

AI Based Power Management System

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Abstract - Energy conservation has become an important concern in modern society due to the increasing demand for electricity and its impact on the environment. This paper presents the design and implementation of an intelligent power management system using machine learning techniques. The proposed system is developed using a Raspberry Pi, camera module, and relay unit to monitor and control electrical appliances in indoor environments. The system detects human presence using a trained object detection model and automatically controls the power supply based on occupancy conditions. When a person is present, the system keeps the appliances in an active state, and when no presence is detected, it switches off the devices to reduce unnecessary power consumption. Unlike conventional systems that depend on manual operation or fixed timers, the proposed system adapts to real time conditions, improving efficiency and reliability. The integration of computer vision and embedded systems enables accurate detection and fast response. The use of local processing ensures reduced delay and eliminates the need for continuous internet connectivity. The proposed system is cost effective, scalable, and suitable for applications in homes, offices, and educational institutions. The results demonstrate that the system can effectively reduce energy wastage and support sustainable energy management practices.

Key Words: Machine Learning, Power Management System, Raspberry Pi, Human Detection, Energy Efficiency, Computer Vision, Automation, Smart Energy Systems

1. INTRODUCTION

The increasing demand for electricity has led to significant concerns regarding energy wastage and environmental impact, especially in indoor spaces where devices are often left operating unnecessarily. Conventional power control methods, such as manual switching and timer-based systems, are not capable of adapting to real-time conditions, resulting in inefficient energy utilization. To address this issue, advancements in artificial intelligence and embedded systems can be utilized to develop smarter and more responsive solutions. In this paper, an intelligent power management system is proposed using a Raspberry Pi, camera module, and relay unit. The system employs computer vision techniques to detect human presence within a monitored area and automatically controls electrical appliances based on occupancy. When a person is present, devices remain active, and in the absence of occupants, the system switches off the power supply to

reduce energy consumption. This approach enhances automation, improves energy efficiency, and minimizes human intervention. The proposed system is cost-effective, scalable, and suitable for applications in homes, offices, and educational institutions, contributing to sustainable energy management practices.

2. LITERATURE REVIEW

Recent studies in smart energy systems emphasize the need for automation to reduce unnecessary power consumption. Traditional lighting and power control methods have been improved using sensors and microcontrollers, enabling automatic switching based on environmental conditions and occupancy. Motion detection systems using infrared sensors and cameras have been widely used for controlling lighting, but their performance can be affected by lighting variations and limited detection accuracy. With the advancement of computer vision and machine learning, human detection techniques using deep learning models have shown better accuracy and reliability in real-time applications. These systems analyze visual data to identify human presence and make intelligent control decisions. Additionally, research in smart lighting systems demonstrates that adaptive control based on user activity can significantly improve energy efficiency. However, many existing solutions lack real-time adaptability and integration of advanced algorithms. Therefore, there is a need for a more efficient system that combines machine learning and embedded platforms for intelligent power management.

3. PROBLEM STATEMENT AND OBJECTIVES

3.1. Problem Statement

In many indoor environments, electrical appliances are often left switched on even when spaces are unoccupied, leading to unnecessary energy consumption and increased electricity costs. Existing power management systems mainly depend on manual control or fixed timers, which are not capable of responding to real-time occupancy conditions. Sensor-based systems offer partial solutions but may suffer from limited accuracy and reliability under varying environmental conditions. Therefore, there is a need for an intelligent system that can automatically detect human presence and control power usage efficiently to minimize energy wastage.

3.2. Objectives

- To design and develop a machine learning-based power management system.
- To implement human detection using computer vision techniques.
- To automatically control electrical appliances based on occupancy.
- To reduce unnecessary energy consumption and improve efficiency.
- To ensure real-time operation with minimal human intervention.
- To create a cost-effective and scalable solution for indoor environments.

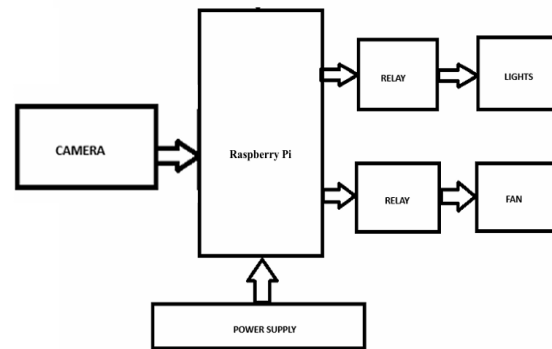


Fig 1. System Block Diagram

4. PROPOSED METHODOLOGY

The proposed system is designed to automatically manage power consumption based on real-time human presence detection using machine learning and embedded hardware. The system consists of a Raspberry Pi, camera module, relay unit, and a trained human detection model. Initially, the camera captures continuous video frames of the indoor environment, which are processed by the Raspberry Pi. These frames are analyzed using a pre-trained object detection model to identify the presence of a person. If human presence is detected, the system allows electrical appliances to remain active. In contrast, when no person is detected for a specified duration, the Raspberry Pi sends a control signal to the relay module to switch off the connected devices, thereby reducing energy consumption.

The implementation process includes setting up the hardware components, installing required software libraries, and integrating the machine learning model with the embedded system. Image data is preprocessed to improve detection accuracy, and the model is optimized for real-time performance. The system is tested under different conditions such as varying light intensity and multiple occupancy scenarios to ensure reliability. This methodology enables efficient automation, reduces manual intervention, and improves energy management in indoor environments.

4.1. System Architecture

The camera continuously captures video frames of the indoor environment. These frames are processed by the Raspberry Pi, where a pre-trained machine learning model detects human presence. Based on detection results, control signals are sent to the relay module to switch electrical devices ON or OFF. Fig 1 shows the block diagram of system architecture.

4.2. Methodology Steps

The working of the proposed system is carried out through the following sequential steps:

1. **System Initialization:** All hardware components such as Raspberry Pi, camera module, and relay unit are initialized and configured for operation.
2. **Image Acquisition:** The camera continuously captures real-time video frames of the indoor environment.
3. **Frame Pre-processing:** Captured frames are resized, filtered, and converted into suitable formats to improve detection accuracy.
4. **Human Detection:** A pre-trained machine learning model (such as YOLO or SSD) is applied to identify human presence in each frame.
5. **Occupancy Analysis:** The system determines whether the space is occupied or unoccupied based on detection results.
6. **Decision Making:**
 - If human presence is detected → System keeps appliances ON
 - If no human is detected → System prepares to switch OFF appliances
7. **Relay Control:** Control signals are sent from the Raspberry Pi to the relay module to switch electrical devices accordingly.
8. **Output Execution:** Appliances operate automatically based on occupancy status.
9. **Continuous Monitoring:** The system continuously repeats the process to ensure real-time response and automation.

4.3. Algorithm Flow

The algorithm for the proposed AI-based power management system is described as follows:

1. Start
2. Initialize system components (Raspberry Pi, camera module, relay).
3. Capture video frame from the camera.
4. Pre-process the captured frame (resize, filter, convert format).
5. Apply the trained human detection model.
6. Check for human presence:
 - o If human is detected → Go to Step 7
 - o Else → Go to Step 8
7. Send signal to relay to **turn ON** electrical appliances.
8. Send signal to relay to **turn OFF** electrical appliances.
9. Repeat the process continuously for real-time monitoring.
10. End

5. COMPONENT DESCRIPTION

The proposed system consists of both hardware and software components that work together to achieve intelligent power management based on human presence detection.

5.1 Hardware Components

1. Raspberry Pi: The Raspberry Pi acts as the central processing unit of the system. It performs image processing, runs the machine learning model, and controls the relay module based on detection results.

2. Camera Module: The camera is used to capture real-time video frames of the indoor environment. These images are processed to detect the presence of a person.

3. Relay Module: The relay functions as an electronic switch that controls the power supply to electrical appliances. It receives control signals from the Raspberry Pi to turn devices ON or OFF.

4. Power Supply: A regulated power supply is used to provide stable voltage to the Raspberry Pi and other hardware components for proper functioning. The hardware setup is shown in fig 2.

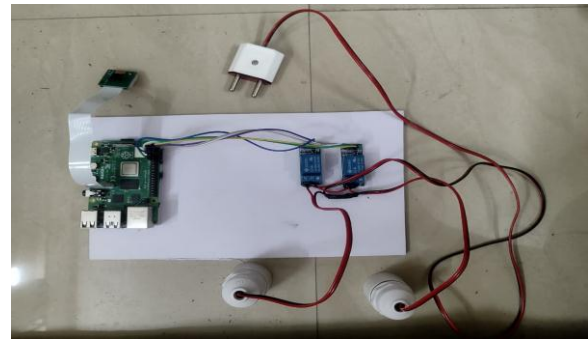


Fig 2. Hardware setup of the model

5.2 Software Components

1. Operating System: A Linux-based operating system (such as Raspbian) is used to run applications on the Raspberry Pi.

2. Programming Language: Python is used for implementing the system logic, image processing, and device control.

3. Machine Learning Model: A pre-trained human detection model is used to identify human presence from captured images.

4. Libraries and Tools: Libraries such as OpenCV and NumPy are used for image processing and numerical computations.

Table-1: Performance Analysis of Proposed Power Management System

Parameter	Description	Observation
Human Detection Accuracy	Ability to detect presence of a person	High in normal lighting
Response Time	Time taken to switch appliances ON/OFF	Fast(real-time response)
Energy Consumption	Power usage compared to traditional systems	Reduced significantly
System Reliability	Consistency of system performance	Stable during operation
Performance in Low Light	Detection under poor lighting conditions	Moderate accuracy
Automation level	Degree of human intervention required	Fully automated

6. RESULTS AND DISCUSSION

The proposed AI-based power management system was implemented using a Raspberry Pi, camera module, relay unit, and a pre-trained human detection model. The system was tested in a controlled indoor environment to evaluate its ability to detect human presence and automatically control electrical appliances. The camera continuously captured video frames, which were processed in real time to determine occupancy status. Based on the detection results, the relay module successfully switched appliances ON when a person was present and OFF when no presence was detected. The system performance was analyzed under different conditions, including varying lighting environments and multiple occupancy scenarios. It was observed that the human detection model performed with high accuracy under normal lighting conditions. However, a slight decrease in accuracy was noticed in low-light situations, although the system continued to operate without significant failure. The response time between detection and appliance control was minimal, ensuring smooth and real-time operation. A comparison with conventional manual and timer-based systems indicates that the proposed system significantly reduces unnecessary energy consumption. The automation eliminates the need for manual intervention and improves overall efficiency. Additionally, the system demonstrated stable and consistent performance during continuous operation. The observations are summarized in Table 1, which highlights key performance parameters such as detection accuracy, response time, and system reliability. Overall, the results confirm that the proposed system provides an effective, reliable, and energy-efficient solution for smart indoor power management. The results observed are shown in Fig 3 and 4.

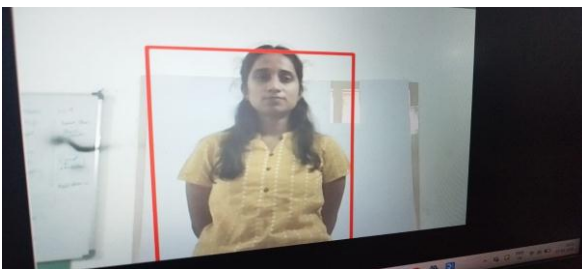


Fig 3. Detection of human



Fig 4. Lights are switched ON based on detection results

7. CONCLUSION

This work presents an intelligent power management system that uses machine learning and embedded hardware to improve energy efficiency in indoor environments. The system combines a Raspberry Pi, camera module, and relay unit to detect human presence in real time and control electrical appliances automatically. By ensuring that devices operate only when occupants are present, the system helps in reducing unnecessary power consumption and improving overall efficiency. The implementation demonstrates reliable performance with quick response and minimal need for manual intervention, making it more effective than conventional control methods. The solution is cost-effective and can be applied in various settings such as homes, offices, and educational institutions. Although the system performs well under normal conditions, minor limitations were observed in low-light environments, which may affect detection accuracy. These challenges can be addressed through further improvements in the detection model and system design. Overall, the proposed approach offers a practical and scalable solution for smart energy management and supports sustainable power utilization.

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