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Arduino-Based Motion Light Controller for Energy Consumption Optimization

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Competing Interests.

The authors declare no competing interests.

ABSTRACT

The rise in electricity usage globally is of major concern. Specifically, Nigeria's electricity demand overrides the country's rapid population growth. Unfortunately, and despite the advancement of technology with regards to electricity in other developed and developing nations, electricity remains one of the most wasted and mismanaged resource in Nigeria. Contemporarily, the reliance on technology is tailored towards getting things done in a faster and more convenient manner. The frightening rate at which electricity is consumed necessitates the development of efficient ways to address this issue. Thus, in response to the pressing challenge, this paper aimed at building and implementing an automated lighting control system based on a microcontroller. The Arduino UNO board is the most significant component of this study; it holds the code created in the Arduino IDE, which controls the activities of the other modules linked to it. The board was connected to a Passive Infrared (PIR) sensor and a relay module. This sensor detects heat waves emitted by humans, while the relay module allows the Arduino to control large electrical loads. In conclusion, this technique will help to extend the life of light bulbs, thereby saving money, lowering monthly electricity bills, and lowering overall electricity use.

Keywords: PIR sensor, Arduino IDE, Microcontroller, Arduino UNO board, Lighting control system, Electricity, Energy consumption optimization

1. Introduction

1.1. Overview

The rise in global electricity usage is of major concern. Nigeria is the most populated country in Africa and the seventh most populated country in the world, according to Internet World Stats (2020). Thus, as the nation experiences growth in population, it is expected that there would be increased demand for power so as to meet the needs of the populace. The demand for electricity in Nigeria regularly outpaces the country's population growth [1]. Thence, with the rapid advance in technology as well as the ever-escalating population in Nigeria, it is pertinent to state that electricity is gradually becoming a general necessity, especially as basic daily activities cannot operate efficiently without it. Despite its high value, electricity remains one of the most squandered resources in some developing nations. Specifically, as observed by literature, in countries such as Nigeria, lights are frequently left on in vacant classrooms, offices, and residences for long periods of time. Consequently, due to a lack of conservation policies and a failure to educate residents about the importance of energy efficiency, around forty-five percent (45%) of electricity generated is squandered [2, 3]. Thus, a system for properly controlling the use of lights is required.

Advancement in modern technology posits a significant impact on lifestyle, while at the same time, has resulted to progress in the environmental concerns which poses threat to residents. Over the years, there has been a rise in environmental dilapidation, which is now a reality hinged on various factors [4, 5]. In Nigeria, it has been revealed that electricity consumption is not managed properly, thus leading to waste of energy generated via electricity. Sadly, electricity is still a major concern in Nigeria, as there is no constant supply of electricity in the nation. Thence, novel ways in which electricity can be managed and conserved properly via technology could help enhance more power supply in the nation. According to Ogbeide-Osaretin [6], the increase in poverty level is responsible for energy sources dependability at the least

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segment of energy consumption by majority of the Nigerian population. Their work alongside other scholars recommend government and stakeholders in formulating policies which can help foster modern energy sources usage targeted at reducing the health and environmental risk of using traditional energy, coupled with ensuring improvement in human life quality [3, 6-8]. Thus, a novel technique via an Arduino UNO board to build and implement an automated lighting control system based on a microcontroller can be deemed useful in solving energy consumption problems both in Nigeria as well as other developing nations. This technique will help to extend the life of light bulbs, thereby saving money, lowering monthly electricity bills, and lowering overall electricity use.

Embedded systems are used to operate many devices today; they are usually dedicated to a single task and can be adjusted to minimize size, cost, as well as boost reliability and efficiency. Many electrical household appliances have benefited greatly from embedded systems [9, 10]. With the use of embedded systems, it is now possible to solve the problem of excessive electricity consumption by automating light control without the involvement of humans. This is beneficial because there is no need to be concerned about electricity waste since the lights are turned down automatically when no one is detected in the room. This extends the life of the light bulbs, saving money and lowering monthly electricity bills.

There is extant literature that have proposed ARDUINO based solutions in engineering and electrical fields, however, there is a gap as regarding how this embedded system can be used in motion light controlling with the aim of optimizing energy consumption. Advancement in technology has of recent improved smart home systems ubiquity, thus leading to a more appreciated living standard [11]. More so, there are still affordability issues linked to commercial automated home systems, which is common among the majority of families in the average and low-income earners. Nevertheless, the emergence of very affordable microcontrollers such as the Arduino, has helped in enabling a smooth and cost-effective implementation of affordable smart home systems [11-16], thence integrating most of the existing features associated with commercial systems.

Furthermore, due to the rise in the global deployment of cellular networks [17], alongside the recent emergence of the 5th Generation technology, popularly known as the 5G network, it is obvious that there seems to be some accompanying problems; two of which includes energy cost of running mobile networks, as well as the hazards caused to the environment. Thus, there is a high rise for novel solutions that can help curb the consumption of energy as well as ensure appropriate conservation of energy. Corroboratively, developing countries are on the high side of facing the derivation of unreliable power grids from non-renewable resources. Thus, they are compelled to rely only on power generated from gas-powered generators or diesel, which eventually leads to increase electricity operation cost as well as caused pollution [6, 10].

A brief background regarding previous works on consumption of electricity, embedded systems, and related works is presented as follows:

A. **Consumption of Electricity:** According to the International Energy Agency, global average energy use per person increased by 10% between 1990 and 2008. In 2008, total global energy consumption amounted to about 132,000 TWh, with energy consumption in Africa increasing by 70% [2]. However, Nigeria's overall electricity usage is 24.72 billion kWh per year, according to World Data Info. This equates to an average of 123 kWh per person. Furthermore, the Nigerian Power Regulatory Commission (NERC) recently increased domestic electricity tariff prices from 30.23 Naira to 62.33 Naira per kWh, effective September 1, 2020. With this rise, purchasing electricity will be more expensive, and if not properly utilized, consumers may suffer significant losses. Humans need energy to achieve various tasks on a daily basis and its importance cannot be overemphasized [18, 19]. Energy plays a very essential role in bettering productivity, income as well as competition via supporting industrial investment facilitation, alongside productive activities, agriculture, and commerce [2, 20,21,22].

A study by Adamu, Adamu [3] revealed that based on the energy ladder theory, a series of

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closely interrelated socio-economic factors which is responsible for the transition of energy as well as the level to which such factors are effective, actually vary across countries. Thus, it has been recommended that government alongside relevant stakeholders in the energy sector should adopt and implement cost-effective measures of optimizing energy consumption in Nigeria, thereby ensuring proper usage of electricity as well as maintaining cleaner energy [3, 5, 6]. Figure 1 illustrates the energy consumption rate in Nigeria per annum (1980-2016).

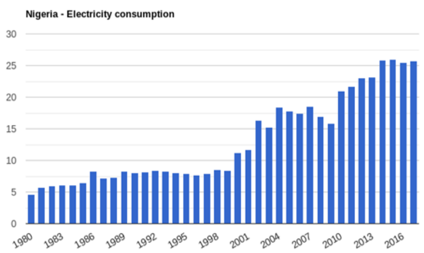

Figure 1: Annual electricity consumption rate in Nigeria (1980-2016)

B. Embedded Systems

Properties such as real-time processing, low power consumption, low maintenance, and high availability, makes smart lighting systems to be considered as embedded systems, and embedded systems play a significant part in IoT. An embedded system is a sort of computer system that executes a set of pre-defined programs and is typically utilized as part of a larger electrical or mechanical system [10]. It usually starts with simple MP3 players and progresses to more complicated hybrid car systems [24]. Embedded systems are not standalone devices; instead, they are frequently employed as part of a larger, more complex equipment. For small size devices, a graphical user interface is not required. The major distinction between a computer and an embedded system is that a computer may do many jobs that are defined by the user. However, an embedded system is utilized to fulfil a certain duty that has been pre-defined by the producers. Interestingly, one of the most significant features of an embedded system is that it must adhere to all real -time limitations [9, 25].

C. Related Works

Hwang and Yu [26] developed a remote monitoring and control system via a Java Media Framework (JMF), which is a multimedia extension API for Java that is used to perform real-time monitoring. The researchers performed their experiment by the use of the Zigbee network. Corroboratively, Alex and Starbell [27] constructed a system aimed at reducing the power consumption rate of streetlights by around 30% when compared to previous designs. This method is completely automated and does not require any human intervention. It also makes use of ZigBee to allow the control station in monitoring the system's functioning. Kim, Lee [28] developed a smart LED light system that incorporates both infrared and ultrasonic sensors. The authors' approach was to continually monitor human motion, with the output data from the sensors determining the smart LED light's On/Off state. Despite the amazing contributions by previous researchers in developing embedding systems to solve various energy issues [19, 21, 29], most of the existing systems, were unable to continually verify the motion of an object by using each sensor separately, thus a gap which the current paper addresses via the Arduino component. Furthermore, the proposed technology employs a PIR sensor that transmits data to an MCU board, which then transmits the data to the LED control layer.

Subramanyam, Reddy [30] developed a model which provides a smart street lighting system powered by solar energy. Apart from managing and monitoring lamps, the system also provides security for late-night workers. The smart light system adopted the ZigBee technology and provides a user interface for controlling and monitoring streetlights. Solar panels, LDRs, and IS sensors are used in the system, which helps to cut power usage and costs. The developers designed this device to operate in two modes: automatic and manual. When the system is in auto mode, the LDR is used to turn on and off the lights. The LDR senses light intensity and controls the light through relays. In a recent review focused on solar usage in Nigeria, the authors informed that due to the large population of Nigeria, there is a need of vast energy for sustenance [17]. This of which has resulted to overdependence on natural gas and crude oil

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for energy. It was also revealed that such overdependence has placed the country in a constant energy consumption crisis when such resources are unavailable [2, 7, 31]. However, though solar energy might be a kind of solution to power consumption issues, yet it has its disadvantages as it is prone to affect the climate change. Notwithstanding, the cost of acquiring a solar system is not affordable for the average Nigerian population. Thus, there is still a need to introduce more practical and cost-effective systems that can help in energy consumption optimization so as to save more energy and avoid solar combustion.

Consequently, Raj and Khan [32] attempted to save energy and observed that smart networks can help monitor energy usage in DC electrical equipment. Lamps are powered by AC, although LEDs can be powered by DC. Using the right protocols, these lights can also be dimmed. The scientists also claimed that replacing standard bulbs with LEDs can save more than 44% of energy. Magno, Polonelli [33] developed a low-cost, sensor-based smart lighting system that uses a PIR sensor. The use of LEDs in this lighting system allows to manage light intensity and reduce power usage [2, 12]. When impediments are detected, the brightest light can be dimmed using a PIR sensor. According to the authors, the system's greatest benefit is the exchange of energy and power. Corroboratively, Alex and Starbell [27] developed a GSM-based remote-control system that was integrated with a ZigBee network of devices and sensors to build an Intelligent Street Lighting System. It was developed using wireless technology and a network of sensors for simplicity of maintenance and control of the system. LED lamps are used in the system, which helped in saving energy while also increasing the bulb's light span. Moreover, in a recent study, Zou, Pan [19] began by analyzing system performance, which included the system's throughput and transmission time. They discovered that high transmission power was the cause of neighbor channel interference, and that when transmission power is increased, the improvement in throughput decreases. They also considered various communication characteristics and requirements of several light control systems. All of these actions aided them in learning and comprehending the controller's capabilities.

In a study which focused on solving the challenges of energy wastage in the lighting of China offices, the authors made use of Arduino as a major controller alongside an infrared inductive sensor and a light sensor with the use of Wi-Fi network for communication [12]. The study proposed the realization of office lighting environment detection as well as solving issues of fixing adjustments of office light. Maksimovic [34] developed a system that monitored and determined the existence of fire in a building, demonstrating the Raspberry Pi's capabilities in home automation. They also built a prototype sensor Web node on the Raspberry Pi, based on RESTful services, with the goal of developing a system that uses fast critical event signaling and remote access via the Internet to detect data using Fuzzy Logic. The authors asserted that integrating the offered technique with the Raspberry Pi allows for an infinite number of sensor node applications.

Similarly, Ferdoush and Li [35] built a wireless sensor network system employing Raspberry Pi, xBee, Arduino, and other open-source software applications. The system features comprise good packaging, low cost, scalable, and easy to adjust requirements, easy maintenance, and easy distribution. It is important to note that the possibility of these features is because the gateway node of the Wireless Sensor Network, database, and web server are all integrated into a single Raspberry Pi. Corroboratively, Baraka, Ghobril [36] built and implemented a smart home that was both energy efficient and remotely controlled using home automation techniques. This smart home was designed to provide protection and comfort to its residents, and it had sensors and actuators that collected data from the house environment in order to operate it. The authors used an Arduino microcontroller to communicate with an Android application that served as the user interface. The house was networked with wireless ZigBee and wired X10, resulting in a cost-effective solution.
Though, the past works that focused on Arduino for several issues such as smart home, street lighting management, object monitoring, mobile health application, amongst others revealed that it is cost

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effective and promotes clean energy [11-14, 37 -39], yet little is known on how it can be used in managing electricity as well as optimizing energy consumption, especially in Nigeria.

2. METHODOLOGY

This section discusses the methodology of the research, stating and describing the hardware requirements, software requirements, system requirements, architectural design as well as the working procedures in this project.

The proposed system's block diagram is presented in Figure 2 below; the system is supposed to turn on lights when the PIR sensor detects motion and switch them off when no motion is detected.

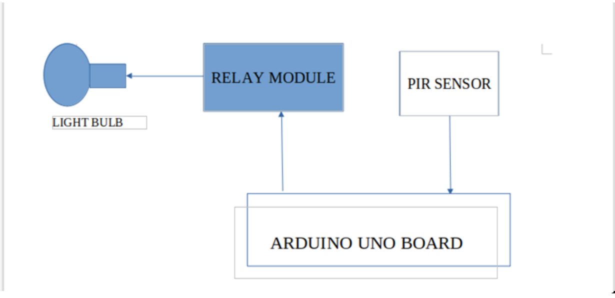

Figure 2: Block diagram of the proposed system

2.1 Hardware Requirements

Arduino UNO , PIR Sensor
5V Relay Module (Relay Board) , LED
Jumper Wires , Power Supply

2.2 Software Requirements

Arduino IDE

The Arduino board is the most important part of this project design; it stores the code that controls the actions of the other modules connected to it. It is coupled with a PIR sensor; PIR refers to Passive InfraRed, and this motion sensor consists of a Fresnel lens, an infrared detector, and supporting detection circuitry. More so, it uses a relay module, a switch that is controlled electrically, which can be turned off or on, thus allowing current to either pass through or not. The relay module basically enables the Arduino board to control big electrical loads.

2.3. System Requirements

The main goal of this system is to save cost and reduce energy usage. The requirements can be either functional or non-functional. The functional requirements are the requirements that define a system or component function. Non-functional requirements are those that define criteria used to evaluate a system's functioning rather than its specific behavior.

Table 1 presents the specification of components for the proposed system.

Table 1: Specifications of components for the proposed system

COMPO-NENTS	SPECIFICATIONS
Arduino UNO	Operating voltage: 6 - 20V; 22 pins
PIR Sensor	Voltage: 5V, Range: 2m–7m; Angle: 110°
Relay Mod-ule	Operating Voltage: 2500W
LED Light	Voltage: 5 W

3. Architectural Design

The overall framework of this embedded system is the architectural design, which was utilized to guide the construction of the lighting system. Figure 3 illustrates the proposed system architectural diagram.

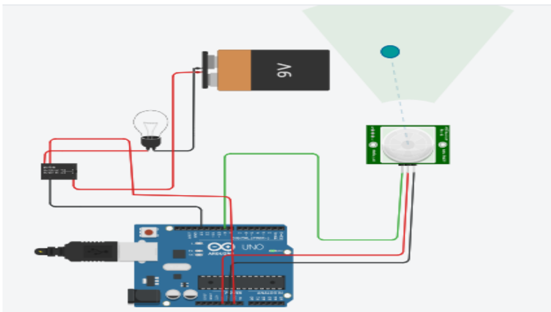

Figure 3: Architectural Diagram of Proposed System

Data Flow Diagram

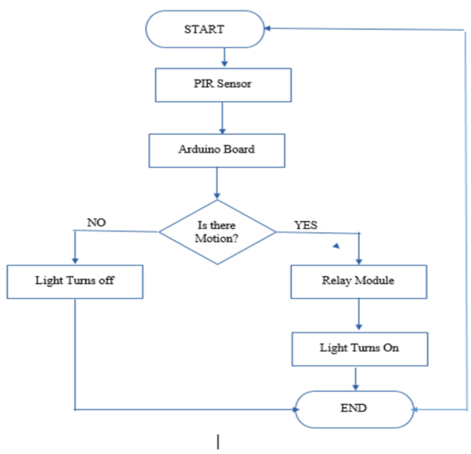

Figure 4: Data Flow Diagram of Proposed System

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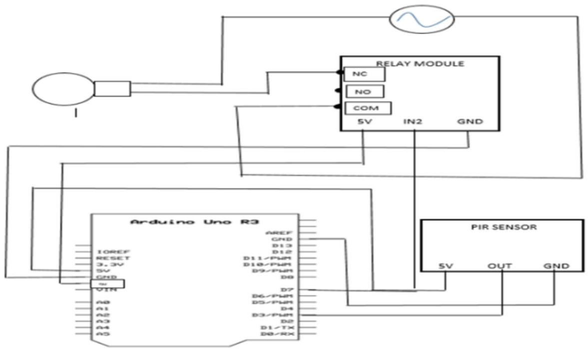

Figure 5: Circuit Diagram of the Proposed System

From Figure 5, the data OUT pin (Output) of the PIR Sensor is connected to Arduino's digital I/O pin 3 in this circuit design. The VCC pin of the PIR Sensor is then linked to one of the Arduino's 5V pins, and the ground pin of the PIR Sensor is connected to one of the Arduino's GND pins.

This experiment employed a two-channel relay module, however only one of the channels was used because only one bulb was being controlled rather than two. The relay connects the bulb to the mains supply. One of the bulb's terminals is connected to one of the mains supply wires. The other terminal of the bulb is linked to the IN2 relay module NO (Normally Open) contact. The relay COM (Common) contact is connected to the other wire of the mains supply.

The relay module's IN2 pin is wired to Arduino's digital I/O pin 7. The VCC pin of the relay module is linked to one of the Arduino's 5V pins, and the ground pin of the relay module is connected to one of the Arduino's GND pins.

Working Procedures

The following phases will explain the working practices for developing this system.

The data OUT pin (Output) of the PIR Sensor was linked to the Arduino's digital I/O pin 3.

Next, the VCC pin of the PIR Sensor was connected to one of the Arduino's 5V pins, and the ground pin of the PIR Sensor was linked to one of the Arduino's GND pin.

The relay was used to connect the bulb to the mains supply. One of the bulb terminals was linked to one of the mains supply wires.

The bulb's other terminal was connected to the IN2 relay module's NO (Normally Open) contact.

The relay's COM (Common) contact was linked to the mains supply's other wire.

The relay module's IN2 pin was linked to the Arduino's digital I/O pin 7.

Next, the VCC pin of the relay module was connected to one of the Arduino's 5V pins, and the ground pin of the relay module was linked to one of the Arduino's GND pins.

The compiler verifies the Arduino IDE written automated lighting software before uploading it to the Arduino board's microcontroller.

4. RESULT S

A lighting automation system prototype was created. Figure 6 depicts the entire prototype design. The Arduino board and the primary power source were connected to all the wiring and connections. The PIR sensor was additionally calibrated to change its timing from 5 seconds to 1 minute, as well as the range from 2m to 5m.

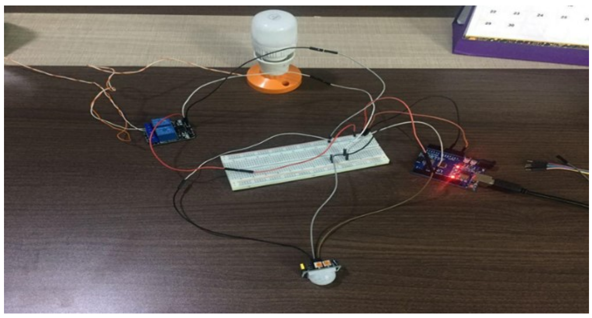

Figure 6: Prototype of the Proposed System

As seen in Figure 7 below, when a person enters the range of the sensor, the light turns on and stays on for nearly a minute instead of 5 seconds before turning off. Moreover, the sensor sensitivity has also been improved, and it can now detect motion from a distance of up to 5 meters.

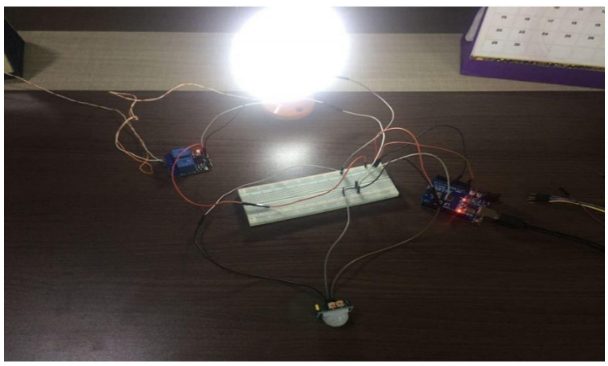

Figure 7: Condition when motion is detected

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However, when the PIR sensor detects no movement, the lights remain turned off. Figure 8 demonstrates this. The system will thereafter return to the initial state.

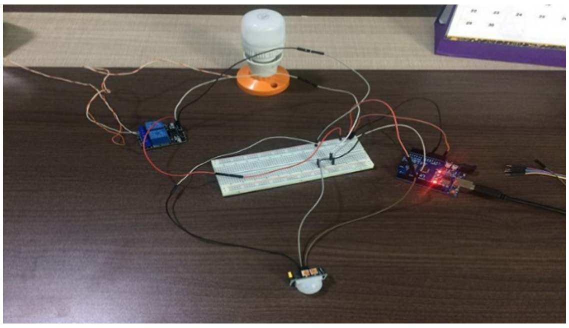

Figure 8: Condition when no motion is detected

5. DISCUSSIONS

Thus, the lighting system can be constructed using LED lights instead of the traditional filament bulb, which consumes energy, as well as save maintenance costs and extend the life of LED bulbs, because the lights are turned on and off automatically, a significant amount of energy can be saved.

In comparison to previous systems, this is less expensive, easier to install and maintain, and more efficient. It also has more versatility than existing systems in the market, as new modules and components may be added in the future. Advancement in technology has of recent improved smart home systems ubiquity, thus leading to a more appreciated living standard [11]. Thus, relative affordability issues connected to commercial automated home systems is prevalent mostly among average and low-income earners. Notwithstanding, the emergence of cost-effective microcontrollers such as the Arduino as proposed in this study and others in literature has helped in enabling a smooth and cost-effective implementation of affordable smart home systems [11-16], thence integrating most of the existing features associated with commercial systems. Most of the previous systems designed specific Arduino based systems, however the work proposed in this paper can be used in several places. The study also has some limitations despite its novel contribution, thus fostering the drive for future work. The motion detection range of the PIR sensor is limited. Thus, small things, such as bugs, may be missed by the PIR sensor. Unwanted objects may trigger the motion detector; for example, a motion detector placed outside may be constantly triggered by bugs and other small objects. Some PIR sensor devices have a short shutoff (timer) (such as 30 seconds), therefore, if more "on time" is needed, it is preferable to get a model with an adjustable timer. Environmental elements such as fireplaces, heaters, and even direct sunshine may also affect the PIR sensors.

Future Work

Because of the adaptability of the microprocessor employed, the system is significantly more scalable. As a result, further modules and components can be simply added in the future to meet the needs of a larger scale of consumers.

6. CONCLUSION

The main goal of this paper was to reduce electricity consumption in offices, homes, schools, and other locations by designing a simple system that will help control lights, thereby increasing the lifetime of light bulbs and lowering monthly bills, as well as reducing the stress on people who have to go around the entire building switching off lights. The architectural concept of a lighting system was successfully realized in this study utilizing the Arduino UNO microcontroller and the associated hardware and software. When the PIR sensor detects motion, the system turns on the lights, and when no motion is detected, it turns them off. The proposed system has also been tested in real world situations and may be tested on a wider scale in the near future. Also, it can be simply deployed in places where light is required only when people are present, such as restrooms, toilets, corridors, balconies, garages, among others.

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