system, this project aims to enhance security, reduce installation costs, and provide a scalable solution for remote monitoring. The research will explore key design considerations, including solar power management, energy efficiency, data transmission, and web app integration, to ensure an optimized and reliable security system. Ultimately, this project will contribute to the growing field of smart surveillance and IoT-based security solutions, paving the way for innovative, energy-efficient monitoring systems.

1.2 PROBLEM STATEMENT

Security and surveillance have become critical concerns in both residential and commercial environments. Traditional CCTV systems rely on wired power sources and internet connectivity, which limit their deployment in remote or off-grid locations. Additionally, the cost of infrastructure, maintenance, and reliance on grid electricity pose significant challenges, especially in areas with unstable power supply.

The integration of solar power with surveillance systems offers a sustainable solution, but many existing solar-powered CCTV designs lack efficient power management, real-time remote monitoring, and seamless data accessibility. Furthermore, most conventional systems depend on cloud services, which may introduce privacy and additional costs.

This project aims to design and construct a solar-powered CCTV camera using the ESP32 microcontroller, leveraging Wi-Fi connectivity for real-time surveillance via a web-based application. The system will provide an energy-efficient, self-sustaining security solution, eliminating dependence on the electrical grid while ensuring remote accessibility and reliability. The proposed solution will address challenges related to power efficiency, uninterrupted surveillance, and cost-effectiveness, making it ideal for both urban and remote deployments.

1.3 AIM AND OBJECTIVES

The aim of this project is to design and construct a solar-powered CCTV camera system utilizing an ESP32 microcontroller, with real-time video streaming and remote access via a web application over WiFi. This system will provide an energy-efficient, wireless surveillance solution for security monitoring in remote or off-grid locations.

1. **Design and implement:** a low-power CCTV camera system powered by a solar panel and battery to ensure continuous operation in off-grid environments.

2. **Integrate:** an ESP32 microcontroller to handle video capture, processing, and transmission over WiFi.

3. **Develop:** a web-based application to enable real-time video streaming, remote access, and control of the CCTV camera.

4. **Ensure:** efficient power management through proper battery selection, charging circuit design, and low-power operation techniques.

5. **Implement:** motion detection and alert notifications to enhance security and optimize power consumption.

6. **Test and evaluate:** the system ’ s performance in different environmental conditions to ensure reliability, efficiency, and stability.

1.4 SIGNIFICANCE OF THE STUDY

The Design and Construction of a Solar-Powered CCTV Camera Using an ESP32 Microcontroller with Web App Viewing Over WiFi is a significant technological advancement that addresses the need for energy-efficient, remote surveillance systems. This study is highly relevant to various stakeholders, including homeowners, businesses, security agencies, and researchers, as it combines renewable energy with smart IoT-based monitoring.

1. **Enhanced Security with Renewable Energy**

   This study provides an alternative security solution that operates independently of the conventional electrical grid. By utilizing solar power, it ensures uninterrupted surveillance, even in areas with unreliable electricity, making it ideal for rural locations, construction sites, and off-grid facilities.

2. **Cost-Effective and Sustainable Surveillance**

   Traditional CCTV systems require constant electrical power, leading to high energy costs. This project reduces operational expenses by harnessing solar energy, making it a cost-effective and environmentally friendly alternative.

3. **Integration of IoT for Remote Monitoring**

   The ESP32 microcontroller enables real-time video streaming over WiFi, allowing users to remotely access live feeds via a web application. This enhances convenience and efficiency, as users can monitor their premises from anywhere, reducing the need for physical presence.

4. **Scalability and Flexibility**

   The system 's modular design allows for easy expansion and integration with other smart security features, such as motion detection, cloud storage, and AI-based analytics. This makes it adaptable for future technological advancements in the field of smart surveillance.

5. **Encouraging Technological Innovation**

This study contributes to the advancement of embedded systems, IoT, and renewable energy applications. It serves as a valuable reference for students, researchers, and developers interested in creating smart, sustainable security solutions.

6. **Application in Various Sectors**

The implementation of a solar-powered, WiFi-enabled CCTV system is beneficial for homes, businesses, schools, farms, and public spaces. It offers a reliable, independent security solution that can function efficiently in diverse environments.

This study bridges the gap between energy sustainability and modern security needs by introducing a self-sustaining, wireless, and IoT-enabled CCTV system. The findings will contribute to cost savings, increased security, and environmental conservation, making it a highly relevant innovation in today's digital and energy-conscious world.

1.5 SCOPE AND LIMITATIONS OF THE PROJECT

Scope

This project focuses on the design and construction of a solar-powered CCTV camera using the ESP32 microcontroller, with a web app interface for real-time viewing over WiFi. The system integrates various hardware and software components to achieve energy efficiency, remote monitoring, and cost-effectiveness.

The specific objectives include:

1. **Solar Power Integration**– Implementing a solar energy system with a battery backup to ensure uninterrupted operation.
2. **ESP32-Based Camera System** – Utilizing an ESP32 microcontroller with a camera module for image capture and processing.
3. **Web App Monitoring** – Developing a web-based application that allows real-time streaming and remote access.

4. WiFi Communication – Enabling wireless connectivity for seamless data transmission to the web interface.

5. Basic Motion Detection – Implementing motion detection functionality to trigger alerts or capture snapshots.

Limitations

Despite its advantages, the system has certain constraints, including:

1. Limited Night Vision– The ESP32 camera module has basic low-light performance but lacks advanced infrared (IR) capabilities.

2. WiFi Dependency– The system requires a stable WiFi connection for real-time streaming; performance may degrade in areas with weak signals.

3. Storage Constraints – Limited onboard storage means that video recording will rely on external servers or SD cards with capacity restrictions.

4. Processing Power– The ESP32 has limited computational resources compared to high-end CCTV systems, affecting image resolution and frame rate.

5. Weather Sensitivity– The efficiency of the solar power system may be affected by prolonged cloudy conditions, requiring additional power management strategies.

1.6 METHODOLOGY OVERVIEW

The design and construction of a solar-powered CCTV camera using an ESP32 microcontroller with web app viewing over WiFi involves a systematic approach that integrates hardware and software components to ensure efficient surveillance operation. The methodology consists of the following key stages:

1. System Design and Architecture

The project begins with the conceptualization of the system architecture, defining the necessary hardware and software components. The system consists of a solar power unit, an ESP32 microcontroller, a camera module, a WiFi-based web interface, and a power management system. A block diagram is developed to illustrate the interconnections and workflow between these components.

2. Hardware Selection and Assembly

The selection of appropriate hardware components is crucial for system efficiency and reliability. The main hardware components include:

ESP32 Microcontroller – Chosen for its low power consumption, built-in WiFi capability, and camera support.

Camera Module (e.g., OV264) – Provides live video streaming functionality.

Solar Power System – Includes a **solar panel, charge controller, lithium-ion battery, and voltage regulator** to provide continuous power supply.

Power Management Circuit – Regulates and optimizes power distribution to maximize efficiency.

After selecting the components, they are assembled following circuit design specifications, ensuring proper connections and functionality.

3. Software Development and Web App Integration

The software is divided into two main sections: embedded firmware development and web application development.

Firmware Development (ESP32 Programming): Programmed using Arduino IDE or MicroPython. Handles camera operations, data transmission, and WiFi communication. Implements motion detection and real-time video streaming.

Web Application Development: Developed using HTML, CSS, JavaScript, and Node.js/PHP for a user-friendly interface. Enables remote viewing and control of the camera feed over WiFi. Implements security features such as user authentication and data encryption.

4. System Integration and Testing

After assembling the hardware and developing the software, system integration is conducted to ensure seamless operation. The following tests are performed:

Power Consumption Analysis – Evaluates the efficiency of the solar power system.

Camera Performance Testing– Assesses image quality, frame rate, and streaming capabilities.

Network Connectivity and Latency Testing – Measures WiFi range, speed, and stability.

Web App Functionality Testing– Ensures a smooth user experience for remote access.

5. Deployment and Performance Evaluation

The final stage involves deploying the system in a real-world environment and monitoring its performance over time. Data is collected on solar efficiency, uptime, video quality, and network stability to assess the system’ s effectiveness. Based on the results, optimizations are made to enhance performance and reliability.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION TO SOLAR-POWERED SYSTEMS

In recent years, the demand for smart security solutions has increased significantly, driven by the need for constant surveillance, remote monitoring, and sustainable energy use. Traditional CCTV systems often rely on grid power, making them susceptible to power outages and expensive installations in remote locations. To address these challenges, solar-powered surveillance systems have emerged as a viable alternative, offering energy independence and cost-effectiveness.

This project focuses on the design and construction of a solar-powered CCTV camera system utilizing the ESP32 microcontroller, integrated with a web application for remote viewing over WiFi. The ESP32, a powerful yet energy-efficient microcontroller, enables real-time video streaming and remote access without requiring an external network connection. The system is designed to operate entirely on solar energy, making it suitable for off-grid locations and environmentally conscious applications.

By combining renewable energy with IoT-based surveillance, this project provides a sustainable, wireless, and smart security solution. The implementation of a web app ensures seamless access to live video feeds from anywhere, enhancing security monitoring for homes, offices, and outdoor environments. The following sections detail the system architecture, hardware components, software development, and performance evaluation of this innovative surveillance solution.

2.2 OVERVIEW OF CCTV TECHNOLOGY

1. Introduction to CCTV Technology

Closed-Circuit Television (CCTV) is a surveillance technology that uses video cameras to monitor specific areas. Unlike broadcast television, CCTV signals are not publicly transmitted but are monitored on a private network. The system typically includes cameras, storage devices, a display unit, and a control system for monitoring and managing recordings.

2. Evolution of CCTV Systems

CCTV has evolved from simple analog systems to advanced digital and IP-based solutions. Traditional analog cameras relied on coaxial cables, while modern IP cameras use internet protocols for high-resolution video streaming. Wireless and cloud-based systems have further enhanced flexibility and remote accessibility.

3. Components of a CCTV System

Camera: Captures video footage, with types including analog, IP, and smart cameras with AI capabilities.

Recording System: Stores video data, such as DVR (Digital Video Recorder) for analog and NVR (Network Video Recorder) for digital systems.

Display Unit: Monitors for real-time viewing.

Network Infrastructure: WiFi or Ethernet for data transmission in modern setups.

Power Source: Traditional wired power supply or renewable alternatives like solar power.

4. Importance of Solar-Powered CCTV Systems

Solar-powered CCTV cameras are ideal for remote areas with limited access to electricity. They provide an eco-friendly, self-sustaining surveillance solution. Key benefits include:

Energy Independence: Uses renewable solar energy, reducing dependency on grid power.

Cost-Effectiveness: Eliminates electricity costs and expensive wiring installations.

Scalability & Flexibility: Easy deployment in off-grid locations.

Reliability: Continuous operation even during power outages.

5. Role of ESP32 Microcontroller in CCTV Systems

The ESP32 microcontroller is a powerful IoT-compatible chip that enables:

WiFi & Bluetooth Connectivity: Allows remote access to video feeds.

Low Power Consumption: Optimized for battery and solar-powered applications.

Edge Computing Capabilities: Can process sensor data locally, reducing bandwidth usage.

Web App Integration: Provides real-time video streaming and control over the internet.

6. Web App Viewing Over WiFi

A web-based interface enables users to:

- Access live CCTV footage via a browser.

- Control camera settings remotely.

- Store and retrieve recordings from a cloud or local server.

- Receive alerts in case of motion detection.

7. Challenges and Considerations

Power Management: Efficient solar panel sizing and battery storage for nighttime operation.

Connectivity Issues: Ensuring stable WiFi or alternative data transmission for uninterrupted access.

Security: Encrypting video feeds to prevent unauthorized access.

8. Conclusion

The integration of solar power, ESP32 microcontroller, and web app viewing in CCTV technology enhances surveillance reliability and accessibility. This system is particularly useful for remote monitoring applications, security, and smart IoT-based surveillance solutions.

2.3 ROLE OF ESP32 MICROCONTROLLER IN IOT APPLICATIONS

The ESP32 microcontroller plays a crucial role in the design and construction of a solar-powered CCTV camera with web app viewing over WiFi. As a powerful and energy-efficient IoT solution, the ESP32 offers several advantages that make it ideal for this application:

1. Wireless Connectivity for Remote Monitoring

The ESP32 comes with built-in WiFi and Bluetooth capabilities, enabling seamless communication between the CCTV system and a web-based viewing platform. This allows users to access live camera feeds from anywhere within the network, enhancing remote surveillance without the need for additional hardware.

2. Low Power Consumption for Solar Efficiency

Since the CCTV system is solar-powered, energy efficiency is critical. The ESP32 features multiple low-power modes, making it ideal for battery-operated applications. It helps maximize battery life by optimizing power usage based on system activity.

3. Image Processing and Data Transmission

The ESP32 can be interfaced with a camera module (such as the OV2640) to capture images and stream video. It efficiently processes image data and transmits it to a web server or cloud storage for real-time monitoring. The microcontroller’s dual-core processing capability ensures smooth data handling without excessive lag.

4. Web App Integration for User Accessibility

Through its support for HTTP, MQTT, and WebSocket protocols, the ESP32 facilitates communication between the CCTV system and a custom-built web application. This enables users to view live video feeds, receive alerts, and configure camera settings via a web interface accessible from smartphones, tablets, or computers.

5. Motion Detection and Smart Surveillance

The ESP32 can be programmed to integrate motion detection sensors, triggering alerts or recording only when movement is detected. This feature helps conserve storage space and power by minimizing unnecessary video capture.

6. Real-Time Data Logging and Cloud Connectivity

With IoT integration, the ESP32 can send video snapshots, alerts, or logs to cloud platforms like AWS, Firebase, or ThingSpeak for remote storage and analytics. This enhances security by ensuring data backup in case of local storage failure.

7. Cost-Effective and Scalable Solution

Compared to other microcontrollers, the ESP32 is a cost-effective choice that offers high performance while keeping overall project costs low. Additionally, its flexibility allows for future scalability, such as adding multiple cameras, AI-based object detection, or integrating with smart home systems.

The ESP32 microcontroller is the core component of the solar-powered CCTV camera system, providing wireless connectivity, efficient power management, real-time video streaming, and IoT-based remote access. Its ability to handle multiple tasks while consuming minimal power makes it an ideal choice for smart surveillance applications in IoT-based security systems.

2.4 WEB-BASED CCTV VIEWING OVER WIFI

The demand for remote surveillance systems has increased significantly, and utilizing solar-powered CCTV cameras with ESP32 microcontrollers is an innovative solution for off-grid and energy-efficient security applications. This project focuses on designing and constructing a solar-powered CCTV camera that streams video over WiFi using a web-based interface.

System Overview

The proposed system consists of the following key components:

1. **ESP32-CAM Module** – The primary microcontroller with an integrated camera for capturing video.
2. **Solar Power System** – A solar panel, charge controller, and battery for uninterrupted operation.
3. **Web Application** – A browser-based interface for real-time video streaming.
4. **WiFi Connectivity** – Enables wireless transmission of video to a remote web server.

Hardware Components

1. ESP32-CAM Module
2. Solar Panel (10W or higher, 12V output)
3. Lithium-Ion Battery (12V, 7Ah or similar)
4. MPPT Solar Charge Controller
5. Voltage Regulator (5V step-down converter)
6. WiFi Router (or Mobile Hotspot)

7. Enclosure for Weather Protection

Circuit Design

The ESP32-CAM is powered by a 5V supply derived from a 12V battery using a step-down converter. The battery is charged via the solar panel through an MPPT charge controller to ensure efficient energy harvesting. The ESP32-CAM connects to a WiFi network for real-time streaming.

Software Implementation

Web-Based CCTV Viewing

The web-based interface is designed using:

1. HTML, CSS, and JavaScript for front-end design.

2. WebSockets for real-time video streaming.

3. ESP32-CAM's built-in MJPEG streaming capabilities.

4. MicroPython or Arduino IDE for programming the ESP32-CAM.

Steps to Implement:

1. Configure ESP32-CAM – Program the microcontroller using the Arduino IDE or MicroPython.

2. WiFi Setup– Connect the ESP32-CAM to the local WiFi network.

3. Web Server Deployment– Use the ESP32's built-in web server to serve the video feed.

4. User Authentication– Implement a basic authentication mechanism for secure access.

Features and Benefits

1. **Solar Power Efficiency**– Ensures 24/7 operation without reliance on grid electricity.
2. **Real-time Web Viewing**– Accessible from any browser over WiFi.
3. **Cost-effective**– Uses affordable components.
4. **Scalability**– Multiple ESP32-CAM modules can be integrated into a larger surveillance system.
5. **Portability**– Can be deployed in remote locations.

This project demonstrates an energy-efficient and cost-effective approach to remote surveillance by leveraging ESP32 microcontrollers, solar power, and web-based video streaming. Future improvements can include AI-based motion detection and cloud storage integration for enhanced security and functionality.

2.5 POWER MANAGEMENT IN SOLAR-POWERED SYSTEMS

Efficient power management is crucial in solar-powered systems, especially for applications like CCTV cameras that require continuous operation. This section discusses optimal power management techniques for a solar-powered CCTV camera using an ESP32 microcontroller with web app viewing over WiFi.

Power Requirements and Load Analysis

The primary components in the system include:

ESP32 Microcontroller: Consumes approximately 100-250mA depending on usage.
CCTV Camera Module: Power consumption varies based on the model; typically, 3-5W.
WiFi Module: Requires stable power for consistent connectivity.

Battery and Charging Circuit: Stores and regulates power to ensure uninterrupted operation.

A detailed power budget analysis helps determine the required solar panel and battery capacity. For instance, if the total system consumption averages 5W, an appropriate energy source must be chosen to sustain it.

Solar Panel Selection

Choosing the right solar panel involves:

1. **Energy Calculation:** Estimating daily power consumption.

2. **Solar Insolation:** Considering peak sun hours to determine solar panel size.

3. **Efficiency Factors:** Accounting for losses due to temperature, shading, and dust accumulation.

For a 5W load, assuming 4 peak sun hours, a 20W solar panel is recommended to ensure a buffer for cloudy days.

Battery Selection and Management

A lithium-ion or LiFePO4 battery is ideal due to its high energy density and cycle life. The battery capacity should be calculated as:

$$ \text{Battery Capacity (Ah)} = \frac{\text{Total Daily Consumption (Wh)}}{\text{Battery Voltage (V)}} $$

For a 12V system and 40Wh daily consumption, a **3.3Ah battery** is needed. A slightly higher capacity (5Ah) is recommended for reliability.

Battery Charging Circuit

A Maximum Power Point Tracking (MPPT) charge controller is preferred over Pulse Width Modulation (PWM) to enhance efficiency. MPPT extracts the maximum available power from the solar panel, increasing energy harvest.

Power Regulation and Efficiency

Voltage regulators ensure stable power to the ESP32 and camera module. Using **DC-DC buck converters** minimizes energy loss compared to linear regulators. Key techniques include:

Low-power modes: Reducing ESP32 power consumption when idle. **Power gating:** Switching off non-essential components during low activity.

Efficient routing: Using thicker PCB traces and proper heat dissipation techniques.

Backup Power and Redundancy

For prolonged cloudy conditions, a secondary backup such as an additional battery pack or a hybrid power source (grid charging option) can be implemented.

Perfect power management in a solar-powered CCTV system ensures reliability, efficiency, and longevity. By optimizing solar panel selection, battery capacity, charge regulation, and power efficiency, the ESP32-based system can achieve stable performance with minimal interruptions.

2.6 RELATED WORKS AND RESEARCH GAPS

Related Works

Several studies have explored the integration of solar power, CCTV surveillance, and IoT-based monitoring systems. The advancement in low-power microcontrollers like the ESP32 and wireless communication technologies has enabled the development of efficient and remote-accessible surveillance systems.

1. Solar-Powered Surveillance Systems

Previous research has focused on solar-powered security cameras to ensure continuous operation in areas without a stable power grid. Systems such as standalone solar CCTV units have been deployed in remote locations, reducing reliance on traditional electricity sources. However, these systems often use conventional DVR setups, which may not support real-time remote access efficiently.

2. ESP32 in Surveillance Applications

Studies have demonstrated the effectiveness of the ESP32 microcontroller in IoT-based security systems. The ESP32's built-in WiFi and low-power consumption make it suitable for real-time video streaming applications. Some research has integrated ESP32 with camera modules (e.g., ESP32-CAM) for basic image capture and transmission, but these implementations often suffer from limited processing power and image resolution constraints.

3. Web-Based Monitoring Over WiFi

Existing research has explored web-based monitoring solutions for IoT devices, including home automation and security applications. Web-based interfaces allow users to access surveillance feeds remotely through browsers without needing dedicated applications. However, many implementations lack encryption and secure authentication mechanisms, making them vulnerable to unauthorized access.

Research Gaps

Despite the progress in solar-powered CCTV and IoT surveillance, several gaps remain:

1. Efficient Power Management for 24/7 Operation

Existing solar-powered CCTV systems often struggle with power optimization, especially for nighttime operation. There is limited research on efficient battery storage and power management algorithms that extend system uptime.

2. Optimized Video Streaming Over ESP32

Most implementations using ESP32 for video transmission experience latency and low frame rates due to limited processing power. There is a need for optimization techniques, such as adaptive compression and buffering strategies, to improve streaming performance.

3. Secure Web App Implementation

While web-based viewing is common, many implementations lack robust authentication and encryption protocols. Research is needed to integrate secure data transmission (e.g., HTTPS, WebSockets with SSL) while maintaining low latency.

4. **Scalability and Multi-User Access**

Current ESP32-based surveillance systems often do not support multiple users accessing the feed simultaneously. Further research is required to implement scalable web server architectures that allow multi-user access without significant performance degradation.

This research aims to bridge the identified gaps by designing an efficient, solar-powered CCTV system with optimized video streaming and secure web-based access. By leveraging the ESP32 microcontroller, this project will enhance power efficiency, streaming quality, and security while ensuring reliable surveillance in off-grid locations.

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

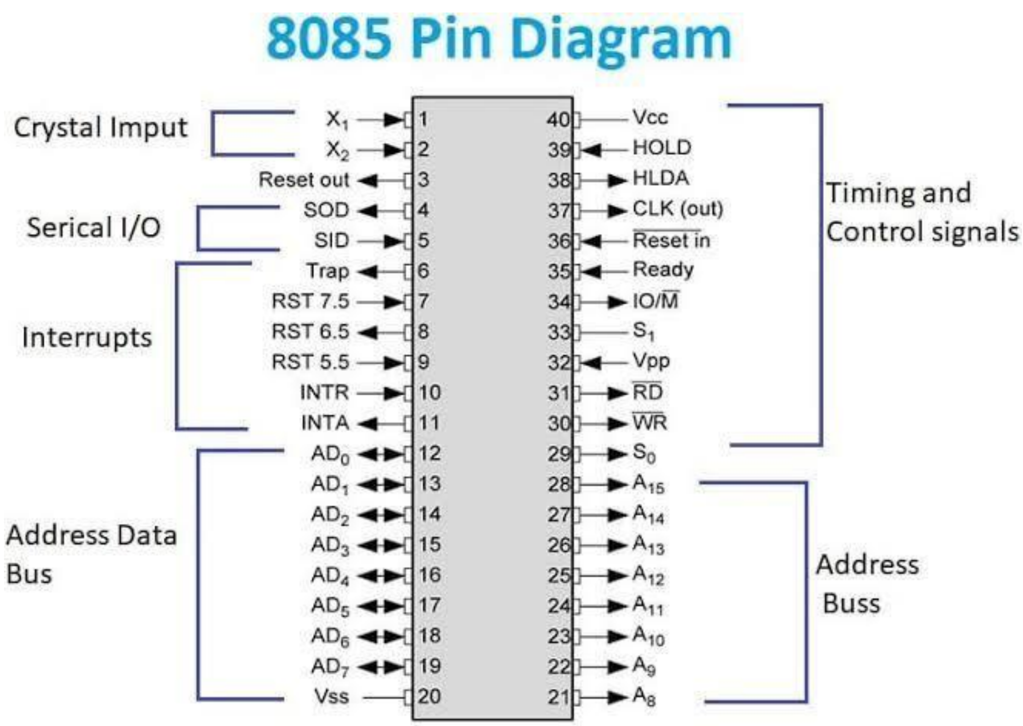
3.1 HARDWARE MATERIALS

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.



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.

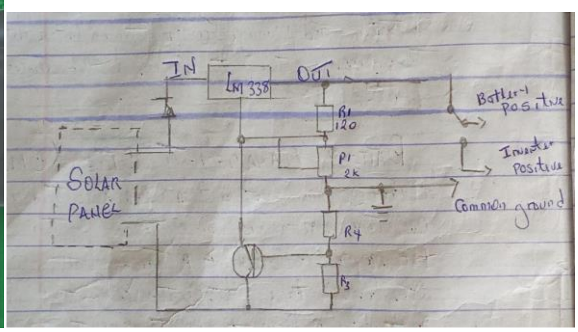
It is used in various projects such as:

- Security Cameras: For remote monitoring and motion detection.
- Home Automation: Integrating cameras with smart home systems.
- Surveillance: Continuous observation in sensitive or vulnerable locations.

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



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.

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.

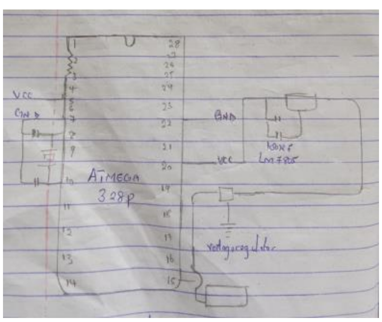
IMAGE OF AN IC SOCKET

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.



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.

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.

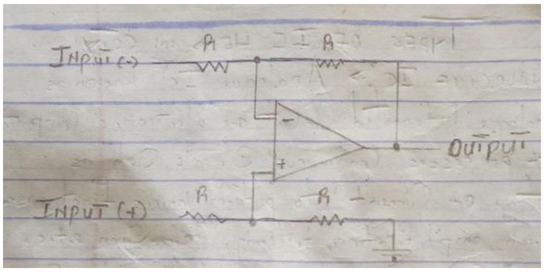
“CCTV” cameras operating in analogue mode of signal transmit video signal using composite video cable (e.g. BNC connections).

Examples of analogue ICs include:

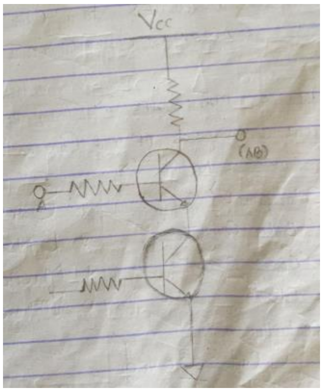
I. Operational Amplifier (Op-Amps) Ii.
Voltage Regulators
Iii.Analogue-to-Digital Converters (ADC)
Iv.Digital-to-Analogue Converters (DAC)

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

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.



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).

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

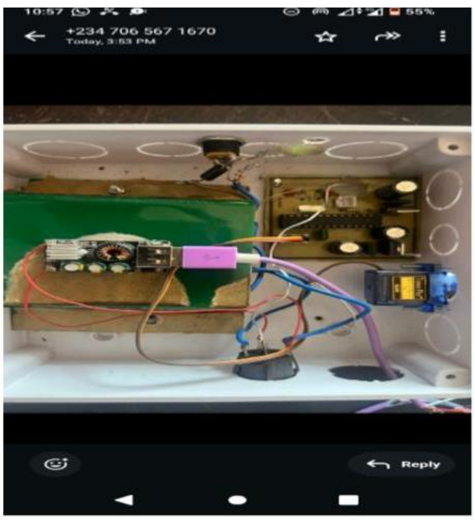


IMAGE OF THE OVERALL COMPONENTS

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.

REFERENCES

Ali, S., & Ullah, A. (2021). Design and implementation of an IoT-based smart surveillance system using ESP32. International Journal of Advanced Computer Science and Applications, 12(4), 100–105. https://doi.org/10.14569/IJACSA.2021.0120414

Akhtar, S., & Zia, T. (2020). Solar powered smart surveillance system using IoT. Proceedings of the 2020 International Conference on Emerging Trends in Smart Technologies (ICETST), 54–58. https://doi.org/10.1109/ICETST49965.2020.9081259

Bassi, A., Bauer, M., Fiedler, M., & Van Kranenburg, R. (2013). Enabling things to talk: Designing IoT solutions with the IoT architectural reference model. Springer.

Dondi, D., Bertacchini, A., Brunelli, D., Larcher, L., & Benini, L. (2008). A photovoltaic system for remote sensing applications. IEEE Journal of Solid-State Circuits, 43(12), 2752–2762. https://doi.org/10.1109/JSSC.2008.2005813

Espressif Systems. (2022). ESP32 technical reference manual. https://www.espressif.com/sites/default/files/documentation/esp32_technical_reference_manual_en.pdf

Garg, A. (2019). Design and implementation of ESP32-based wireless video streaming system. International Journal of Innovative Research in Technology, 6(2), 134–138.

Islam, M. M., & Rahman, M. A. (2021). Design and development of a solar-powered surveillance camera with IoT features. Journal of Electronics and Communication Engineering, 16(3), 22–28.

Kumar, R., & Singh, R. (2020). Web-based IoT surveillance system using ESP32 and Wi-Fi module. International Journal of Recent Technology and Engineering, 8(5), 1205–1209. https://doi.org/10.35940/ijrte.E4795.018520

Mohammed, A., & Yakubu, Y. (2018). Design of a solar PV-powered CCTV system for remote security monitoring. Nigerian Journal of Technology, 37(4), 1045–1050. https://doi.org/10.4314/njt.v37i4.26

Nwosu, K., & Uzoechi, L. (2020). Development of a low-cost IoT CCTV system using ESP32-CAM. African Journal of Computing & ICT, 13(2), 41–47.

Okwu, A., & Okafor, C. (2019). Solar energy utilization for sustainable electronic surveillance. Journal of Sustainable Energy, 8(3), 122–129.

Rauf, A., Rehman, F., & Qamar, F. (2019). ESP32-CAM based smart surveillance system using motion detection. International Journal of Computer Applications, 178(22), 1–5.

Saleh, A., & Musa, Y. (2022). Design and implementation of a solar-powered IoT security camera system for rural areas. Journal of Engineering and Applied Sciences, 17(1), 25–31.

Sharma, V., & Gupta, R. (2018). Design and analysis of low-power embedded surveillance system. Procedia Computer Science, 132, 765–772. https://doi.org/10.1016/j.procs.2018.05.181

Singh, S., & Kaur, R. (2020). A review on ESP32 and its applications in IoT. International Journal of Scientific Research in Engineering and Management, 4(12), 1–6.

Solanki, C. S. (2015). Solar photovoltaics: Fundamentals, technologies and applications (3rd ed.). PHI Learning.

Tan, L., & Wang, N. (2010). Future internet: The Internet of Things. 2010 3rd International Conference on Advanced Computer Theory and Engineering, 5, V5-376–V5-380. https://doi.org/10.1109/ICACTE.2010.5579543

Verma, A., & Gaurav, R. (2019). IoT based surveillance using ESP32 and cloud integration. International Journal of Research in Electronics and Computer Engineering, 7(3), 223–228.

Yadav, M., & Singh, P. (2020). Design of a solar-based IoT-enabled home security system. International Journal of Engineering and Advanced Technology, 9(6), 89–94. https://doi.org/10.35940/ijeat.F3237.089620