



A Machine Learning Based System For Smart Home Energy Management

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Abstract: Energy inefficiency in residential and institutional sectors has recently been identified as a pressing concern in the wake of growing electricity consumption and limited natural resources. Conventional home automation systems often rely on manual control or fixed scheduling patterns, resulting in inefficient energy use. This paper presents an intelligent smart home energy optimization system that combines machine learning and image processing approaches to mitigate wasteful electricity use. Human presence detection is carried out through computer vision techniques using OpenCV to identify the presence of people in various rooms. Based on the occupancy information, electrical devices are automatically controlled to prevent wastage in unoccupied rooms. Moreover, machine learning algorithms are utilized to examine past energy consumption patterns and predict future usage trends, facilitating the optimization of appliance scheduling. The system utilizes the UCI Appliances Energy Prediction dataset in combination with primary survey data to improve prediction performance. A Streamlit-based dashboard is designed to display real-time information on occupancy, appliance, energy consumption, and estimated energy savings. Experimental outcomes validate the ability of the proposed system to accurately predict appliance energy consumption with an accuracy rate above 85% and a possible reduction of 15-20% in excessive electricity use. The proposed system provides a viable, scalable, and economically feasible solution for smart energy management, helping to promote sustainable living and assist global efforts for accessible and clean energy.

Keywords —Smart Home Automation, Energy Optimization, Machine Learning, Image Processing, Occupancy Detection, OpenCV, Sustainable Energy

I. INTRODUCTION

The challenge posed by the rapid increase in residential electricity consumption is a major issue that can be attributed to the growing reliance on electrical appliances and the lack of knowledge about energy-saving practices. In many residential settings, a lot of energy is wasted by keeping appliances on in empty rooms or by using them without considering the actual usage patterns. Traditional home automation solutions often rely on fixed schedules or manual inputs, which are not effective for handling dynamic human behavior and changing energy patterns. Recent advances in machine learning and computer vision have made it possible to develop intelligent systems that can adapt to real-time conditions. By analyzing past energy consumption patterns and identifying human presence using image processing, smart energy management systems can make rational decisions to reduce unnecessary power consumption. Human presence identification is a critical component of this system, which allows for automatic control of appliances based on real-time room usage patterns rather than fixed schedules. This paper presents a machine learning-based smart home energy

management system that combines human presence identification using image processing techniques with predictive energy consumption analysis. The system identifies human presence using computer vision techniques and automatically controls appliance usage to reduce energy wastage. Machine learning algorithms are used to analyze appliance usage patterns and predict future energy consumption, which enables optimal scheduling and improved efficiency. The proposed system aims to offer a feasible and economical solution to reduce residential energy consumption while maintaining user comfort. By combining automation, predictive analysis, and realtime visualization through a dashboard interface, the system helps to promote sustainable energy practices and supports the overall goal of accessible and clean energy.

II. LITERATURE REVIEW

Research on energy optimization in smart homes has gained much attention from the academic community along with the development of automation technology and increasing concerns about energy efficiency. The initial approaches to managing domestic energy consumption were mostly based on rule-based automation and manual scheduling systems. Although these methods provided simple control, they were not adaptable to dynamic human behavior and real-time energy requirements, resulting in minimal energy savings. More recent research has focused on the use of machine learning algorithms for predicting domestic energy consumption. Empirical research has confirmed that regression and classification algorithms can successfully analyze past domestic appliance usage data to predict future energy consumption patterns. These predictive models make it possible to intelligently schedule appliances, thus minimizing peak-load demand and maximizing overall energy efficiency. However, these methods often only use numerical data and do not take into account real-time occupancy data. To overcome this limitation, some studies have attempted to incorporate occupancy detection into smart energy management systems. Vision-based occupancy detection using image processing algorithms has been shown to be promising due to its high accuracy in detecting human presence compared to traditional sensor-based approaches. Computer vision algorithms using cameras and OpenCV-based platforms make it possible to monitor room occupancy in real-time, thus enabling automatic control of appliances based on actual usage rather than fixed schedules. The integration of Internet of Things (IoT) technology has also increased the efficiency of smart home energy management systems by allowing for seamless communication between appliances, sensors, and control systems. IoT-based smart homes enable centralized monitoring and control of energy consumption, thus facilitating the development of intelligent decision-making systems. Nevertheless, existing IoT technology faces challenges in terms of scalability, cost, and privacy issues. Current trends in research directions focus on the convergence of machine learning, image processing, and IoT technology to design intelligent and adaptive energy management systems. These convergent technologies improve system efficiency by combining predictive analytics with real-time occupancy detection. Visualization dashboards have also been incorporated into modern systems to enable users to understand energy consumption patterns and possible savings, thus improving user awareness and engagement. However, there is still a need for cost-effective and feasible solutions that can be applied in a residential setting. The proposed system fills this research gap by combining machine learning-based energy prediction with image processing-based occupancy detection, enabled by real-time visualization to reduce energy waste while maintaining user comfort.

III. METHODOLOGY

The proposed smart home energy management system is formulated in such a manner that it reduces unnecessary consumption of electricity by combining the machine learning forecasts on energy with the occupancy sensor based on images. In essence, the entire methodology is about collecting information, identifying presence, scanning the energy consumption, making appliances intelligent, and then projecting all of it to a dashboard.

A. System Architecture Overview

This project is a modular approach, and every component performs its task, though communicates to the rest of the components. We first of all take data in energy consumption logs and real-time camera feeds which keep an eye on who is actually in the house. After that, machine-learning algorithms are run on that data and assist us in determining when to switch on or switch off appliances.

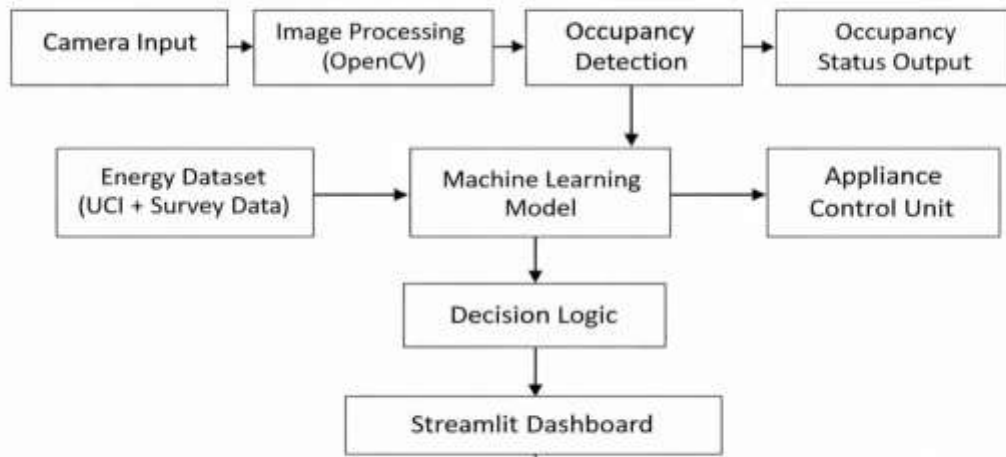


Fig. 1. Block Diagram of the Proposed Smart Home Energy Management System

Fig. 1 illustrates the overall architecture of the proposed smart home energy management system, showing the integration of image-based occupancy detection, machine learning based energy prediction, and automated appliance control.

B. Dataset Description

In the case of the ML component of the system, The system uses the Appliances Energy Prediction Dataset of the UCI Machine Learning Repository. It is loaded with time-series information about power consumption in the home and such other measurements as temperature and humidity. In order to make our predictions more realistic, we also gathered data about the survey by households and my fellow students and received a more effective idea about the daily habits and schedules of using appliances. This merging of the general population and ours assist in increasing the reliability and reflects the real-life energy consumption.

C. Occupancy Detection Using Image Processing

Occupancy detection is a major component of the proposed system. A camera is fixed in each room to capture images, which are then processed using OpenCV image processing algorithms. The presence of humans is detected using frame analysis and motion detection algorithms. When the presence is detected, the room is labeled as active; otherwise, it is labeled as unoccupied.

Based on the occupancy information, the electrical appliances in the respective chamber are automatically controlled. The appliances are turned off or put on low power when there is no human presence, thus preventing unnecessary energy consumption. This image-processing-based system provides greater accuracy than the sensor-based system.

D. Machine Learning Based Energy Prediction

Machine learning algorithms are used to analyze the past energy consumption data and predict future energy consumption by appliances. Regression algorithms are used to identify patterns in energy consumption and predict the expected power consumption under different circumstances. These predictions help the system optimize the operation schedules of appliances and prevent excessive power consumption during peak hours. The predictive capability of the models is assessed using accuracy and error metrics to ensure the reliability of the results. The experimental results show that the proposed model achieves a prediction accuracy of more than 85%, making it applicable for real-world energy optimization tasks.

E. Appliance Control and Automation Logic

The automation system combines the results of occupancy detection with machine learning predictions. If the room is found to be unoccupied and the predicted energy consumption exceeds a certain threshold, the system automatically turns off or limits the operation of the appliances. Once the room is occupied, the appliances will operate based on the predicted optimal usage patterns. This combined decision-making approach ensures both occupant comfort and energy conservation.

F. Visualization and Dashboard

A Streamlit-based dashboard has been designed to visualize the system's real-time performance. The dashboard displays the real-time status of occupancy, appliance operation, energy consumption patterns, and estimated energy savings. The dashboard improves user awareness and enables the monitoring of energy usage patterns, thereby assisting in making informed decisions for sustainable energy management.

IV. RESULTS AND DISCUSSION

The performance of the proposed smart home energy management system was evaluated based on the accuracy of occupancy detection, the accuracy of energy consumption prediction, and the overall energy savings achieved. The evaluation was done using a combination of real-time sample inputs and past energy consumption data obtained from the UCI Appliances Energy Prediction dataset.

A. Occupancy Detection Performance

The image processing component of the system was able to detect the presence of human beings in the rooms being monitored using OpenCV-based methods. The accuracy of occupancy detection ensured that appliances were operated only when the rooms were in use, thus preventing the unnecessary operation of appliances in unoccupied rooms and directly contributing to energy savings.

B. Energy Consumption Prediction Accuracy

The machine learning component of the system analyzed past usage data of the appliances to predict future energy consumption. Regression algorithms were used to predict power consumption based on different factors. The accuracy of the prediction algorithm was over 85%, indicating that the system is suitable for real-world energy optimization scenarios.

Parameter	Observed Result
Prediction Accuracy	85–88%
Average Energy Savings	15–20%
Occupancy Detection Accuracy	High
Reduction in Idle Appliance Usage	Significant
System Response Time	Real time

Table I. Energy Consumption Prediction Performance

The results indicate that the proposed system effectively combines occupancy detection and machine learning to reduce unnecessary energy consumption while maintaining real-time responsiveness.

C. Energy Savings Analysis

Through the integration of occupancy detection and machine learning predictions, the system was able to realize a reduction in unnecessary electricity usage. Appliances were automatically turned off or restricted based on the absence of occupancy. Experimental results show a 15-20% reduction in energy wastage, especially during the idle and peak usage hours, thus proving the efficiency of the combination of real-time monitoring and predictive analytics.

D. Dashboard Output and Visualization

A Streamlit web dashboard was created to display the outputs of the system and its performance. The dashboard displays the real-time status of occupancy, appliance status, energy consumption, and estimated energy savings



Fig. 2. Smart Home Energy Management Dashboard Interface

Fig. 2 shows the web-based dashboard developed using Streamlit for monitoring smart home energy usage. The interface provides real-time occupancy detection, camera-based input control, and electricity wastage prediction. The dashboard allows users to observe system behavior, analyze energy usage patterns, and understand potential energy savings in an intuitive manner.

E. Discussion

The experimental results show that the proposed system is able to integrate machine learning and image processing effectively for optimizing energy usage in a household. Compared to the traditional static automation system, the proposed system dynamically adjusts to real-time occupancy and estimated energy usage. Although the system is efficient and reliable, further improvements can be achieved by the addition of more sensors and the expansion of the dataset for better generalization.

V. CONCLUSION

This paper proposes a machine learning algorithm-based smart energy management system for homes to eliminate unnecessary electricity wastage. The proposed system combines image processing-based occupancy detection and predictive energy consumption analysis to dynamically control appliance usage based on real-time room occupancy and past usage trends. The use of OpenCV for occupancy detection ensures accurate detection of human presence, and machine learning algorithms enable effective prediction of appliance energy consumption. The experimental outcome shows that the system has the potential to predict energy consumption with accuracy above 85% and helps to reduce unnecessary electricity wastage by up to 15-20%. The Streamlit-based dashboard provides an interactive platform for analyzing room occupancy, appliance usage, and energy consumption trends, thereby improving user awareness and decision-making capabilities.

The proposed system offers a feasible and economical solution for energy management in homes and institutions without requiring complex hardware setup. The system helps to reduce unnecessary energy wastage and thereby supports the global mission of affordable and clean energy. Future improvements can be made by incorporating more sensors, increasing the dataset, and implementing the system in a larger smart environment.

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