Sustainable Energy Management Through IoT-Driven Smart Zone-Based Control System

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Abstract. This paper presents an Internet of things(IoT) based automation and monitoring system intended to conserve electrical energy in classroom environments. The system will make use of image processing techniques to detect human presence, thereby activating an automatic control system for the lighting and fans. The area of the classroom is divided into such zones; each zone is fitted with a corresponding fan. The presence of humans in a particular zone activates the relevant fan, while in the absence, it will be switched off. This is applied to all fans and lights and helps avoid common mistakes such as students not switching off appliances. The system, thus, automates this function and reduces energy wastage, thus conserving power and helping preserve natural resources like coal. In addition, the system detects power consumption for every classroom and reports this data to the cloud for real-time monitoring and evaluation. This data-based approach leads to judicious decisions and implementation of added measures in maximizing energy efficiency. With automation and Internet of things (IoT), users ensure sustainable use of energy, conserving the environment and inspiring effective management practices.

Keywords: IoT-based automation, Energy conservation, Sustainable energy use.

1. Introduction

Power misutilization is a huge problem in today's world with great environmental implications. For example, the production of thermal power is mainly based on coal, a non-renewable commodity extracted through extensive mining. Inordinate extraction of coal disturbs the earth's balance with the resultant potential environmental hazards [1] like land degradation and earthquakes. On average, 1 kilogram of coal produces about 7 kWh of electricity. This means that many tons of coal need to be consumed so as to cater to the rising power demands in the residential and industrial fields. The trend of consumption of more coal and other non-renewable sources to generate energy makes a strong case for finding sustainable alternatives to reduce energy consumption and save resources. Automation techniques will find use in ensuring that there is minimal wastage of power. These intelligent systems can be used to automate the control of electrical devices, so that they would only operate when really needed [2]. One problem that it may easily solve is the lights and fans turned on in the classroom, office, and other shared facilities. Automation using advanced technologies such as image processing and IoT would significantly reduce power consumption. Some of these systems would automatically detect the presence of humans in a room and adjust devices appropriately so as not to waste any energy. This energy-saving hardware also benefits the

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coal by stopping overconsumption. Subsequently, this measure reduces the environmental effect of electricity generation and supports sustainability. This paper presents an automation system specifically developed to optimize electricity use in classrooms, which will probably improve potential energy saving and contribute to environmental conservation.

2. Related Work

Automation of electrical appliances is achieved through sensor-based technologies to optimize power consumption. The widely used method among these is the passive infrared (PIR) sensors [3], which detect movement in order to automate switching of devices. PIR sensors are very effective in turning appliances on or off based on human motion within a designated area. The second technique uses inductive or magnetic sensors located in the doors [4]. A switch is activated when one opens or closes the door. This is a simple method, but it proves most effective for rooms where entry is regulated, such as in classrooms and offices. An important area of research includes sound-based systems. Examples are clap-controlled switches which can be activated using sound waves produced by claps. Speech recognition systems extend this principle, allowing voice-command activation for a user-friendly and accessible means of managing electrical devices [5]. Infrared, or IR, and laser sensors are also employed, measuring interruptions of light beams or patterns to activate devices [6]. However, these systems tend to be sensitive to environmental influences, requiring fine calibrations to maintain effectiveness. Although these methods are effective, they also pose accuracy, reliability, and scalability concerns. To overcome such limitations, this paper presents an advanced automation system using image processing to detect human presence within predefined zones, thus accurately and effectively controlling electrical appliances.

3. Proposed Design

The proposed design uses a Raspberry Pi as the central processing unit, with integration of the Pi Camera, relay modules, and current sensors to provide all the necessary software tools. OpenCV was implemented with the Python programming language to enable image processing [7], and the MediaPipe library was applied in order to improve the human detection ability. The Pi Camera captures images of the designated area and the Raspberry Pi processes the images to detect the presence of humans. Whenever a human is detected, the signals are sent to the relay modules by the Raspberry Pi. The control of AC electrical appliances like fans and lights is operated so as to minimize the number of unnecessary power services. Here, the area is divided into zones, where the system strictly controls and takes decisions in choosing the appliances to be activated within each zone according to the occupancy in that zone. In addition to automation, the design uses live monitoring of power consumption.

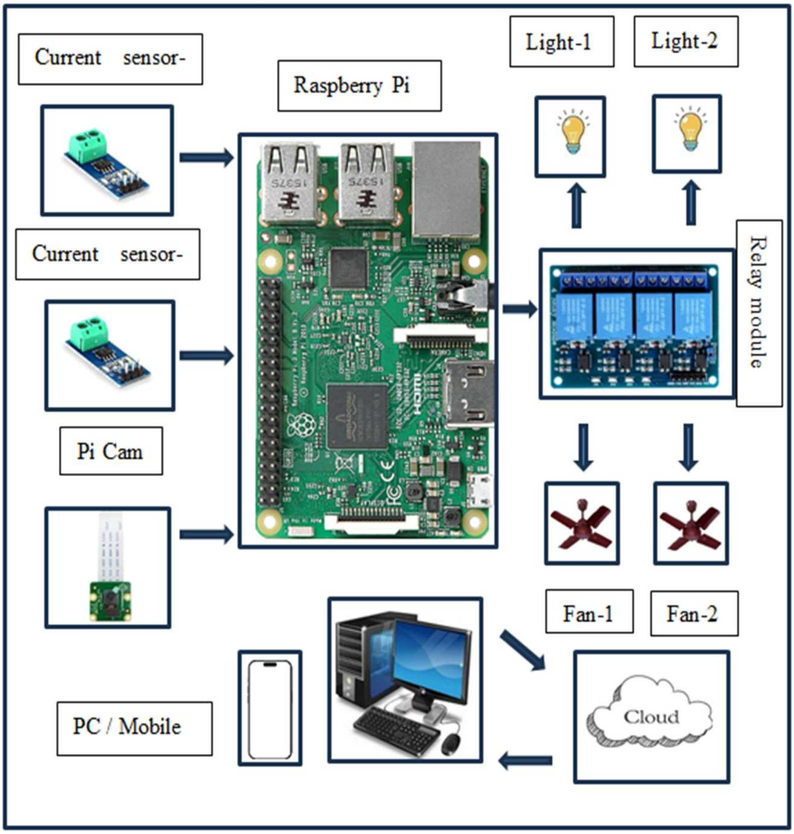

Fig.1. Block Diagram

The current sensors of ACS 712 measure the power intake of the devices connected. The Raspberry Pi will process the readings and then send the power consumption to the cloud platform via its Wi-Fi abilities, access to which is via a local hotspot. The system allows for the monitoring and analysis of such patterns from remote locations [8]. This information can then be analyzed to identify opportunities for further power consumption optimization. With automation coupled with real-time monitoring, this system minimizes energy wastage yet generates insights into policies that maximize energy efficiency, such that management of the power resource will be sustainable and resources will be conserved.

4. Hardware and Software used

4.1. Raspberry Pi

One can use Raspberry Pi as an open platform in developing Matter-enabled applications and devices. It can be applied in this manner: Build and test matter-compatible devices using the available SDKs and libraries with Raspberry Pi. This can also act as a smart home hub, where Matter-enabled devices and ones not enabled with Matter are bridged, for a seamless smart home experience.

Fig. 2. Raspberry Pi

4.2. PI Camera

Raspberry Pi Camera: It is the small camera module specifically developed for working on Raspberry Pi boards. Captures snaps of super-quality pictures and videos. Standard version: usually 5MP and, more excellent version: 12MP; may capture video up to 1080p at 30fps. Connects via the CSI (Camera Serial Interface) port on the Raspberry Pi. Compact in design, specifically for all projects that require embedding small-size, light-weight.

Fig. 3. Pi Camera

4.3. Current Sensor

It acts as a sensor, which senses the current of wire and puts out a signal corresponding to it. The signal so produced may be in the analog form in terms of voltage or current and/or as a digital output. This resultant signal can be further used for display of the current which was measured in an ammeter or for storage purposes in a data acquisition system, or it can be put to use for the purpose of control. Analog output reproduces the waveform of the sensed current. Bipolar output that reproduces the waveform of the measured current. unipolar output proportional to the average or rms value of sensed current.

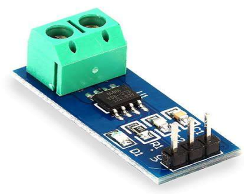

Fig. 4. Current Sensor

4.4. Relay Module

A relay module is a transistor electronic component used to control a high-voltage device with a signal from low voltage. It commonly contains one or more relay and the complementary circuitry that safely supports opto-isolators. Due to its prevalence in automation projects, relay modules enable microcontrollers like Arduino or Raspberry Pi to be controlled over the on/off state of devices such as lights, motors, or appliances. It provides electrical insulation between the control signal and the high-voltage circuit. It can drive multiple relays through the utilization of a single microcontroller pin. Variety: Variant in various configurations: 1, 2, 4, or more channels. The IoT-based smart management system enhances sustainable consumption of energy by the use of interconnected devices that monitor and optimize energy use in real time. A relay module typically consists of an electromagnet (coil) and a switching mechanism (contacts). When the coil receives a low-voltage control signal, which either opens or closes the contacts, switching the high-power circuit on or off.

Fig. 5. Relay Module

4.5. Operation.

The microcontroller applies a low or high signal to the enter pin accompanying each relay module to activate the relay module. Upon activation, the relay closes its transfer, allowing cutting-edge to slide into the associated device. When deactivated, it opens its switch, cutting off electricity to the device.

4.6. OpenCV-Python

OpenCV has Python binding and enables Python programmers to easily add powerful graphics and video processing features to their applications. OpenCV is a powerful image processing library that can efficiently. perform operations like rescaling images, applying filters, and color space conversion. It also supports video capture. That means real-time video from cameras. Opens up loading capabilities and thereby opens up image processing capabilities as well. Its object recognition and background capabilities include face and pedestrian recognition and tracking in a video frame besides it, OpenCV also offers its machine learning and AI modules combined. It enables image classification, object recognition, and all the advance features that are provided by AI functions. Its cross-platform support includes Windows, Linux, macOS, Android, and iOS makes it a versatile cross-platform tool [9].

Many situations, both for Thonny and OpenCV-Python, make these very friendly tools for tutorial scenarios or start-up projects in graphics and computer vision. Thonny will make easy to write code and debug, and OpenCV brings graphical-processing capabilities to Python OpenCV is a powerful image processing library that can efficiently perform operations like rescaling images, applying filters, and color space conversion. It also supports video capture. That means real-time video from cameras. Opens up loading capabilities and thereby opens up image processing capabilities as well. Its object recognition and background capabilities include face and pedestrian recognition and tracking in a video frame besides it, OpenCV also offers its machine learning and AI modules combined. It enables image classification, object recognition, and all the advance features that are provided by AI functions. Its cross-platform support includes Windows, Linux, macOS, Android, and iOS makes it a versatile cross-platform tool.

5. System Implementation

The system described is of an automation and optimization setup of power management in a building using a Raspberry Pi, a Pi camera, current sensors, and a relay module. It detects the presence of a human being in a room divided into four zones, where each zone has its own set of electrical appliances that activate upon occupancy. The Pi camera, with OpenCV being a computer vision library in Python, captures and processes real-time images. The system uses image processing to detect human presence within each predefined zone of the room. Whenever a person enters one of the zones, the system will contact the relay module to start the appliances confined to that zone, for example lighting or fans. This is the reduction of wastage in the system by not activating all the devices. It is monitored at the consumption levels, and there will be granular understanding of the usage of energy in different zones and the entire building block from the sensing of currents.

This system of intelligent energy management depends on the Internet of Things technology and artificial intelligence. Here, in this system, power usage is optimized by a sequence of IoTs with real-time remote monitoring and analysis of the power consumption pattern through IoTs. Then AI algorithms pass all these data for trends of peaks as well as that points which may be wastage. From this, the system can automatically take the self-conservation of energy-related actions such as dimming lights, adjusting HVAC to certain levels, or powering off devices in areas of the zone that are unused. The system is therefore significantly efficient and saves the loss of energy by doing its work without human interference. Dynamic appliance management via real-time usage helps make the system contributory to building management's sustainability and eco-friendliness. It, therefore, gives AI-driven responsive energy control, bringing convenience in high user comfort while heightening responsibility for the environment. Real-time alerts can give building managers a chance at receiving these, and with real-time energy reports, actionable information becomes available to them on the effective management of energy use and cost.

This high-tech system, hence, enables energy saving besides supporting general goals of sustainability with respect to minimizing the carbon footprint of the building. Also, since IoT and AI have been used, this system looks into the future when managing the consumption of energy since it will develop its pattern and helps the customers save more for better energy use. Overall, these end users might save the money in energy usage with efficiency improvement of operation and ensure sustainability with no effort on their side. It has an innovative way of lowering the environmental impact in school settings, commercial building s, and even office spaces so as to give the world a smarter, greener future in energy management.

6. Results

Test The proposed system integrates image processing, hardware control, and cloud monitoring into an intelligent power management system in classrooms. A Table.1 shows live or cloud-updated values for power consumption by Classroom 1 and Classroom 2, representing the real-time energy usage accessible through a mobile or PC. The Fig.6 shows a classroom divided into four zones using OpenCV and MediaPipe for human detection. The data will be processed by the Raspberry Pi when a human is detected in a specific zone. It then activates the electrical appliances in that zone, such as lights and fans, via relay modules while maintaining all other, non-occupied zones in an off state to conserve energy. The Fig.7 displays the hardware prototype: the Raspberry Pi attached to a camera, relay modules, and current sensors. These components enable real-time power usage monitoring and appliance control, with data transmitted to the cloud for logging and remote access. This system ensures efficient, automated control and live monitoring for optimal energy management.

Table 1. Current sensor values with time stamp

Time (HH)	Current (A)	Voltage (V)	Power (W)	Room No.
08:00	2.5	230	575	Room 1
08:15	1.8	230	414	Room 2

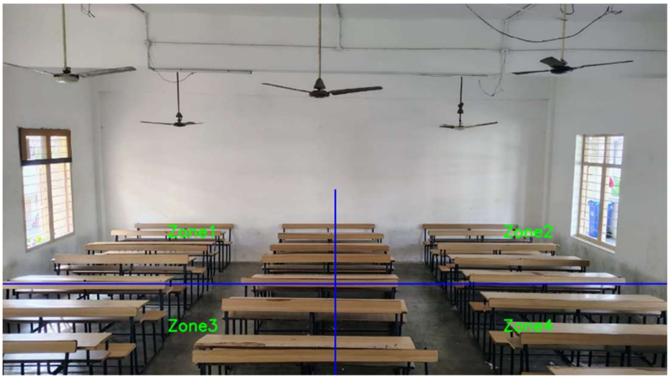

Fig. 6. Classroom divided into four zones

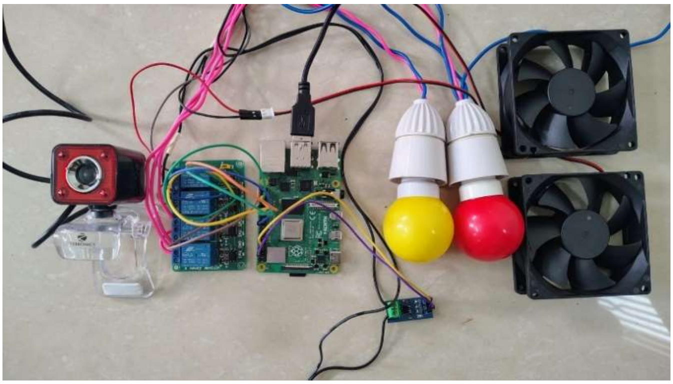

Fig. 7. Prototype of proposed design

7. Conclusion

This project successfully designed and developed an IoT-based system for optimizing power usage in classrooms, detecting human presence through image processing to accurately control electrical appliances, such as fans and lights. Unnecessary energy wastage is thus reduced with this system. Real-time power consumption measurements were made possible through current sensors, which sent and conveyed data to a cloud platform for viewing and analysis. The dual approach of automation and data-driven monitoring of the system minimizes energy wastage while facilitating informed decision-making that can enable further optimization. This contributes to conserving resources such as coal as well as promoting environmental sustainability, since it cuts the ecological impact of energy usage. Future improvements could focus on the integration of advanced AI models to strengthen human detection and scaling the system for larger applications to overcome current issues, including lighting variations and scalability. This system is a practical realization of a sustainable energy management system with great scope for greater deployment.

8. **Declaration:** The authors declare no conflict of interest

9. References

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