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ENERGY-EFFICIENT LIGHTING CONTROL SYSTEM BASED ON MQTT AND RASPBERRY PI

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ABSTRACT

Energy consumption in lighting systems significantly contributes to electricity usage, especially in commercial and industrial environments. As demand for energy efficiency grows, intelligent lighting control systems offer a practical solution to optimize energy consumption. This research proposes designing and implementing an energy-efficient lighting control system based on the MQTT (Message Queuing Telemetry Transport) protocol and the Raspberry Pi platform. The goal is to develop an energy-efficient lighting solution that reduces energy waste, improves user comfort, and provides real-time data for better energy management in residential and industrial buildings. The MQTT protocol enables communication between the Raspberry Pi and other devices in the system, such as sensors and light bulbs. By using MQTT brokers, the system is capable of exchanging messages in real time, triggering light adjustments based on sensor data. The system supports remote control capabilities through a smartphone or computer, allowing users to modify the lighting settings from any location, thus offering enhanced flexibility and ease of use. The MQTT protocol publish-subscribe model enables multiple devices to interact with minimal latency, ensuring fast and efficient control of the lighting system. To ensure energy efficiency, the system continuously monitors energy consumption by tracking the power usage of connected light bulbs. It records the data on the Raspberry Pi and provides real-time feedback to the user via an online interface or mobile app. The energy consumption data is displayed in graphical formats, allowing users to analyze trends and make informed decisions about lighting usage. Furthermore, the system offers the potential for machine learning algorithms to optimize energy consumption patterns based on historical data, allowing the system to "learn" and predict energy-saving strategies for future use. The design of the system is modular and scalable, making it adaptable to a wide range of applications. Whether in a single room or a large industrial complex, the system can be expanded to accommodate additional sensors, lights, and control units. The system can be customized to meet specific energy-saving goals or to integrate with existing smart home systems, providing a flexible solution that can evolve as user needs change over time. In conclusion, this project demonstrates the potential of combining the Raspberry Pi platform and MQTT communication protocol to create a smart, energy-efficient lighting control system. By integrating real-time sensor data with automated lighting adjustments and remote-control features, the system not only improves user comfort but also contributes to significant energy savings. The scalability, flexibility, and modular nature of the design make it a promising solution for a variety of applications, from residential to industrial settings, promoting sustainability and reducing the environmental impact of lighting systems.

Keywords: Energy-Efficient, Lighting, Energy Consumption, MQTT Protocol, Raspberry Pi

1. INTRODUCTION

In recent years, energy consumption has become a growing concern worldwide, particularly in the lighting sector. As the demand for electricity continues to rise, there is an increasing need for energy-efficient solutions that not only reduce consumption but also provide flexibility and convenience for users. Traditional lighting systems often operate continuously at fixed intensities, leading to unnecessary energy wastage, especially in unoccupied or well-lit areas. The need for smart lighting systems has emerged, which can adapt to real-time conditions and optimize energy use. This project aims to develop an energy-efficient lighting control system using the MQTT (Message Queuing Telemetry Transport) protocol and the Raspberry Pi platform, which enables automated and intelligent control of lighting in both residential and industrial environments.

The key objective of this system is to provide a solution that reduces energy wastage through automated, sensor-driven lighting adjustments. The system integrates environmental sensors, such as motion detectors, light-dependent resistors (LDRs), and temperature sensors, with the Raspberry Pi microcontroller to create a smart, responsive lighting network. Motion detectors are used to identify occupancy, ensuring that lights are only turned on when required, while LDRs monitor ambient light levels to adjust the intensity of artificial lighting. Temperature sensors help maintain a comfortable lighting environment by adjusting the brightness or turning off lights when not needed. This system aims to optimize the use of energy by ensuring that lights are only on when necessary and that their intensity is adjusted according to the prevailing conditions.

A major feature of this lighting control system is the use of the MQTT communication protocol, which facilitates low-latency, reliable communication between devices. MQTT is a lightweight, publish-subscribe messaging protocol widely used in IoT (Internet of Things) applications for transmitting data between devices in real-time. This protocol is ideal for managing multiple devices in a smart lighting system, as it allows for efficient communication between the Raspberry Pi, sensors, and lights. The use of MQTT enhances the system's scalability, allowing it to be expanded to larger environments or integrated with other smart devices. The system also supports remote control, allowing users to modify lighting settings through smartphones or computers, providing greater flexibility in managing energy consumption.

With the integration of the Raspberry Pi microcontroller, the system offers the advantage of cost-effective and efficient computing power. The Raspberry Pi is capable of handling sensor data, controlling the lights, and running the MQTT protocol to facilitate communication between components. Its GPIO pins enable direct connection to sensors and lights, making it a suitable platform for creating smart and energy-efficient solutions. Additionally, the Raspberry Pi's compatibility with various programming languages, such as Python, allows for the development of custom software to meet specific user requirements.

This system also provides users with the ability to monitor and analyze their energy usage in real time. Through the use of energy monitoring tools, the system can track power consumption and provide feedback to users, helping them understand their energy usage patterns and make informed decisions. By presenting energy usage data through graphical interfaces on mobile apps or web browsers, users can easily track their energy-saving progress and identify areas for improvement.

In this energy-efficient lighting control system, based on MQTT and Raspberry Pi, presents a promising solution to the growing problem of excessive energy consumption in lighting systems. By utilizing real-time sensor data, wireless communication, and automated control, the system aims to reduce energy wastage, enhance user comfort, and promote sustainability. With its scalability and flexibility, the system can be applied in various environments, from homes to large industrial complexes, providing an effective means of energy management. Energy-efficient lighting control systems utilizing MQTT and Raspberry Pi represent a significant advancement in reducing energy consumption across various settings. These systems leverage IoT technologies to optimize lighting based on occupancy and environmental conditions, leading to substantial energy savings.

2. METHODOLOGY

The methodology for developing the Energy-Efficient Lighting Control System is structured into several key phases, including system design, hardware and software development, integration, and testing. The system aims to combine the benefits of MQTT communication and the Raspberry Pi microcontroller to provide a smart lighting solution that adjusts in real time based on environmental conditions. The following steps outline the approach used to design and implement the system.

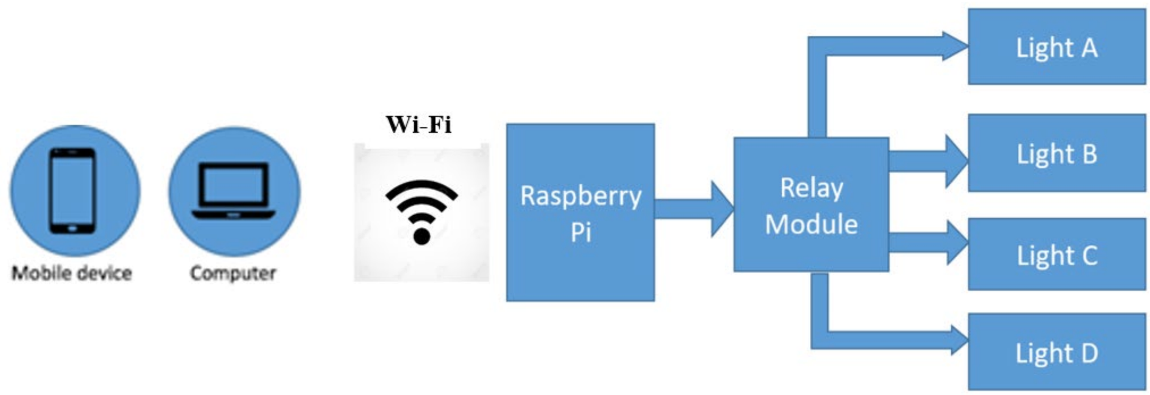
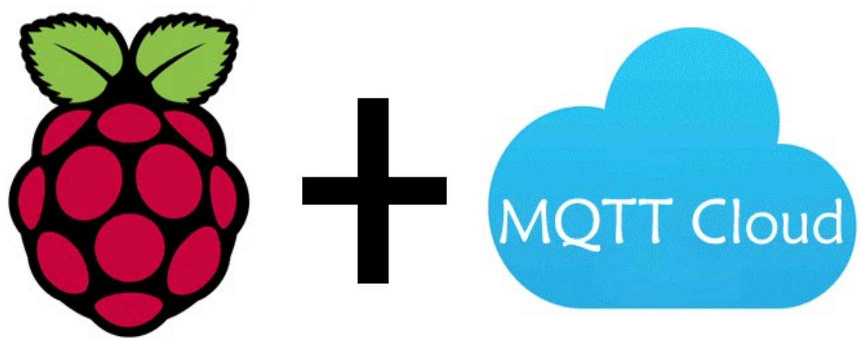


Fig 1. Proposed System Block Diagram



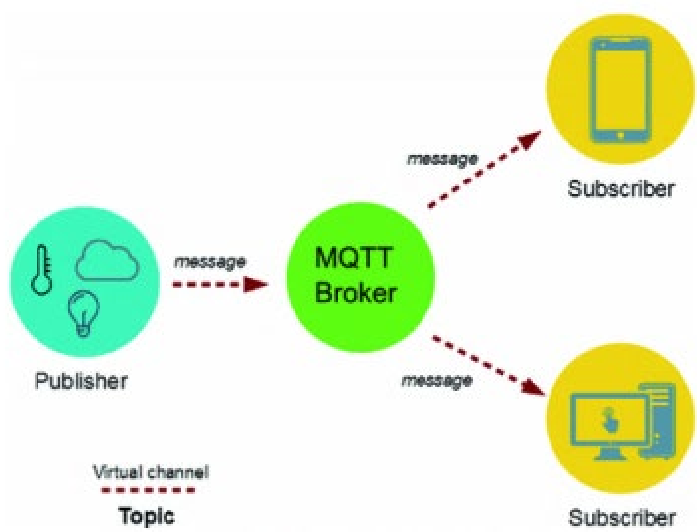


Fig 2. MQTT Architecture diagram

The first step in the methodology involves defining the system's overall architecture and functional requirements. The main objective of the system is to control lighting based on sensor data to optimize energy consumption. The design involves using sensors for real-time environmental monitoring, a Raspberry Pi for data processing and control, and MQTT for communication between components.

The system is designed to monitor occupancy, ambient light levels, and temperature in a room or area to automatically control the lighting. The Raspberry Pi serves as the central controller, which receives data from the sensors and processes the information to make decisions about whether to turn lights on or off or adjust their brightness.

The hardware and software components required for the system include Raspberry Pi is the central processing unit, responsible for controlling the system, interfacing with sensors, and sending/receiving messages via MQTT. Motion Sensor sensors detect human presence or movement within the area. When motion is detected, the system will turn the lights on. Light sensors measure the ambient light levels. When sufficient natural light is available, the system will turn off the artificial lighting. Temperature sensors are used to monitor the temperature of the room. The system may adjust the lighting conditions based on the temperature to maintain user comfort and the relay Modules control the on/off state of the light bulbs based on the signals received from the Raspberry Pi.

The software development phase involves writing the code to process the sensor data, control the relay modules, and implement MQTT communication. The Raspberry Pi runs a Python-based program that continuously reads data from the sensors and makes real-time decisions to control the lights. The MQTT protocol is implemented for communication between the Raspberry Pi and other devices in the system. The Raspberry Pi will act as both the MQTT publisher (sending sensor data) and subscriber (receiving control commands for the lights). The MQTT broker will facilitate the communication. The Python program processes the input from the sensors, determining whether the light should be turned on or off. The relay modules are controlled via the Raspberry Pi GPIO pins. The program switches the relay on or off depending on the occupancy status, ambient light levels, and temperature data. A simple mobile application interface is developed to allow users to monitor and control the lighting remotely. This interface can also display real-time data on energy usage and lighting status. Once the hardware and software components are developed, the next step is integrating the system. The sensors, Raspberry Pi, relay modules, and communication links are all connected, and the system is tested for proper operation. The system is tested for energy-saving capabilities by monitoring the lights' power consumption. Energy usage data is logged, and efficiency is measured against traditional lighting systems to ensure that the system achieves the intended energy savings. After initial testing, the system may undergo optimization to improve efficiency and accuracy. Software Implementation steps are

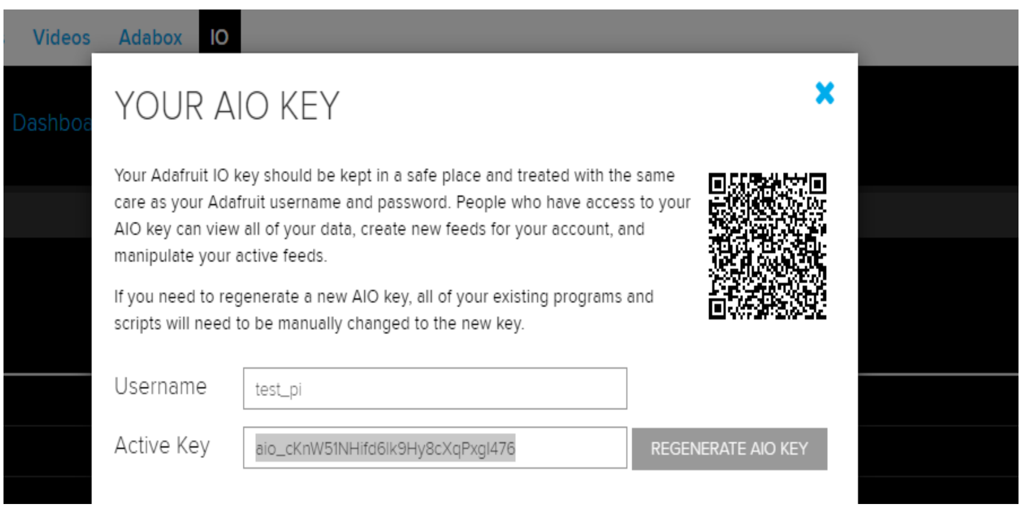


Fig3. Adafruit_IO_Key and Username credential window.

The Python_3 is used for the software purpose. The login ID and password are created first. The enrolled unique ID number is given, which matches when the actual code is executed.

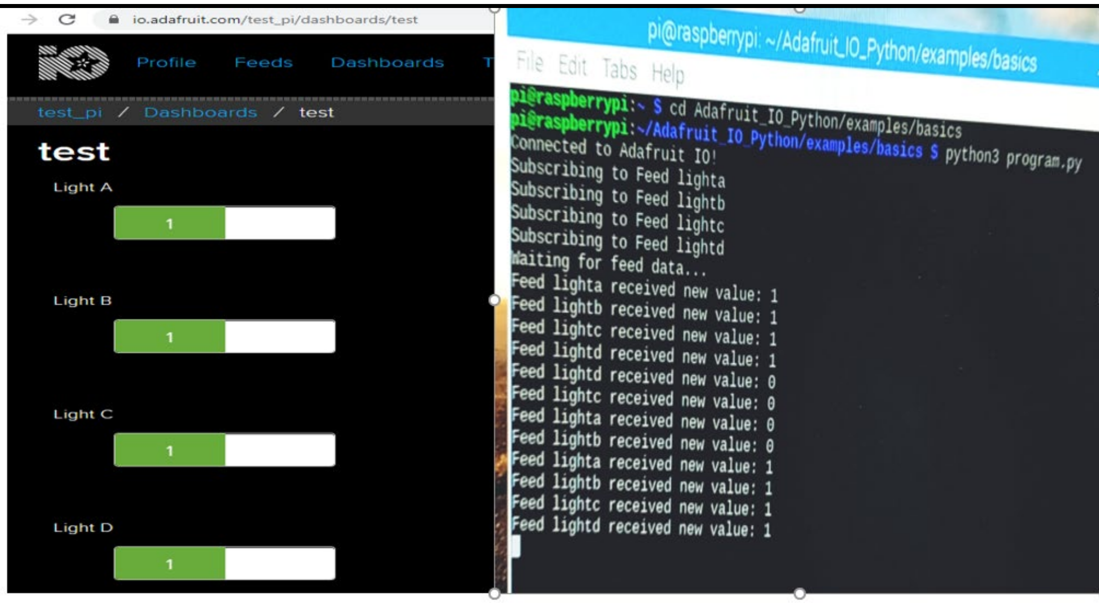


Fig4. View of Adafruit dashboard

You will need the ADAFRUIT_IO_KEY And ADAFRUIT_IO_USERNAME, which can be found on the Adafruit dashboard The software has to use support to run the module for the Adafruit library for an Adafruit library The whole system setup of the proposed Relay module

3. RESULTS ANALYSIS

The proposed system was successfully implemented and tested. Key observations include the local MQTT server providing reliable and instantaneous control within the local network. The Adafruit IO platform enabled seamless global access to connected lighting appliances. Response times were minimal, demonstrating the efficiency of the MQTT protocol. The integration with Adafruit IO provided an intuitive interface for managing feeds and monitoring device status. The system can be easily extended to control multiple lighting devices by adding additional feeds and configuring corresponding GPIO pins. The results highlight significant energy savings achieved through IoT-based lighting control and optimized scheduling. The system's ability to remotely monitor and control appliances ensures efficient energy use, contributing to sustainability goals this proposed system used 4 LED tubes each 20 watts per LED tube. Considered working hours the lights are used for 6 hours per day. Analysis Energy Savings for two methods First traditional On-Off method in this method no savings because the lights remain on for the entire duration, even when not required. The second MQTT Protocol-Based method lights are optimized to operate only when needed, reducing the usage to 4.5 hours per day (25% reduction). This case considers break hours, and no occupancy detection at that time, to turn off the LED tube.

Energy Consumption (kWh) = (Power in Watts × Hours of Usage × Number of Tubes)/1000.

Table 1. Energy Consumption

Method	Daily Usage (hours)	Energy Consumption (kWh/day)	Monthly Consumption (kWh)	Energy Savings (%)
Traditional On-Off	6	0.48	14.4	-
MQTT Protocol-Based	4.5	0.36	10.8	25%

The table analyses daily energy consumption for traditional methods of 0.48 kWh/day and MQTT of 0.36 kWh/day, saving 0.12 kWh/day due to reduced operational hours. The Monthly Energy Consumption for both methods is 14.4 kWh for traditional and 10.8 kWh, saving 3.6 kWh/month for MQTT. Compared to these two methods a 25% reduction in energy usage highlights the efficiency of the MQTT system in managing lighting based on actual requirements.

4. CONCLUSION

This research demonstrates the feasibility and effectiveness of an MQTT-based lighting control system using Raspberry Pi and the Adafruit IO platform. The integration of a cloud-hosted MQTT broker overcomes the limitations of local control, enabling global access to connected appliances. The system is efficient, scalable, and user-friendly, making it a promising solution for energy-efficient lighting control. The analysis of energy consumption in the two lighting control methods—Traditional On-Off and MQTT Protocol-Based—demonstrates the significant energy-saving potential of the latter. By reducing the operational hours of the lights from 6 hours to 4.5 hours per day, the MQTT-based system achieves a 25% reduction in energy usage. This results in a daily energy savings of 0.12 kWh and a monthly savings of 3.6 kWh, as compared to the traditional method. The energy consumption calculation clearly shows that the traditional lighting control system consumes 14.4 kWh per month, while the MQTT-based system reduces consumption to 10.8 kWh per month. This 25% reduction not only leads to cost savings but also contributes to more sustainable energy practices by optimizing lighting operations based on actual environmental conditions. In conclusion, the integration of the MQTT protocol for lighting control offers an effective and efficient solution for reducing energy consumption in lighting systems. This method proves to be highly beneficial in managing operational hours and ensuring that energy is used only when necessary, thereby promoting both economic and environmental sustainability. In future enhancements, Lights will be managed based on motion, ambient light, and temperature sensors for efficient energy use. Machine learning, cloud integration, and smart grid compatibility for further energy optimization. This system offers a cost-effective, scalable solution to improve energy efficiency, comfort, and sustainability in various environments.

CONFLICT OF INTERESTS

None.

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None.

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