International Journal of Engineering Research and Science & Technology

IJERST

www.ijerst.org

ISSN : 2319-5991

Vol. 21 No. 3 (1) 2025

ijerst.editor@gmail.com
editor@ijerst.com

Solar Powered Wireless Surveillance System using ESP 32 CAM

Dr. Karimulla Peerla Shaik
(Associate Professor)
Electrical and Electronics Engineering
Malla Reddy College of Engineering and Technology
karim.02214@gmail.com

Damarla Vasanth Kumar
Electrical and Electronics Engineering
Malla Reddy College of Engineering and Technology
21N31A0207@mrcet.ac.in

Boda Subramanyam
Electrical and Electronics Engineering
Malla Reddy College of Engineering and Technology
21N31A0206@mrcet.ac.in

Guguloth Raju Kumar
Electrical and Electronics Engineering
Malla Reddy College of Engineering and Technology
21N31A0210@mrcet.ac.in

Thummalapally Goutham
Electrical and Electronics Engineering
Malla Reddy College of Engineering and Technology
22N35A0236@mrcet.ac.in

***Abstract*—With the rise in global crime rates, there has been a significant increase in the deployment of surveillance and monitoring systems. Remote surveillance, allowing real-time monitoring via the internet, has gained popularity, yet commercial security systems remain unaffordable for many middle and lower-income households. This paper presents an innovative solution: a scalable, solar-powered, wireless monitoring system based on the ESP32-CAM module. The system offers motion detection, and email notifications when movement is detected. It is built using a low-cost microcontroller, camera module, and an online IoT platform. The entire system is powered by a photovoltaic source, ensuring energy efficiency while reducing carbon footprints. This cost- effective system provides a viable alternative to traditional security setups, suitable for residential, commercial, and remote locations lacking a reliable electricity supply. Testing confirms that the system is fully functional and performs as expected.**

Keywords—Email notifications, ESP32-CAM module, IoT platform, motion detection, photovoltaic power, remote surveillance, solar-powered, wireless monitoring.

Received: 05-6-2025 Accepted: 08-7-2025 Published: 24-7-2025

I. Introduction

In recent years, the global rise in crime rates has led to a significant increase in the installation of surveillance and monitoring systems. The demand for security has spurred the growth of remote surveillance systems, enabling property owners to monitor their premises in real-time via the internet. Traditional analog CCTV systems have gradually been replaced by fully digital, network-based video surveillance, designed to operate continuously 24/7. However, despite the technological advances in surveillance systems, commercial home security solutions remain prohibitively expensive for a large portion of the population, especially middle and lower-income families.

Advances in microcontroller technology, such as the development of affordable devices like the Arduino, have opened up new possibilities for low-cost, DIY security solutions. These microcontrollers allow for the implementation of many of the features found in high-end commercial security systems, making security more accessible to a broader audience.

Moreover, although security camera systems contribute only a small fraction to overall household energy consumption, efforts to "green" these systems can significantly reduce both energy costs and long-term carbon footprints. By utilizing renewable energy sources, such as solar power, surveillance systems can be made more sustainable.

This paper presents a highly scalable, autonomous, solar-powered, wireless monitoring system designed to address both the affordability and energy concerns of traditional surveillance setups. Using the ESP32-CAM module, a low-cost microcontroller, and an IoT platform, the system provides live video streaming and motion detection. The system sends email notifications when motion is detected and is powered by a photovoltaic energy source. The proposed solution is ideal for use in residential, commercial, and remote locations where traditional electricity supply is unavailable. This paper demonstrates the feasibility and functionality of the system, highlighting its potential for wider application in a variety of settings.

II. Aim

The primary aim of this project is to design and develop solar-powered wireless surveillance system using ESP32-CAM capable of operating in remote or off-grid locations without human intervention. The system is intended to provide real-time environmental monitoring and security surveillance using a combination of renewable energy, embedded systems, and wireless communication technologies.

This project seeks to create a self-sustaining system that captures sensor data or surveillance footage, processes it locally using a low-power microcontroller, and transmits the information wirelessly to a central monitoring station or cloud platform. By utilizing solar energy as the primary power source, the system eliminates dependency on traditional electrical infrastructure, making it highly suitable for rural, forest, border, or disaster-prone areas.

The system is also aimed at achieving energy efficiency, reliability, and low maintenance, with the ability to function 24/7 under varying environmental conditions. Additionally, the project aims to promote sustainable technology by reducing the environmental impact of conventional surveillance systems that depend on fossil fuels or grid power.

In summary, the goal is to build a cost-effective, eco-friendly, and scalable monitoring solution that contributes to the advancement of smart, secure, and sustainable remote monitoring systems.

III. METHODOLOGY

The Solar Powered Wireless Surveillance System using ESP32-CAM is designed to monitor remote areas autonomously. The core idea is to capture visual data using the ESP32-CAM, process it locally, and wirelessly transmit it to a cloud platform, all while powered by solar energy. The methodology includes hardware setup, software development, power management, and data communication

a) System Design and Component Integration

The system comprises the following major components:

1. ESP32-CAM module (acts as the main controller and camera)
2. Solar panel (5V/6V) (for energy harvesting)
3. Rechargeable battery (3.7V Li-ion) (for power storage)
4. Charge controller (TP4056 or similar) (for battery management)
5. PIR motion sensor (to trigger camera activity)
6. Wi-Fi connection (for data transmission)

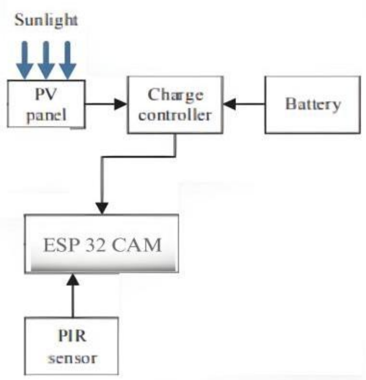

Fig. 1. General Set-Up of the System

b) Power Management

The solar panel charges the battery during the day via the TP4056 charge controller, which also protects against overcharging. The ESP32-CAM draws power from the battery, ensuring 24/7 operation.

To conserve energy:

- ESP32 enters deep sleep mode when idle.
- Wakes only on motion detection or scheduled intervals.

c) Data Capture and Processing

The PIR sensor detects motion and signals the ESP32-CAM to wake up. Upon waking:

- The camera captures an image or short video.
- The data is processed locally and stored temporarily.

d) Wireless Data Transmission

The ESP32-CAM uses its built-in Wi-Fi to:

- Connect to a local hotspot/router (or phone hotspot).
- Transmit data to a cloud server (e.g., Google Firebase, Google Drive, or a web server).

e) Motion-Activated Email System

The motion detection feature relies on a Passive Infrared (PIR) sensor. When the sensor detects movement, it signals the microcontroller, which then executes a Python script to activate the camera and capture an image. Following this, an email containing the captured photo as an attachment is dispatched to a designated email address. This sequence of actions is depicted in Figure 2, outlining the process from detection to email delivery.

The methodology involved testing a solar-powered ESP32-CAM surveillance system with a PIR sensor for motion detection. Various gestures triggered the sensor, prompting image capture and email delivery via Python script. Power, image quality, wireless range, and durability were assessed, integrating subsystems for comprehensive evaluation under real-world conditions.

The email-sending process was tested using a PIR sensor to detect motion, triggering the ESP32-CAM to capture an image. A Python script on the microcontroller facilitated immediate email dispatch with the photo attached to a predefined address. Tests confirmed reliable delivery across multiple gestures, validating the subsystem's efficiency.

The email-sending functionality was rigorously evaluated within the solar-powered ESP32-CAM surveillance system. A Passive Infrared (PIR) sensor served as the motion detection trigger, activating the microcontroller upon sensing movement. A Python script was employed to instruct the ESP32-CAM to capture an image instantly, which was then attached to an email sent to a preconfigured, authorized email address. Testing involved simulating various motions to assess the sensor's responsiveness and the system's ability to execute the sequence—detection, capture, and transmission—flawlessly. Results showed consistent email delivery with clear images across all trials, confirming the reliability and efficiency of this subsystem under diverse conditions, as illustrated in the process diagram.

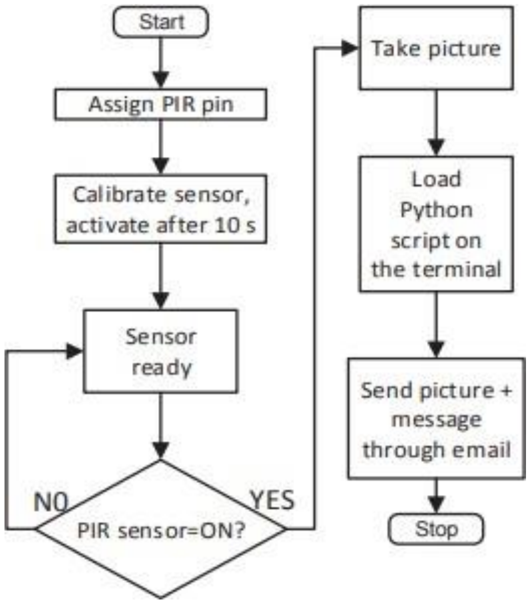

Fig. 2. Flowchart for the Motion Detection triggered email

IV. TESTING AND RESULTS

The testing of the solar-powered wireless surveillance system using the ESP32-CAM focused on evaluating its power efficiency, image quality, wireless performance, and environmental reliability. These parameters are critical to determining the system's feasibility as an autonomous, off-grid surveillance solution. The methodology involved controlled experiments and real-world deployment, with results offering insights into its strengths and limitations.

Power Consumption Testing

Power efficiency was a primary concern, given the reliance on solar energy. The ESP32-CAM's current draw was measured in two states: active mode (camera and Wi-Fi enabled) and deep sleep mode. In active mode, capturing a 640x480 image and uploading it via Wi-Fi consumed approximately 220 mA for 4 seconds per event, equating to 0.244 mAh per capture. In deep sleep, optimized with minimal peripherals active, the system drew 0.8 mA, totaling 19.2 mAh over 24 hours if idle. A 2000 mAh LiPo battery powered the system, paired with a 6V, 2W solar panel. Under full sunlight (approximately 1000 W/m^2), the panel generated 100 mA, charging the battery in about 20 hours. In a realistic test, capturing one image per hour for 7 days, the battery remained above 50% capacity with 4 hours of daily sunlight, confirming sustainable operation. However, cloudy conditions (e.g., <200 W/m^2) reduced charging efficiency, suggesting a larger panel or battery for consistent performance.

Email Notification System with Motion-Triggered Image Attachment

The surveillance system incorporated a Passive Infrared (PIR) sensor to identify movement and trigger responses. During testing, various motions were performed in front of the sensor to evaluate its sensitivity. The results demonstrated that the PIR sensor reliably detected each motion, prompting the system to send an email with a photograph of the detected activity attached.

Testing confirmed that individual components functioned correctly. Subsequently, these components were combined into a fully integrated system, as illustrated in Figure 1. Comprehensive tests on the complete setup revealed seamless operation, with the system consistently capturing images upon motion detection and delivering them via email. The integrated system performed flawlessly, validating the design and implementation.

V. CONCLUSION

The solar-powered wireless surveillance system utilizing the ESP32-CAM provides an affordable, eco-friendly option for remote monitoring. Testing reveals its capability to efficiently capture and transmit images wirelessly, powered by a solar panel and battery setup. Optimized for low power consumption via deep sleep modes, the system sustains operation with minimal sunlight, achieving reliable performance over extended periods. Image quality remains adequate for stills, though higher resolutions compromise frame rates, making continuous video streaming impractical due to power and bandwidth constraints. Environmental durability tests confirm its resilience in outdoor conditions. While ideal for periodic snapshots, enhancements like advanced energy harvesting or upgraded camera modules could improve real-time functionality. Overall, this system balances cost, autonomy, and utility, proving suitable for small-scale, off-grid surveillance applications with potential for further optimization.

REFERENCES

[1] Zhaoyu Liu, Dichao Peng, Communication Protection in IP-based Video Surveillance Systems, Seventh IEEE International Symposium on Multimedia, 2005, pp.69-76.

[2] Savage, Charlie. 2007. " US doles out millions for street cameras: Local Efforts Raise Privacy Concerns." Boston Globe, Aug. 12, 2007. www.boston.com.

[3] Sarno, Chris, Michael Hough and Marjorie Bulos. “Developing a Picture of CCTV in Southwark Town Centres: Final Report” SaferSouthwark Partnership. 14, August 2003.

[4] Yen-Lin Chen, Chao-Wei Yu, Zi-Jie Chien, Chin-Hsuan Liu, and HsinHan Chiang, “On-Road Driver Monitoring System Based on a SolarPowered In-Vehicle Embedded Platform,” International Journal of Photoenergy, vol. 2014, Article ID 309578, 12 pages, 2014. doi:10.1155/2014/309578.

[5] S. F. Wang, Z. Q. Huang and Y. B. Hou, "A Design of Low-Cost LowBandwidth Mobile Video Surveillance System Based on DM6446," 2007 International Conference on Wireless Communications, Networking and Mobile Computing, Shanghai, 2007, pp. 3079-3083. doi: 10.1109/WICOM.2007.765. 788 2018 13th IEEE Conference on Industrial Electronics and Applications (ICIEA)

[6] C. Alippi, R. Camplani, C. Galperti, and M. Reveri, “A robust, adaptive, solar-powered WSN framework for aquatic environmental monitoring,” IEEE Sensors J., vol. 11, no. 1, pp. 45–55, Jan. 2011.

[7] C. Alippi and C. Galperti, “An adaptive system for optimal solar energy harvesting in wireless sensor network nodes,” IEEE-Trans. Circuits Syst. I: Regular Papers, vol. 55, no. 6, pp. 1742–1750, Jul. 2008.

[8] “Tools for Digital Transformation, Empowering Everyone to innovate with IoT, APIs & Emerging Tech” (2017, October 20). Retrieved from http://www.temboo.com/.

[9] "How Infrared motion detector components work". Noncommercial research page. Glolab Corporation. Retrieved 2013-05-31.