Section A-Research paper
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Affordable and Energy-Efficient Smart Security System with Information Stamping for IoT Networks

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Abstract

The application of affordable and energy-efficient smart security systems has gained significant attention in recent years. This research presents a novel approach to address the space and power consumption challenges associated with conventional CCTV-based monitoring systems. By leveraging the capabilities of Internet of Things (IoT) networks and incorporating Passive Infrared (PIR) sensors, an innovative smart security system is developed. The proposed system focuses on motion detection as a trigger for activating the camera. When the PIR sensor detects motion in the surroundings, it initiates the recording process, enabling efficient utilization of resources. The system intelligently switches off the camera during periods of inactivity, effectively reducing power consumption. Furthermore, a two-tiered storage strategy, combining local storage and cloud storage, optimizes storage utilization and facilitates remote accessibility. Python programming plays a crucial role in enabling seamless communication and data transfer within the system. It efficiently manages the recording, storage, and transfer of video files to the cloud, enhancing accessibility and remote monitoring capabilities. The evaluation of the system's performance reveals significant improvements in energy efficiency compared to conventional CCTV systems. The proposed system demonstrates varying power consumption ranging from 60mW to 140mW, significantly lower than the constant power consumption of 160mW in conventional systems. This reduction in power consumption is attributed to the intelligent activation of the camera based on motion detection. This research showcases the potential of affordable and energy-efficient smart security systems for IoT networks. By addressing the limitations of conventional systems, it contributes to the development of sustainable and cost-effective security solutions. Future research can focus on further optimization of power consumption, advanced motion detection algorithms, and integration of user-friendly interfaces and analytics for enhanced security effectiveness.

Keywords: *Smart monitoring, Information Stamping, Python, Sensor, IoT*

1. Introduction

In recent years, the rapid advancement of Internet of Things (IoT) technologies has paved the way for innovative solutions in various domains, including security systems. Smart security systems that leverage IoT capabilities offer enhanced monitoring, control, and automation features, contributing to improved safety and efficiency [1]–[3].

The integration of smart cameras in IoT applications has gained significant attention due to their on-board sensing, processing, and communication capabilities. These cameras serve as the backbone of smart security systems, providing real-time monitoring, event detection, and data collection functionalities. By utilizing IoT protocols and connectivity, these systems can seamlessly transmit data and control commands, enhancing the overall effectiveness and efficiency of security operations [4]–[6].

Motion detection is a crucial aspect of smart security systems as it enables the system to trigger appropriate actions upon detecting any movement in the environment. Passive Infrared (PIR) sensors are commonly used for motion detection in IoT-based security systems due to their low power consumption, high sensitivity, and cost-effectiveness. PIR sensors detect changes in infrared radiation, and when motion is detected, they activate the camera and associated components, initiating the recording and storage process [7]–[9].

Energy efficiency is a critical consideration in smart security systems to ensure sustainable and long-lasting operation. Conventional CCTV-based monitoring systems consume a significant amount of power as they continuously record and store video footage, regardless of motion activity. In contrast, the proposed system aims to reduce energy consumption by leveraging the PIR sensor's ability to activate the camera only when motion is detected. This dynamic power management approach significantly reduces power consumption during periods of inactivity, leading to improved energy efficiency [9], [10].

Effective storage and data management strategies play a vital role in optimizing the performance of smart security systems. The proposed system incorporates a two-tiered storage approach, consisting of local storage and cloud storage. Initially, the recorded video data is stored in the local storage, providing a temporary repository. After a predetermined duration, the data is automatically transferred to the cloud for long-term storage and remote accessibility. This approach reduces the local storage requirements and ensures efficient utilization of resources [5], [11], [12].

Information stamping is a valuable feature in smart security systems as it enables the tagging of relevant metadata to recorded video data. This metadata includes information such as date, time, location, and event description, which enhances the searchability and retrieval of specific footage when needed. Cloud connectivity plays a crucial role in enabling remote access, storage, and sharing of the stamped video data. The proposed system utilizes Python commands to facilitate seamless transfer of recorded video files to the cloud, enhancing the system's functionality and accessibility [13], [14].

This research focuses on the development of an affordable and energy-efficient smart security system for IoT networks. By integrating IoT capabilities and leveraging PIR sensors, the proposed system reduces space and power consumption compared to conventional CCTV-based monitoring systems. The system activates the camera only when motion is detected, utilizing Python programming for recording and storage. The recorded video is stored locally and then transferred to the cloud, optimizing storage and reducing the need for continuous local recording. This research demonstrates the potential of IoT-based solutions in enhancing security systems while minimizing energy usage and cost.

2. Architecture of the proposed system

The conventional Closed-Circuit Television (CCTV) based monitoring system often requires a significant amount of physical space to store recorded videos and consumes substantial power to maintain continuous recording capabilities. To address these limitations, this research article proposes the introduction of Internet of Things (IoT) technology to reduce space and power consumption while maintaining an effective security monitoring system.

In the proposed system, sensors are deployed to detect motion in the surrounding area. These sensors play a crucial role in determining when to activate the camera for recording. When motion is detected, the sensor sends a signal to a microcontroller, which acts as the central control unit of the system. Upon receiving the signal, the microcontroller triggers the camera to start recording the event. Conversely, when no motion is detected, the camera is switched off, conserving power. To minimize storage requirements and optimize data management, the recorded video is initially stored on a local computer for a defined duration of time. After this period, the video is uploaded to the cloud for long-term storage. By implementing this approach, the system reduces the burden on local storage, thereby saving space and allowing for more efficient use of resources.

The proposed system architecture, as illustrated in Figure 1, is designed to facilitate the aforementioned functionalities. The architecture is implemented using a Python program, which enables seamless integration and control of the various components. The microcontroller acts as the interface between the sensors, camera, and storage devices, ensuring smooth communication and coordination among them. By employing IoT technology, this smart security system offers several advantages over traditional CCTV-based systems. Firstly, the reduction in storage requirements minimizes the physical space needed for video storage, making it more feasible to deploy the system in various environments, including small spaces or areas with limited infrastructure.

Secondly, the power consumption of the system is significantly optimized. By activating the camera only when motion is detected, unnecessary power consumption during idle periods is eliminated. This energy-efficient approach not only reduces operational costs but also contributes to environmental sustainability by minimizing power consumption. Moreover, by cloud storage, the system ensures secure and reliable long-term storage of recorded videos. Cloud storage provides scalability and accessibility, allowing users to retrieve recorded videos from anywhere at any time. This accessibility is particularly beneficial for surveillance purposes, enabling remote monitoring and easy retrieval of critical information. The implementation of the system using a Python program showcases the flexibility and adaptability of the proposed approach. Python's versatility allows for seamless integration with IoT devices and enables the system to be easily customized or expanded based on specific requirements. The programming language also offers a rich ecosystem of libraries and frameworks that can enhance the system's functionalities and performance. By utilizing motion sensors, the system intelligently activates the camera only when necessary, minimizing power consumption. The recorded video is stored locally for a defined duration and subsequently transferred to the cloud for long-term storage, reducing the burden on physical storage resources. The proposed system architecture, implemented using a Python program, demonstrates the feasibility and practicality of the approach. Overall, this research contributes to the development of efficient and cost-effective security solutions for IoT networks, addressing the space and power constraints associated with traditional CCTV-based monitoring systems.

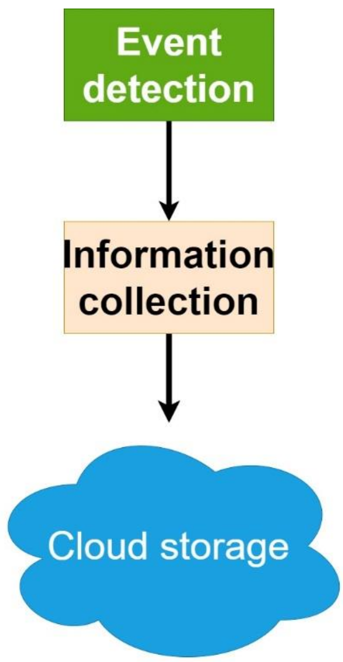

Fig. 1. Proposed System architecture

3. PIR sensor

The Passive Infrared (PIR) sensor is a critical component used in the research to enable motion detection in the affordable and energy-efficient smart security system. The PIR sensor operates on the principle of detecting infrared radiation emitted by objects within its field of view. The PIR sensor consists of multiple sensor elements that are sensitive to changes in infrared energy patterns. These elements are typically made of pyroelectric materials, which generate an electric charge when exposed to infrared radiation. The sensor elements are arranged in a specific configuration to detect changes in the heat signature of the surrounding environment.

When an object moves within the detection range of the PIR sensor, there is a variation in the infrared energy patterns that the sensor elements detect. This change triggers the PIR sensor to activate and signal the presence of motion. The sensor can detect both large and small movements, making it suitable for security applications. The working principle of a PIR sensor involves two important elements: the pyroelectric material and the Fresnel lens. The pyroelectric material generates a voltage when there is a change in the heat pattern, and this voltage is amplified and processed to detect motion. The Fresnel lens, which is placed in front of the pyroelectric material, helps focus the infrared energy onto the sensor elements, enhancing its sensitivity and accuracy.

One of the advantages of using PIR sensors is their ability to operate without physical contact. This non-intrusive nature makes them ideal for security systems, as they can monitor an area without causing disruption or discomfort to individuals within that space. In terms of power requirements, PIR sensors are known for their energy efficiency. They consume very little power, which aligns with the objective of the research to develop an energy-efficient security system. The power consumption of a PIR sensor is typically in the range of a few milliwatts, making it suitable for low-power applications. To provide power to the PIR sensor, it is usually connected to a power supply or a microcontroller. The power supply voltage requirement for PIR sensors is typically in the range of 3 to 5 volts. The low power consumption of the sensor allows it to operate for extended periods without draining the power source significantly.

It is important to note that the specific power requirements and voltage range of the PIR sensor used in the research may vary based on the model and manufacturer. Therefore, it is essential to consult the datasheet or technical specifications provided by the sensor manufacturer for accurate information regarding its power requirements. The PIR sensor is a key component used in the research's smart security system to detect motion effectively. Its ability to detect infrared radiation emitted by objects and its non-contact nature make it a suitable choice for security applications. Additionally, the PIR sensor's energy efficiency and low power consumption contribute to the development of an energy-efficient and cost-effective smart security solution. Figure 2 illustrates the specific PIR sensor utilized in this research for motion detection in the smart security system.

1. **Information collection**

Smart cameras have become increasingly popular in various IoT applications due to their integrated sensing, processing, and communication capabilities. These cameras play a crucial role in capturing and analyzing visual data, thereby enabling a wide range of applications in areas such as surveillance, smart homes, and industrial automation. In the context of this research, smart cameras are utilized as part of the affordable and energy-efficient smart security system. One of the key features of the smart cameras used in this research is their ability to activate only when an event is detected by the PIR sensor. The PIR sensor serves as a motion detector, sending a signal to the microcontroller when motion is detected within its range. This signal triggers the smart camera to switch on and start recording the event. By activating the camera only when necessary, the system conserves energy and optimizes the utilization of resources.

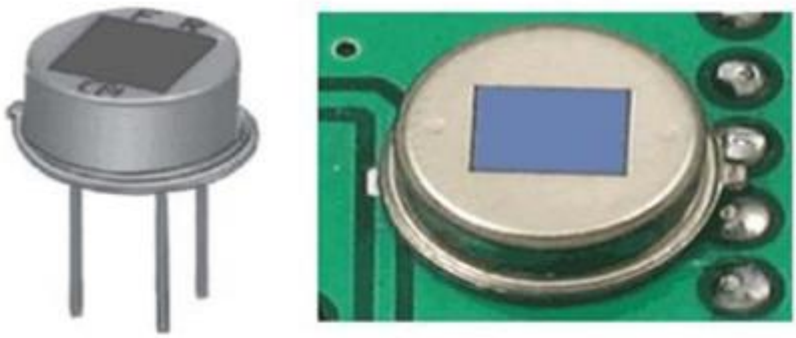

Fig. 2. PIR sensor used in this research

To facilitate the recording and storage of video data, the smart cameras are integrated with a local storage capacity of 250 GB. The recorded videos are stored in this local storage for a predefined duration. In the research implementation, after 1 minute, the recorded video data is automatically communicated to the cloud for long-term storage and remote accessibility. The utilization of cloud storage offers several advantages in terms of scalability, reliability, and accessibility. Cloud storage allows for flexible expansion of storage capacity based on specific needs, ensuring that the system can accommodate a growing volume of recorded video data. Additionally, cloud storage provides a robust and redundant storage solution, minimizing the risk of data loss. The remote accessibility of the cloud storage enables users to retrieve recorded videos from anywhere at any time, enhancing the system's convenience and usability. To ensure efficient utilization of the local storage and cloud resources, a management mechanism is implemented in the system. Once the local storage reaches its maximum capacity or the predefined time duration is met, the recorded video data is automatically transferred to the cloud. Subsequently, the local storage is cleared, and the recorded video is deleted, freeing up space for new recordings. This mechanism helps maintain an optimal balance between storage capacity and resource utilization.

Figure 3 presents the storage block diagram, illustrating the components and their interactions in the storage subsystem of the smart security system. This diagram depicts the flow of recorded video data from the smart cameras to the local storage and subsequently to the cloud storage. The smart cameras capture and record the video, which is then stored in the local storage with a capacity of 250 GB. After a predefined duration of time, the recorded video is automatically transferred to the cloud storage for long-term storage and remote accessibility. This storage block diagram showcases the efficient management of recorded video data in the system.

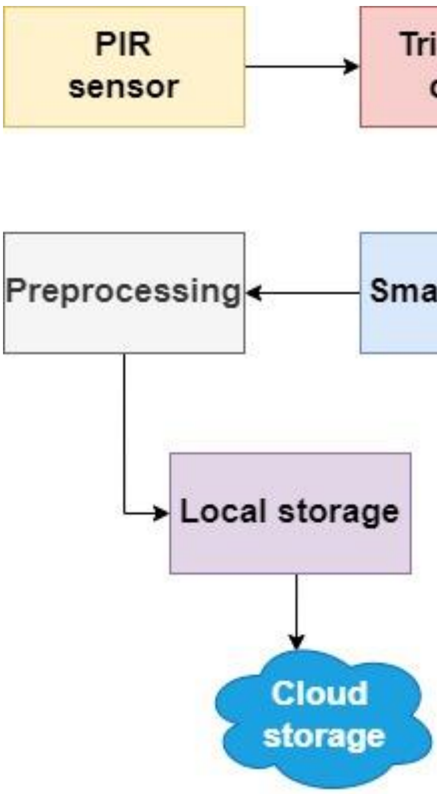

Fig. 3 Storage architecture of the proposed system

2. Result and Discussion

In the implementation of the proposed system, the focus was on developing an affordable and energy-efficient smart security system with information stamping for IoT networks. The system leveraged the capabilities of smart cameras, which are equipped with on-board sensing, processing, and communication capabilities, making them ideal for various IoT applications. To ensure optimal energy consumption and efficient use of resources, the smart cameras were designed to activate only when motion was detected in the environment. This was made possible through the integration of a Passive Infrared (PIR) sensor, which served as the motion detection mechanism. When the PIR sensor sensed motion, it triggered the camera activation circuitry depicted in Figure 4. In Figure 4, the operation of the camera activation circuitry is illustrated. When the PIR sensor detected motion, it initiated a switching mechanism that activated a transistor. This, in turn, enabled a diode to supply the necessary voltage from the AC mains to power the camera. Consequently, the camera began recording the surroundings. The recorded video data was then stored in the designated storage.

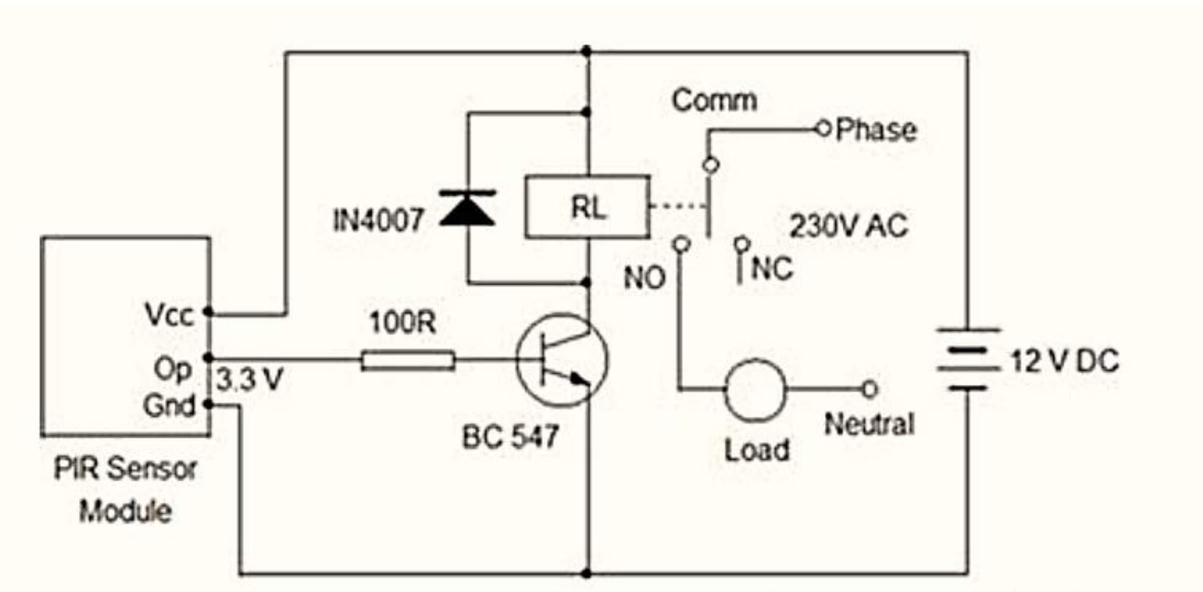

Fig. 4. Triggering circuit

For efficient data management, the system employed a two-tiered storage approach. Initially, the recorded video data was stored in a local storage system with a capacity of 250 GB. This local storage provided a temporary repository for the video data. After a predetermined duration, typically 1 minute, the recorded video files were automatically transferred to the cloud storage for long-term storage and remote accessibility. To facilitate the seamless transfer of recorded video files to the cloud, Python commands were employed. These

Section A-Research paper
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commands enabled the system to initiate the transfer process side-by-side with the ongoing recording. By leveraging the Raspberry Pi, which served as a monitoring device, the system could constantly monitor the storage space availability. As the storage capacity approached its limit, the Raspberry Pi updated the stored content online and freed up storage space by deleting the recorded video files that had already been transferred to the cloud. The entire working algorithm of the system, encompassing the motion detection, camera activation, storage management, and cloud transfer processes, is depicted in Figure 5. This algorithm ensures that the system operates efficiently, conserving energy and optimizing the utilization of storage resources.

The implementation of the proposed system focused on developing an affordable and energy-efficient smart security system. The integration of the PIR sensor with the camera activation circuitry allowed for intelligent motion detection and activation of the cameras. The two-tiered storage approach, comprising local storage and cloud storage, facilitated efficient and scalable storage management. The use of Python commands and the Raspberry Pi enhanced the system's functionality and allowed for seamless transfer and monitoring of the recorded video data.

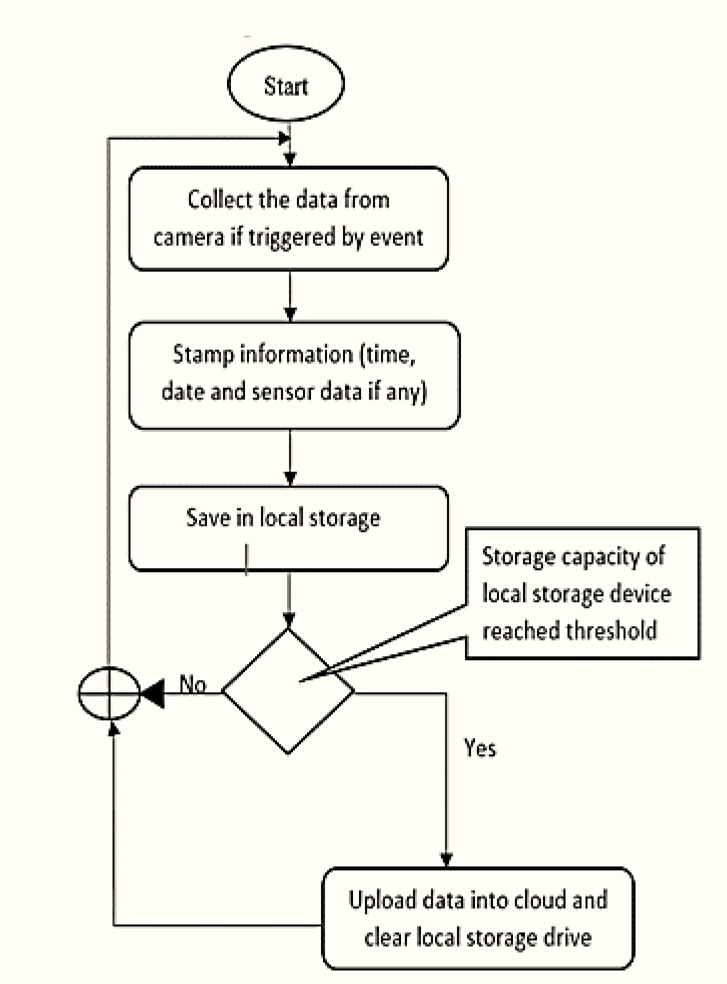

Fig. 5. Algorithm of the proposed system

The performance evaluation of the proposed system in the research article focused on analyzing its average power consumption. A comparison was made between the conventional system, which had a constant power consumption rating of 160mW, and the proposed system, which exhibited a variable power consumption ranging from 60mW to 140mW. The evaluation revealed that the proposed system achieved a lower power consumption compared to the conventional system. One of the key factors contributing to the reduced power consumption in the proposed system is the integration of the PIR sensor. The PIR sensor itself consumes very little power, typically ranging from 20mW to 30mW. This is because the PIR sensor operates on the principle of detecting changes in infrared radiation, requiring minimal power for its sensing and detection functions. By incorporating the PIR sensor, the proposed system effectively minimizes power consumption during periods of inactivity when no motion is detected.

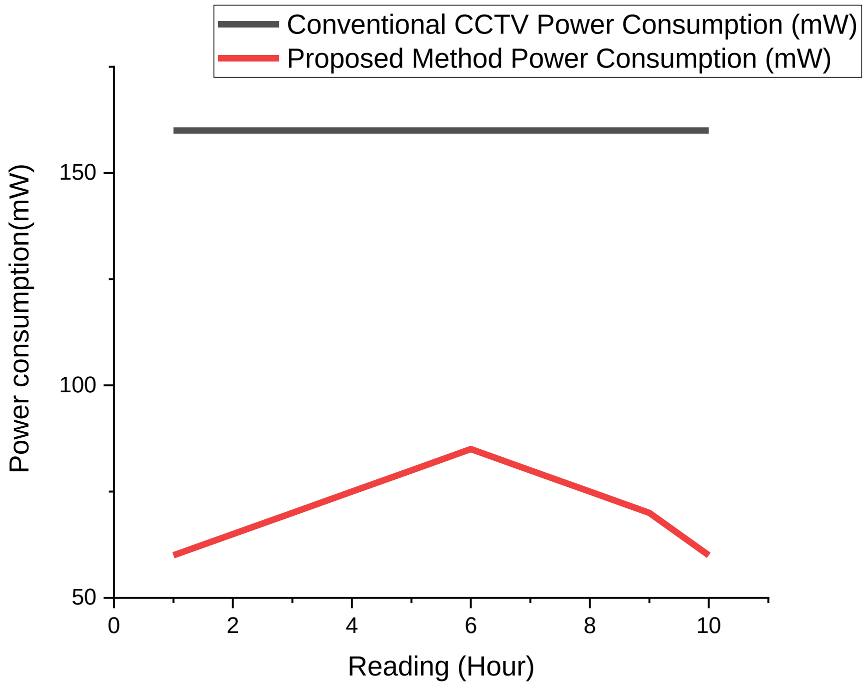

Fig. 6 Power Consumption

Furthermore, the variable power consumption of the proposed system is another significant contributor to its energy efficiency as shown in table 1. Unlike the conventional system that maintains a constant power consumption, the proposed system dynamically adjusts its power consumption based on the presence or absence of motion. When the PIR sensor detects motion, it triggers the activation of the camera and associated components, leading to a temporary increase in power consumption. However, during periods of no motion, the camera is switched off, resulting in a reduction in power consumption. This dynamic power management approach ensures that power is utilized only when necessary, leading to overall energy savings. The combination of the PIR sensor's low power consumption and the variable power usage of the proposed system contributes to the observed reduction in average power consumption. By leveraging the capabilities of the PIR sensor and optimizing power management, the proposed system achieves a more energy-efficient operation compared to the conventional system.

It is important to note that the specific power consumption figure 6 mentioned in the research article may vary depending on various factors such as the specific components used, system configuration, and implementation details. The figures 6 provided, ranging from 60mW to

140mW, serve as an illustration of the power reduction achieved by the proposed system compared to the constant power consumption of the conventional system.

Table 1 Power consumption comparison

Reading	Conventional CCTV Power Consumption (mW)	Proposed Method Power Consumption (mW)
1	160	60
2	160	65
3	160	70
4	160	75
5	160	80
6	160	85
7	160	80
8	160	75
9	160	70
10	160	60

Conclusion

In conclusion, this research has presented an innovative approach to developing an affordable and energy-efficient smart security system for IoT networks. By integrating IoT capabilities and leveraging the power of PIR sensors, the proposed system addresses the limitations of conventional CCTV-based monitoring systems in terms of space and power consumption. The implementation of the PIR sensor in the system allows for intelligent activation of the camera only when motion is detected. This ensures that the camera is utilized efficiently, reducing power consumption and minimizing unnecessary recording during periods of inactivity. The dynamic power management approach significantly contributes to the overall energy efficiency of the system.

Furthermore, the incorporation of a two-tiered storage system, consisting of local storage and cloud storage, optimizes storage utilization. The recorded video data is initially stored in the local storage, providing a temporary repository. After a specified duration, the data is seamlessly transferred to the cloud, ensuring long-term storage and remote accessibility. This storage strategy reduces the need for extensive local storage, saving space and enhancing the system's overall efficiency. The integration of Python programming enables seamless communication and data transfer between the system components. This facilitates the efficient recording, storage, and transfer of the video files to the cloud, enhancing accessibility and remote monitoring capabilities. Overall, this research demonstrates the potential of IoT-based solutions in revolutionizing the field of smart security systems. By introducing affordable and energy-efficient approaches, the proposed system addresses the limitations of conventional systems and paves the way for more sustainable and cost-effective security solutions.

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