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Design and Implementation of an Iot-Based Safety and Energy Efficient System

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The paper provides a safe and power-efficient Internet of Things (IoT)-based solution. With the growing concerns about environmental sustainability and the demand for improved safety measures in today's society, it has become critical to focus on building systems that decrease energy consumption and assure the safety of humans and the environment. The proposed system employs cutting-edge technologies and novel approaches that will result in optimal energy usage with minimal or no human involvement thereby assuring the safety of people. The proposed system leverages on existing IoT technologies and is comprised of smart sensors,

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energy-efficient gadgets, and a centralized control unit. Therefore, it is able to demonstrate cutting-edge power control strategies including power gating and dynamic central power regulation which control the usage of gadgets to operate at optimal power levels vis-a-vis the real-time demand to achieve energy efficiency. The system is also able to collect data on occupancy, lighting, temperature, and power consumption trends which can assist in making data-driven choices that improve the usage of energy. The proposed system provides large energy savings without sacrificing user comfort by dynamically altering lighting, and cooling systems based on occupants and ambient factors. Multiple simulations and real-world trials in homes and institutions' buildings were used to assess the efficacy of the suggested system. The findings revealed substantial reductions in energy consumption without jeopardizing safety.

Keywords: Internet of Things (IoT); EspressifSystem32; Light Dependent Resistor (LDR); Light Emitting Diode (LED).

1 INTRODUCTION

The constant supply of electricity is the driving factor in improving every economy and by extension, the living standards of all citizens in today's world [1]. However, the wastage of electrical power especially in government institutions in Ghana is fast becoming a huge burden, which in recent years has taken a toll on government. Electrical gadgets in most public offices are ofter left on and idle long after working hours. According to the Energy Commission in 2021, [2], electricity generation in Ghana had increased tremendously by more than 70% over the last 10 years, but this does not reflect in the of the Gross Domestic Product (GDP) which has merely doubled. A huge percentage of electricity generated has not been channeled into productive ventures, but has gone waste as a result of negligence and forgetfulness on the part of consumers. In the majority of Ghana's governmental institutions, some employees tend to leave electrical gadgets and other devices on even after working hours or when they are not in use. These behaviors have therefore caused many of these institutions to spend much on electricity and also a contributing factor to the many recorded fire outbreaks in government institutions. The challenges therefore require efforts from both the government and the citizens to reduce energy loss to the barest minimum. This paper therefore seeks to employ Internet of Things (IoT) technology as a means to address challenge of power wastage by consumers.

IoT is a term used to describe the network of physical objects, including cars, electrical appliances that are integrated via sensors, resistors, LEDs etc in other to communicate with one another over the internet for the purpose sharing data. This is to ensure that, these gadgets are able to perform various functions with minimal or no human intervention, [3]. IoT has been used over the years to assure safety and conserve eneregy. For example, using IoT sensors and devices, energy consumption in homes and offices are monitored and controlled to prevent energy wastage, this is done through IoT devices that are able to turn gadgets off remotely when those gadgets are not in use by the users and with monitoring IoT devices users are informed of how the consumption is at a particular point in time. Furthermore, since the introduction of smart grids, information on energy use, supply, demand, and grid performance is gathered via IoT sensors and devices. This information is used to detect places that are using more energy than they should in order to optimise usage. By optimizing energy output in real time, smart grids assist in lowering energy costs and usage. Finally, by altering temperature and lighting systems based on occupancy, the time of day, and ambient temperature, building automation systems that use IoT devices and sensors can improve heating, ventilation, and air Conditioning (HVAC) systems. As a result, building owners save energy and pay less for electricity. The tremendous benefits of IoT show that if explored, it could help to address several problems in the Ghanaian context, [4, 5].

The proposed energy efficient and safety IoT system is structured as an organizational framework with three layers, thus, the perception layer, the network layer, and the application layer. Each of the layers is critical to guaranteeing the overall system's safety and energy efficiency. The *perception layer* consists of a network of a sensor and devices that collect data from the physical environment. The proposed system makes use of a sensor known as Light dependent Resistor (LDR) to determine environmental conditions and trigger a reaction from the system, also, other relevant monitoring devices are employed to help the system perform its basic function which is to ensure energy efficiency and safety. This layer's primary goal is to collect reliable and precise information and deliver it to the network layer for processing. The *network layer* makes the interaction between the perception and application layers easier. It is in charge of safely and efficiently delivering the obtained data while minimizing energy utilization. The network layer's primary component is the ESP32 microcontroller. Additionally, the network layer implements energy-efficient routing algorithms to minimize power consumption. Finally, the *application layer* is the topmost layer of the IoT energy efficiency and safety system, and it is in charge of analyzing and transforming the information collected in order to extract useful insights and trigger necessary actions. This layer comprises various software applications and algorithms tailored to the specific use case of the IoT system. The rest of the paper is organised as follows: Section 2 presents sampled works relating the the proposed system, Section 3 presents the design, methodology and tools employed to develop the systems and some simulated/tial results discussed in Section 4. The paper concludes in Section 5.

2 RELATED WORKS

Many researchers have proposed various schemes for energy efficiency and safety in the use of electrical appliances. The work by [6] proposed the idea of an Arduino-based Intelligent Energy tracking system with a GSM Short Message Service (SMS). The system showcased a design for an intelligent energy meter that decreases the consumption of electricity and provides savings on energy by using a motion detector that instantly transmits signals that switch off the power supply whenever there are no indicators of individuals in the vicinity. However, this system can cause damage to electrical gadgets and can cause a fire outbreak due to how it functions. Also, [7] presented a smart socket as an innovative approach to addressing energy utilization and difficulties. One master and multiple slave sockets were employed in the system. The master socket is made up of Wi-Fi connectivity which manages interconnections between the slave sockets. The slave sockets are less sophisticated and use ZigBee communication to receive instructions from the master and report back power readings. The data produced by the Smart Plug system aids in the analysis and comprehension of real-time power usage behaviors. The smart plug system proposed in the work is very expensive considering that each department needs to purchase and install many master and slave plugs before the needed results are obtained. Another work by [3] designed and implemented an intelligent automation framework that makes use of long-range (LoRa) technologies. The suggested LoRa-based system consists of a wireless communication technology and a variety of sensors, operated by an application for smartphones and powered by a low-power battery, with a range of operation of 3–12 km distance. At the sender's end, the system created a Wi-Fi link between a smartphone running on Android and a microcontroller (ESP32). A LoRa transmitter was attached to the ESP32 module. This system proved efficient for non-line-of-sight transmission, but its main drawback was the loss of data during transmission, especially over longer distances.

The work in [8] sought to design an IoT-based energy tracking system for enhancing energy management levels and reducing energy consumption. By utilizing a database, communication channels, etc., the energy monitoring system (EMS) and IoT are used to gather, transmit, and save a significant quantity of data in power-running processes. The perception, transport, and application layers make up the three tiers of the system's execution. Although this suggested IoT system has some merits over conventional approaches, such as strong feasibility and dependability, it does not appear to have found an answer to consumers' wasteful power use. The work by [9] also proposed a residential power tracking system that makes use of a program that can predict a user's energy costs. The solution that they suggested makes use of an Application Programming Interface (API), which enables the program to access stored information from the hardware unit, forecast the user's energy bill, and send an overview to the user via email each day. From this daily update to the user, he or she will discover how their actions or behaviors affect their energy cost. This technique solely forecasts energy usage using data from the previous seven days' energy use. The technique suggested produces inaccurate findings or forecasts since consumers' daily electricity usage varies depending on a number of variables. Again, [10] designed an intelligent home energy management system based on ZigBee and a PLC-based green energy gateway that takes into account both power consumption and production. The home server collects consumption data, does power estimate evaluations, and regulates the residence's consumption routine. This system concentrates on monitoring the energy consumption of the user but does not assist the user to control the inefficient use of electric power. The work by [11] proposed an internet of Things and GSM cloud-based computing for intelligent power racking which employs a dual communication channel to link the metering network and the customer end. The multiple energy conservation live report is delivered to the user to warn them about power utilities. However, the system does not make attempts to solve the issue of power wastage but only reports on the utilities of the user. This paper therefore seeks to leverage on Espressif System32 microcontroller, Smoke Sensor, Light Dependent Resistor (LDR) among other components and a mobile application to develop IoT-based safety and energy efficient system which offers the user the opportunity to monitor and switch on/off devices remotely when the need arises.

The proposed system, therefore, seeks to help users keep devices off when they are not in use especially when there is no occupant within a room and also address the canker of workers failing to turn off devices in their offices before closing for the day. All these is within the Ghanaian context, first with a localised adoption of the technology which can be scaled up to many areas or sectors.

3 METHODOLOGY

The proposed system is used to control the power consumption of buildings, residences, businesses and most importantly government institutions. The Esp32 microcontroller is configured to allow the user to control the system remotely due to its inbuilt Wi-Fi feature. The proposed system gives the user the opportunity to put on/off any switch, plug, or device in the building with the help of a mobile application with buttons configured to perform these tasks.

3.1 Main Components of the Proposed System

3.1.1 *Espressif System32 microcontroller*:

The Esp32 is the ESP8266's replacement, and it integrates wireless features such as WiFi and Bluetooth. It has a 3.3V voltage control, which reduces the input voltage for powering the ESP32 chip. It also includes a CP2102 chip, which enables the ESP32 to be programmed without the use of an FTDI (Future Technology Devices International) programmer. The ESP32 microcontroller board is employed in the design of the system since it is a more effective and efficient microcontroller board than the Arduino. The ESP32 also includes dual Wi-Fi and Bluetooth connectivity. It can function as both an access point and a Wi-Fi base owing to its Wi-Fi component. It is significantly ahead of Arduino due to its 32-bit microcontroller and clock frequency of up to 240MHz. The Fig. 1 is an example of an ESP32 micro-controller board.

Fig. 1. ESP32 Microcontroller

3.1.2 *Smoke Sensor*:

A smoke sensor, also known as a smoke detector is a device used to detect the odor of smoke in the surrounding area. Its main purpose is to alert individuals, about fire hazards and provide warning of any fires. There are many types of smoke sensors but the MQ2 sensor was adopted for this work. This particular sensor has the capability to detect several gases such as smoke, flammable gases, and other harmful substances. Furthermore, the MQ2 sensor consumes less power making it suitable for battery-operated devices or power-efficient IoT systems like the one proposed in this study. This sensor also has the ability to swiftly detect and respond to gas presence. Operating on a 5V DC power supply and consuming 800mW of energy the MQ2 gas sensor offers a detection range of 200 to 10000 ppm, for LPG (liquefied petroleum gas) Smoke, Alcohol, Propane, Hydrogen, Methane, and Carbon Monoxide. Fig. 2 is an image depiction of an MQ2 smoke sensor.

3.1.3 *Light Dependent Resistor(LDR)*:

An LDR, which is also called a photo resistor or photocell, is a passive electrical component that adjusts its resistance in response to the amount of light it receives. It is a particular kind of resistor whose resistance falls off when light intensity rises and vice versa [12]. Typically, a semiconductor substance with variable conductivity is used to create the LDRs. It consists of a light-sensitive substance deposited on a surface, such as cadmium sulfide (CdS) or lead sulfide (LbS). When light strikes the sensitive material, the resistance of the LDR increases, and reduces when the light intensity rises. Fig. 3 is an image of a Light Dependent Resistor (LDR).

3.1.4 *Bread Board*:

A breadboard is a prototyping gadget that is used to quickly and efficiently build and test circuits without soldering. A plastic board with numerous linked holes organized in rows and columns makes up the gadgets. These holes enable jumper wires to be placed into and linked to the various electronic components. The breadboard is preferred because it does not require any soldering, therefore making the setup faster. Fig. 4 is an example of a breadboard tool.

3.1.5 *Jumper Cables*:

These are Short cables with connectors at each end, used to make transient connections on a breadboard or between gadgets. They are a crucial tool for breadboard prototyping since they make it possible to connect various spots on the board and connect components without soldering. Jumper wires give you versatility when creating and testing circuits because they come in a variety of lengths, colors, and connector types (such as male-to-male, female-to-male, and female-to-female). Because jumper cables are made to fit into breadboard holes and establish a secure and dependable connection between components, they are specifically taken into consideration for this system. Fig. 5 depicts an example of jumper cables.

Fig. 2. MQ2 Smoke Sensor

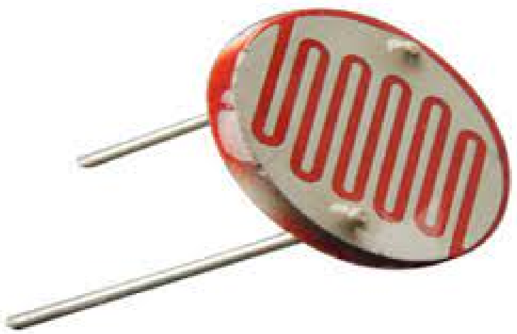

Fig. 3. Light Dependent Resistor (LDR)

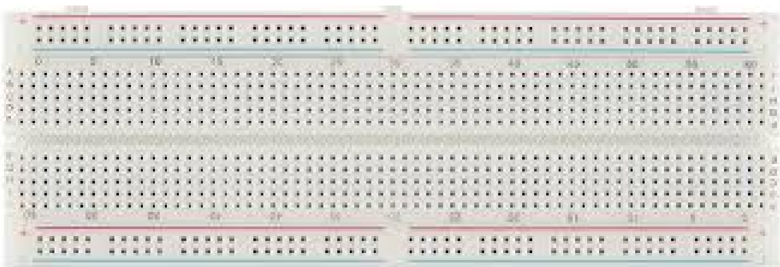

Fig. 4. BreadBoard

3.1.6 *Relay Model*:

Fig. 6 is an image of a relay module. The relay module is an electronic device used to regulate the circuits with higher voltage using control signals with lower voltage. It functions as an electrical switch that makes it possible to manage the circuits that will otherwise be risky or difficult to manage using lower-power control signals from microcontrollers, Arduino boards, or other devices. In order to protect the control circuit and the microcontroller, the module safely separate and control circuits with various voltage and current needs. A 5V control signal from a microcontroller for instance, can be used to turn on/off a 220V household lamp or manage a powerful motor.

3.1.7 *Light Emitting Diode(LED)*:

It is employed to directly transform electrical energy into light. LEDs are a crucial part of the IoT systems because of their effectiveness, dependability, and adaptability. IoT devices frequently use LEDs for a variety of functions, including indicators, display panels, and environmental sensing, they are therefore employed in this paper as indicators. Fig. 7 is an image of Light Emitting Diodes (Led).

4 SYSTEM IMPLEMENTATION

The proposed scheme utilizes a combination of devices namely the ESP32 microcontroller, smoke detecting sensor and the LDR sensor to achieve this objective. The EPS 32 microcontroller serves as the central controller of the system. This system also make use of the smoke detecting sensor for detecting the presence of smoke or gases of different kind and then communicate to the user by turning on the LED automatically so that evacuation the office or the needed action could be taken. The LDR sensor is utilized for determining the state of the atmosphere and controlling the security lightening of the office accordingly. A mobile app is built to enable the systemadministrator control the system from a remote location via a mobile device. That is, turning security lights ON and OFF and also control devices and sockets remotely. The Espressif System 32 (Esp32) is programmed using the C++ programming language. The Arduino IoT cloud development platform was also used to create the mobile application. Fig. 8 is the flow diagram of the proposed scheme.

The proposed scheme was simulated using C++ on a core i3 processor running on 8GB RAM. The LDR analyses the environment and reports to the ESP32 to either turn security lights on or off based on the report received. It can be noticed from Fig. 9 that the LED remains off, indicating that the LDR reported daylight to the ESP32 board whiles in the case of Fig. 10, the LDR reported darkness to the board by turning LED on which eventually triggers the security lights on by the ESP32 board.

5 RESULTS AND DISCUSSION

The results from the simulation of the proposed scheme were analyzed based on standard metrics of security and safety, failure rate and latency.

Fig. 5. Jumper Cables

Fig. 6. Relay Module

Fig. 7. Light Emitting Diode (LED)

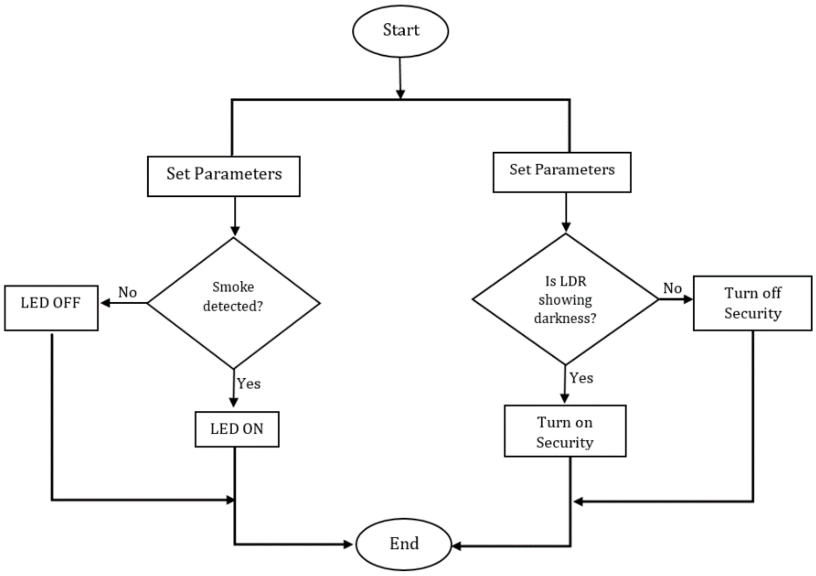

Fig. 8. System Module

5.1 Security and Safety Evaluation

The system constantly monitors the surroundings and responds accordingly by either switching on or off the security lights based on the condition of the atmosphere. Additionally, the proposed system has the capacity to monitor and report on devices that are not in use but have been left on for an extended period of time so that they can switched off from a remote location. Again, the proposed system is built to monitor and report any form of smoke detected in and around the premises so that the necessary action can be taken. Therefore it can be concluded that the system is effective in improving safety and security.

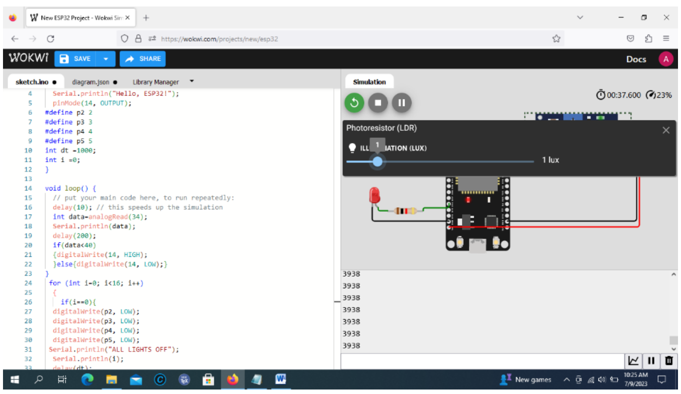

Fig. 9. When the day is bright

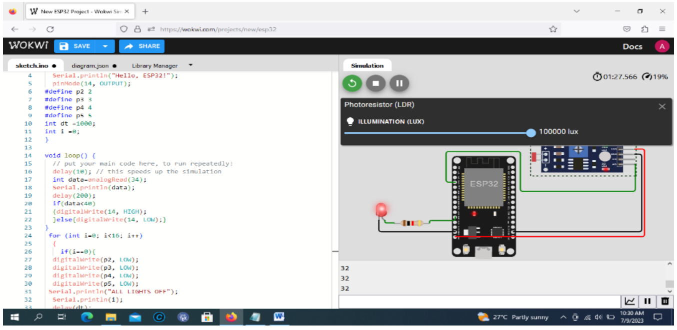

Fig. 10. When the day is dark

5.2 Failure Rate Analysis

A system's failure rate is the number of failures that occur during the course of a particular period, divided by the total period of operation for the system [13]. This can represented mathematically as;

$$FR = \frac{NF}{TP}, \tag{5.1}$$

where *NF* is the number of failure recorded recorded and *TF* is the time period. The lower the percentage of the failure rate the more robust the system and vice versa. The proposed system recorded 2 failures in seven days, thus, (a week) of its operation which represents a failure rate of 0.28, indicating that system is much more reliable.

5.3 Latency

Latency refers to the time taken from the beginning of a request from a client to the server to return response back to the client. It can also be referred to as the time lag between a command or data transmission and the matching response or action from the Internet of Things devices or networks [4]. An energy-efficient Internet of Things (IoT) system's latency has a significant impact on both its overall functionality and ease of use. The proposed system recorded a latency of 10 milliseconds, due to direct device-to-device communication, which allows for the quicker response times by removing the need for centralized servers.

6 CONCLUSION

The paper presented an IoT-enabled system developed locally for monitoring the usage of power and where necessary conserve energy with safety. Thus, the main purpose of the proposed system is to increase energy efficiency and ensure safety in a variety of situations, including workplaces, households, and industrial settings. The remote control capabilities of the system affords individuals the opportunity to remotely control gadgets, which further saves energy, and prevents the likelihood of a fire outbreak as result of power triggers.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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