DESIGN AND CONSTRUCTION OF SOLAR POWERED C CTV CAMERA USING ESP32 MICROCONTROLLER WIT H WEB APP VIEWING OVER WIFI

BY

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CERTIFICATION

This is to certify that this project work has been written by**OHIANI AHUO IZA FATIMAT**with matric number **HND/23/SLT/FT/0040** and has been read an d approved as meeting the parts of the requirements for the award of Higher N ational Diploma (HND) in Science Laboratory technology Department, Institute of Applied Sciences, Kwara State Polytechnic.

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DEDCATION

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

To my late father, though you are no longer here to witness this milestone, your love, sacrifice, and unwavering belief in me have brought me this far. This project is dedicated to you, your memory, and your dreams for me, an d the strong foundation you laid for my success.

Death may have taken you from this world, but your spirit lives on in every step I take.

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TABLE OF CONTENTS

Table of Contents

ABSTRACT

Security surveillance is a critical component in protecting lives and property, especially in areas lacking reliable electricity and internet infrastructure. This project presents the design and construction of a solar-powered CCTV camera system using the ESP32-CAM microcontroller, with real-time video streaming accessible via a web application over WiFi. The system was developed to offer a cost-effective, energy-efficient, and easily deployable solution for continuous surveillance in both rural and urban environments. The core of the system is the ESP32-CAM module, which integrates a microcontroller and camera for image capturing and processing. A 6V solar panel, in conjunction with a TP4056 charging module and a rechargeable lithium-ion battery, powers the system. The ESP32 hosts a local web server, allowing users to view the live video feed on any device connected to the same WiFi network, either in station mode or access point mode. The prototype was successfully built and tested. It provided stable video streaming, sustained power through solar charging, and user-friendly access via a browser interface. Performance tests showed that the system could operate reliably for several hours without sunlight, making it suitable for 24/7 monitoring. Although the system lacked advanced features such as night vision and cloud integration, it laid a solid foundation for future improvements. This project demonstrates the potential of combining renewable energy with IoT-based surveillance technology to create sustainable and scalable security systems. It is ideal for deployment in homes, farms, construction sites, and other remote areas where traditional power supply is not guaranteed.

Keywords: ESP32-CAM, Solar Power, CCTV, WiFi Surveillance, Web Streaming, IoT, Renewable Energy, Wireless Camera System.

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND OF THE PROJECT

The increasing need for effective and reliable surveillance systems has become a glo bal priority, especially with the rise in security challenges in urban and rural areas. Tr aditional CCTV systems rely heavily on grid electricity, which limits their applicability in remote locations or regions with unstable power supply (Smith et al., 2020). As a re sult, solar-powered CCTV cameras have emerged as an innovative solution to provide consistent surveillance in off-grid and underserved areas, leveraging renewable energ y sources to ensure uninterrupted operation.

Solar CCTV systems combine photovoltaic technology with modern surveillance equi pment to create self-sustaining security solutions. These systems are equipped with solar panels, rechargeable batteries, and advanced cameras that operate efficiently without requiring a direct connection to the electrical grid (Chen et al., 2021). This inte gration has gained significant attention due to its potential to reduce operational cos ts and promote environmental sustainability by utilizing clean energy sources.

Moreover, the adoption of solar CCTV cameras aligns with global efforts to combat c limate change and reduce carbon footprints in the security sector. According to Olatu nji and Ibrahim, (2022), the shift toward solar-powered security systems has seen su bstantial growth in developing countries, where access to electricity is limited. These systems not only address energy challenges but also enhance security in critical area s such as highways, construction sites, and remote communities.

Recent advancements in technology, such as improved solar panel efficiency and en hanced camera capabilities, have further driven the adoption of solar CCTV systems. For instance, artificial intelligence integration into these systems now enables featur

es such as motion detection, facial recognition, and real-time alerts, making them mo re efficient and user-friendly, (Martins et al., 2023). This innovation ensures that solar CCTV systems are not only cost-effective but also capable of meeting modern surveil lance demands.

Overall, solar CCTV cameras present a sustainable and practical solution to current s ecurity challenges, particularly in regions facing power supply issues. As noted by Ka lu and Adetayo (2024), their adoption is expected to grow rapidly in the coming years due to their environmental benefits, operational reliability, and adaptability to various use cases. This study explores the technological advancements, applications, and ch allenges of solar CCTV systems, providing insights into their role in modern security i nfrastructure.

Figure 1: 4G Solar Powered CCTV Camera

https://www.amazon.sa/-/en/Security-Monitoring-Intrusion-Solar-Powered-Waterproof/dp/B0C8DJKGRS

1.2 PROBLEM STATEMENT

Security challenges have become a pressing concern in both urban and rural areas, with an increasing demand for effective surveillance systems to deter criminal activities and ensure safety. Traditional CCTV systems, while effective, often rely heavily on uninterrupted grid power, making them impractical in remote locations and areas with unreliable electricity supply. This limitation poses significant challenges in providing adequate security coverage, especially in developing countries where power infrastructure is in consistent, (Olatunji& Ibrahim, 2022).

Furthermore, the high operational costs associated with electricity-powered surveillance systems and their susceptibility to power outages limit their efficiency and accessibility. In rural and off-grid communities, the lack of affordable and sustainable security solutions exacerbates the vulnerability to crimes and hinders economic development (Martins et al., 2023). Addressing these issues requires innovative solutions that do not depend on conventional energy sources.

Solar-powered CCTV systems have emerged as a potential solution to these challenges. However, their adoption faces several barriers, including high initial installation costs, performance variability due to weather conditions, and limited awareness of their long-term benefits. Additionally, questions remain regarding their efficiency, durability, and ability to meet the evolving demands of modern surveillance, such as high-definition recording and real-time monitoring (Kalu&Adetayo, 2024).

This study seeks to address these gaps by exploring the technological, economic, an d environmental implications of solar CCTV systems. It aims to identify how these sy stems can provide reliable and cost-effective surveillance solutions in areas with limi ted power infrastructure while contributing to the global push for sustainable energy practices.

1.3 OBJECTIVES OF THE PROJECT

The primary objective of this study is to explore the viability and impact of solar-pow ered CCTV systems as a sustainable and effective solution for modern surveillance c hallenges.

- To evaluate the technological advancements in solar CCTV cameras.
- To examine the economic feasibility of implementing solar CCTV systems.
- To identify the key applications and use cases of solar CCTV cameras.
- To investigate the challenges associated with solar-powered CCTV system s.
- To assess the environmental and social benefits of adopting solar CCTV s ystems.
- To provide recommendations for optimizing the adoption and performanc e of solar CCTV cameras.

1.4 SIGNIFICANCE OF THE PROJECT

This study on solar-powered CCTV cameras holds significant importance across mul tiple dimensions, addressing critical technological, economic, environmental, and so cial concerns.

1.4.1 Technological Advancement

The project highlights the innovative integration of renewable energy with modern su rveillance systems. It showcases how advancements in solar technology, battery stor age, and smart surveillance features can provide efficient and sustainable solutions t o security challenges. This contributes to the growing body of knowledge on renewa ble energy applications in technology-driven sectors, (Olatunji& Ibrahim, 2022).

1.4.2 Economic Impact

By examining the cost implications of solar CCTV systems, the study provides insigh ts into how these systems can reduce long-term operational costs compared to conv entional CCTV systems. It offers valuable information for businesses, government ag encies, and property owners seeking cost-effective and energy-efficient security solut ions, particularly in regions with unstable power infrastructure (Martins et al., 2023).

1.4.3 Environmental Benefits

The project underscores the role of solar-powered systems in promoting environment al sustainability. By reducing reliance on fossil fuels and grid electricity, solar CCTV c ameras help lower carbon emissions and support global efforts to combat climate c hange. This aligns with the United Nations' Sustainable Development Goal 7, which a dvocates for affordable and clean energy, (Kalu&Adetayo, 2024).

1.4.4 Social Relevance

In areas where traditional surveillance systems are impractical due to power limitatio ns, solar CCTV cameras offer a viable alternative for enhancing security. This study d emonstrates how these systems can improve safety in remote communities, protect critical infrastructure, and support law enforcement efforts. Enhanced security contri

butes to social stability, economic growth, and overall quality of life, (Smith et al., 202 0).

1.4.5 Policy and Implementation Guidance

The findings of this study can serve as a guide for policymakers, urban planners, and private sector stakeholders in developing frameworks for adopting solar-powered CC TV systems. It offers recommendations for addressing implementation challenges, making it a valuable resource for promoting sustainable security solutions.

1.5 SCOPE AND LIMITATION OF THE PROJECT

This project focuses on the exploration and analysis of solar-powered CCTV systems as a sustainable solution for modern surveillance needs. It examines the technologic al, economic, environmental, and social dimensions of these systems, with an emph asis on their application in regions with limited or unreliable access to grid electricity. The project covers key aspects such as the components of solar CCTV systems, their functionality, and their benefits in different environments, including urban, rural, and r emote areas.

The scope includes an evaluation of the technological advancements in solar panels, energy storage solutions, and smart surveillance features like motion detection and f acial recognition. The study also investigates the economic feasibility of solar CCTV cameras by analyzing installation costs, maintenance requirements, and long-term s avings. Furthermore, it addresses the environmental impact of adopting renewable e nergy for security purposes, highlighting its role in reducing carbon footprints and su pporting sustainable development goals.

However, this study has certain limitations. First, it focuses primarily on the general p rinciples, design, and performance of solar CCTV systems rather than the specific br ands or models available in the market. Second, while the study includes a discussio

n on the challenges of implementing solar CCTV systems, such as weather dependen cy and high initial costs, it does not provide exhaustive technical solutions to all ident ified challenges. Third, the study relies on secondary data, including case studies, rep orts, and academic literature from 2020 to 2024, which may limit the inclusion of the latest real-world implementation experiences or region-specific data.

Additionally, the geographical focus is broader, with examples drawn from global an d developing country contexts, rather than being tailored to a specific location. This may restrict the study's direct applicability to local conditions or policies. Despite the se limitations, the study provides a comprehensive framework for understanding the potential of solar CCTV systems and offers valuable insights for stakeholders in the security and renewable energy sectors.

1.6 DEFINITION OF TERMS

Solar CCTV Camera: A solar-powered CCTV camera is a surveillance system that use s photovoltaic panels to generate energy for operation, eliminating the need for grid e lectricity. These systems often include energy storage solutions like batteries to ensu re functionality during low sunlight conditions (Smith et al., 2020).

Photovoltaic (PV) Panel: A photovoltaic panel, also known as a solar panel, is a devi ce that converts sunlight into electrical energy through the photovoltaic effect. It is a critical component of solar-powered systems, providing the energy required for conti nuous operation, (Chen et al., 2021).

Battery Storage: Battery storage refers to the use of rechargeable batteries to store e nergy generated by solar panels. In solar CCTV systems, battery storage ensures the system operates during nighttime or periods of low sunlight (Olatunji& Ibrahim, 202 2).

Surveillance System: A surveillance system is a setup that monitors activities and en

vironments for security purposes, typically using cameras, sensors, and recording de vices. Solar CCTV cameras are a sustainable alternative to traditional surveillance sy stems, (Martins et al., 2023).

Weather Dependency: Weather dependency refers to the reliance of solar systems on adequate sunlight for optimal performance. Solar CCTV cameras may experience red uced efficiency during cloudy or rainy conditions, highlighting one of their primary li mitations, (Kalu&Adetayo, 2024).

Carbon Footprint: A carbon footprint measures the total greenhouse gas emissions c aused directly or indirectly by an individual, organization, or product. Solar-powered s ystems reduce carbon footprints by using renewable energy instead of fossil fuels, (U nited Nations, 2020).

Smart Features: Smart features in surveillance systems refer to advanced functional ities, such as motion detection, facial recognition, and real-time alerts, often enabled by artificial intelligence and machine learning (Martins et al., 2023).

Off-Grid System: An off-grid system operates independently of the central electrical grid, relying on alternative energy sources like solar power for its functionality. Solar CCTV systems are particularly beneficial in off-grid locations, (Olatunji& Ibrahim, 202 2).

CHAPTER TWO

2.0 LITERATURE REVIEW OF SOLAR CCTV CAMERAS

Solar CCTV cameras are advanced surveillance systems powered by renewable ener gy derived from solar panels. Unlike traditional CCTV cameras that rely on grid electri city, solar CCTV systems use photovoltaic technology to capture sunlight and conver t it into electrical energy, enabling their operation in off-grid and low-power environme nts, (Smith et al., 2020). These systems are equipped with rechargeable batteries that store excess energy during the day, ensuring uninterrupted functionality during nightt ime or cloudy conditions.

A standard solar CCTV camera system consists of three primary components: the sol ar panel, which captures solar energy; the battery, which stores the energy; and the ca mera unit, which includes various functionalities such as high-definition video record ing, motion detection, and real-time monitoring (Chen et al., 2021). Some advanced models also incorporate smart features like facial recognition, AI-powered analytics, and cloud storage for seamless operation and enhanced security capabilities.

The primary advantage of solar CCTV cameras lies in their independence from the co nventional power grid. This makes them particularly useful in remote or rural areas w here electricity supply is either unavailable or unreliable. According to Olatunji and Ibr ahim (2022), these systems are increasingly being adopted in infrastructure such as highways, farms, and construction sites, where consistent monitoring is crucial.

2.1.2 COMPONENTS OF SOLAR CCTV SYSTEMS

1. Solar Panel: The solar panel is the core component that captures sunlight and con verts it into electrical energy through the photovoltaic effect. The efficiency of the pa

nel depends on factors such as material quality, panel size, and sunlight availability. Monocrystalline panels are commonly used in solar CCTV systems due to their high efficiency and durability, (Chen et al., 2021).

2. Rechargeable Battery: The rechargeable battery stores excess energy generated by the solar panel during the day for use at night or during cloudy conditions. Lithium-ion batteries are often preferred for their high energy density, long lifespan, and fast charging capabilities. The battery capacity determines how long the system can operate without direct sunlight, (Martins et al., 2023).

3. CCTV Camera Unit: The camera unit is responsible for capturing video footage and transmitting it for storage or real-time monitoring. Solar-powered CCTV cameras typically feature high-definition video resolution, infrared capabilities for night vision, and smart features such as motion detection and facial recognition, (Smith et al., 2020).

4. Solar Charge Controller: The solar charge controller regulates the flow of electricity from the solar panel to the battery and camera unit. It prevents overcharging of the battery and ensures that the system operates efficiently. Advanced controllers may also provide data on energy usage and storage levels, (Olatunji& Ibrahim, 2022).

5. Mounting System: The mounting system secures the solar panel and camera unit in place, optimizing their exposure to sunlight and ensuring stability. Adjustable mounts allow the solar panel to be angled for maximum efficiency based on the geographical location and time of year, (Kalu&Adetayo, 2024).

6. Connectivity Module: The connectivity module facilitates communication between the camera and monitoring systems. Depending on the setup, this can include Wi-Fi, GSM, or wired connections. Advanced systems may include cloud-based storage a

nd real-time alerting capabilities, (Chen et al., 2021).

7. Cables and Wiring: High-quality cables and wiring are used to connect the various components of the system. These are typically weatherproof and designed to withst and outdoor conditions. Proper wiring ensures minimal energy loss and efficient oper ation of the system, (Martins et al., 2023).

8. Monitoring and Storage System: Monitoring systems enable real-time viewing of f ootage, while storage systems, such as SD cards, hard drives, or cloud storage, allow users to archive recorded videos. Modern solar CCTV cameras often integrate with m obile apps or web platforms for remote access and control, (Smith et al., 2020).

2.1.3 TYPES OF SOLAR CCTV CAMERAS

1. **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.
2. **Solar-Powered IP Cameras**
    - These cameras are connected to a network via Wi-Fi and powered by so lar 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.

3. **Solar PTZ (Pan-Tilt-Zoom) Cameras**
   - These cameras provide adjustable camera angles and zooming capabilities, making them ideal for large or wide surveillance areas.
   - They can be controlled remotely and are often used in areas requiring extensive monitoring.
   - The solar panels ensure they can operate continuously in areas without reliable power.
4. **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.
5. **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 s witch to a backup power source when necessary.

- These cameras provide enhanced flexibility and reliability.

2.2 TECHNOLOGY BEHIND SOLAR CCTV CAMERAS

Solar CCTV cameras are an advanced security solution that combines traditional sur veillance technology with solar power to provide efficient, eco-friendly, and cost-effec tive monitoring. These cameras are equipped with solar panels, allowing them to ope rate without relying on external power sources or traditional electricity grids. The tech nology behind solar CCTV cameras integrates several components that make them r eliable, sustainable, and highly adaptable for use in remote or off-grid locations. This section will explore the key technologies that power solar CCTV cameras, including s olar power systems, camera components, and smart features.

2.2.1 SOLAR PANEL TECHNOLOGY

Solar panel technology is a critical component of solar CCTV cameras, as it enables t hem to operate independently without relying on external power sources. Solar panel s convert sunlight into electricity through the photovoltaic (PV) effect, making them a sustainable and eco-friendly solution for powering surveillance systems, especially i n off-grid or remote locations. The advancements in solar panel technology over the past few years have significantly improved their efficiency, durability, and cost-effecti veness. This section will explore the key developments in solar panel technology, hig hlighting recent innovations and their impact on the performance of solar CCTV cam eras.

1. Photovoltaic Cells and Efficiency Improvements

The core technology behind solar panels is the photovoltaic (PV) cell, which converts sunlight into direct current (DC) electricity. Over the past few years, there have been si gnificant improvements in the efficiency of these cells, which directly impact the over all performance of solar-powered systems like CCTV cameras. The efficiency of sola r panels refers to the percentage of sunlight that can be converted into usable electric ity. In 2020, the efficiency of monocrystalline silicon solar panels, which are common ly used in solar CCTV systems, reached about 20-22%. However, with advancements i n materials and manufacturing processes, the efficiency of these panels has continu ed to improve. According to Zhang et al. (2023), recent innovations in perovskite sola r cells have led to efficiency rates of up to 26%, offering even higher power conversio n rates for solar-powered devices, including surveillance systems. This increase in eff iciency allows solar CCTV cameras to function for longer periods with less exposure t o sunlight, making them more reliable in varying weather conditions.

2. Bifacial Solar Panels

Bifacial solar panels are another significant development in solar panel technology t hat enhances the performance of solar-powered systems. Unlike traditional monofac ial panels, which capture sunlight only from one side, bifacial panels can absorb ligh t from both the front and the rear of the panel. This allows them to generate more ele ctricity, especially in environments where sunlight is reflected off surfaces like walls, snow, or concrete. Bifacial panels can increase the overall energy output by up to 3 0%, depending on the installation conditions. According to Lee et al. (2021), the adop tion of bifacial panels in solar-powered CCTV cameras is becoming increasingly pop ular due to their enhanced energy production, particularly in areas with high reflectivit y or limited direct sunlight. These panels are ideal for solar CCTV installations, as the

y maximize the energy harvested from available sunlight, ensuring consistent power supply for the cameras.

3. Thin-Film Solar Panels

Thin-film solar panels are a newer form of photovoltaic technology that has gained p opularity due to their lightweight, flexible, and low-cost nature. Unlike traditional silic on-based panels, thin-film panels are made by layering photovoltaic material on a su bstrate such as glass, plastic, or metal. This makes them more adaptable to various surfaces and installation environments. In recent years, thin-film solar panels have b een used in solar CCTV systems due to their ability to conform to different shapes an d sizes, as well as their resistance to shading and partial obstructions. In 2022, resear chers from the University of Califomia (2022) demonstrated that thin-film solar panel s could effectively power small, low-energy devices like solar CCTV cameras in areas where traditional rigid panels might not be suitable. Although they generally offer low er efficiency compared to monocrystalline or polycrystalline panels, their versatility a nd cost-effectiveness make them an attractive option for certain solar-powered appli cations.

4. Integration with Energy Storage Systems

The integration of solar panels with energy storage systems is another crucial develo pment that enhances the functionality of solar CCTV cameras. Solar panels generate electricity during the day, but CCTV cameras often require continuous power, includin g at night. Modern solar-powered systems have been designed to include efficient ba ttery storage, typically lithium-ion or lithium iron phosphate (LiFePO4) batteries, whic h store excess energy generated during daylight hours. This stored energy is then use

d to power the CCTV cameras when sunlight is not available. According to, Wang et a l. (2021), advancements in battery storage technology have made it possible to creat e compact, long-lasting storage solutions that are both energy-dense and lightweight, ensuring that solar CCTV systems can operate reliably even in areas with limited sunl ight. The combination of high-efficiency solar panels and advanced battery technolo gy enables solar-powered CCTV cameras to function continuously with minimal mai ntenance and downtime.

5. Durability and Weather Resistance

The durability and weather resistance of solar panels have significantly improved ov er the past few years, making them more suitable for outdoor installations, such as t hose required for solar CCTV cameras. Solar panels must be able to withstand harsh environmental conditions, including extreme temperatures, humidity, rain, and dust. T o address these challenges, manufacturers have developed panels with improved dur ability features, such as reinforced glass and enhanced anti-corrosion coatings. In 20 20, a study by Lyu et al. found that modern solar panels, equipped with robust protect ive coatings and frames, could withstand the effects of environmental stressors for u p to 25 years or more, ensuring long-term reliability. This increased durability is essen tial for solar CCTV systems, which are often installed in remote locations or harsh cli mates where maintaining the panels may be difficult or costly. As a result, the advan cements in solar panel technology have made solar CCTV systems a more viable sol ution for long-term, outdoor surveillance applications.

6. Cost Reductions and Accessibility

The cost of solar panel technology has decreased significantly over the past decade,