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Building Energy Utilization with LED Lighting and Occupant Sensing System

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Abstract: ***Building Energy management systems (BEMSs) are needed to monitor and regulate energy consumption in buildings, thus, contribute in reducing the environmental challenges facing our planet. A new energy saving method based on BEMS is proposed in this paper. The proposed method is a smart LED lighting system based on an Arduino microcontroller, a simple motion sensor, and a camera. A complete design and implementation of the smart lighting system is presented in the paper. In addition, the proposed smart system is validated in the paper under various experimental conditions. The results show that simple installation of commercially available motion sensors and cameras can contribute significantly to reduce the electricity bill and*** CO_2 ***emission.***

Keywords: Energy; Buildings; Energy Management System; Smart Lighting System.

I.INTRODUCTION

Building environments are an essential part of our daily lives, since people spend an average of 20 hours per day inside buildings [1]. However, today's buildings consume a lot of energy and contribute significantly to carbon dioxide emissions[2]. According to literature, buildings are responsible for one-third of carbon emissions, and they consume about one-half of global electricity and one-third of global energy [3]. Therefore, there is a real need for effective strategies to reduce energy consumption in buildings [4]. In buildings, lighting systems account for a large part of the world's total energy consumption. According to [5], it accounts for roughly 20% of the electricity consumption. Therefore, it is important to develop new strategies to reduce the demand for energy used for lighting while simultaneously maintaining the illumination comfort of buildings occupants. Using Light Emitting Diode lamps (LEDs) is one possible strategy to reduce both energy consumption and energy cost. The LED lighting device consumes only 50% of the energy consumption compared to the fluorescent lighting device.

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LEDs have special features like power saving, environmental friendliness, dimmable and multi-color features of solid state lighting system. However, the replacement of traditional light bulbs by the LED will not provide a high energy saving; as the rate of saving depends also on lighting usage pattern. For example, illumination of unoccupied spaces is a form of energy wastage[6].Thus, it is recommended to use occupancy sensing strategy, which is a modern technology that senses the occupancy through a number of distributed sensors that operate based on different detection methods (motion, vision,..etc.) [7].

Several studies have demonstrated that occupancy information can play a vital role in reducing the energy consumption of lighting systems in buildings [8–10]. According to [11], use of occupancy information in controlling lights' operation reduces electricity consumption by 24%. As a result, most recent studies have focused on saving the greatest possible amount of energy by using high-efficient LEDs coupled with smart lighting control system based on occupancy information [12,13]. In this paper, a smart LED lighting system based on an Arduino microcontroller, a simple motion sensor, and a camera is proposed. A complete design and implementation of the smart lighting system is presented in the paper. In addition, performance of the proposed system was tested through a number of lab experiments under different occupancy conditions, which should be an accurate indicator of the system real-time performance. Furthermore, a cost analysis is performed on proposed system to quantify its impact on the energy saving.

II.MATERIALS AND METHODS

In this paper, multiple different sensors are combined to achieve greater energy savings. Combination of an efficient energy appliance together with an occupancy detector and vision based technology is proposed for low cost and low energy consumption. The following subsections present the main components used in the experimental prototype of this paper.

Light-Emitting-Diode (LED)

Common methods for reducing energy consumption include the adoption of new light technologies, for example LEDs, along with the automatic control of their operation depending on the occupancy status. LEDs working principle is based on passing an electrical current through a microchip, which illuminates the tiny light sources we call LEDs, and the result is visible light. A photo for a LED is shown in Fig.

In comparison to Incandescent Light Bulbs (ILBs) and Compact Fluorescent Lamps (CFLs), LEDs have many advantages; including higher energy efficiency, lower energy cost, lower environmental impact, and higher light output. These advantages are compared in numbers in Table. Recent research reports highlight that, LEDs have almost two times better efficiency compared to CFLs and eight to ten times more efficient than ILBs [14]. In addition, in comparison to incandescent bulbs, LED has longer life span, less heat, and higher brightness.

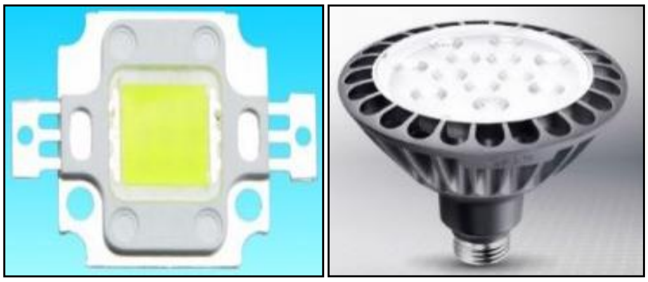

Fig. 1 Light-emitting-diode (LED)

Table. 1 Comparison chart of LED Lights vs. ILBs and CFLs [15]

	Factor	LEDs	ILBs	CFLs
Energy Efficiency and Energy Cost	Life span (average) (in hours)	50,000	1,200	8,000
	Watts of electricity used (in W) (equivalent to 60 watt bulb)	6-8	60	13-15
	Kilo-watts of electricity used (in kWh/year) (30 incandescent bulbs per year equivalent)	329	3285	767
	Annual operating cost In ($/year)	32.85	328.59	76.65
Environmental Impact	Contains the TOXIC Mercury	No	No	Yes
	RoHS compliant	Yes	Yes	No
	CO_2 Emissions (in pounds/year) (30 bulbs per year)	451	4500	1051
Light Output	Lumens		W	
	450	4-5	40	9-13
	800	6-8	60	13-15
	1,100	9-13	75	18-25
	1,600	16-20	100	23-30
	2,600	25-28	150	30-55

Passive Infrared (PIR) Motion Sensor

Occupancy sensors are sensing devices used to enable the control system to switch off the lights when not required. They operate on the principle of motion detection and have to be managed as per their sensitivities. The most common device for motion detection is called Passive infrared (PIR) sensor. Its working principle is based on sensing the changes in the surrounding infrared radiation and converting these changes into electrical signals that can be read by microcontrollers. If an object passes in the field of sensor view, the infrared radiation changes due to the temperature difference between the background and the object, and this change is converted into change in sensor output voltage. The sensor has two sensing elements connected in a voltage bucking configuration. This arrangement eliminates any signals resulting from any change in the infrared radiation due to conditions other than movements of objects, such as vibration, temperature changes, and sunlight [16]. This is because the change in the infrared radiation resulting from these conditions is symmetric in both sensing elements and therefore the resulting difference in voltage is zero. In the case of passing objects, the change in the radiation is asymmetric, resulting in a difference in voltage, which is used as an indicator for occurrence of movement in front of the sensor [10,17]. A photo for a HC-SR501PIR Sensor is shown in Fig.

Fig. 2 HC-SR501PIR Sensor

Acer Crystal Webcam

Imaging sensors using web camera technology and image processing techniques are increasingly being adopted for detecting the occupancy, given their advantages as being cheap and able to store captured scenes [18–20]. Vision-based detection system is based on the principle of capturing and processing a series of video frames, comparing these frames to determine the stationary background and separate it, and then identifying the passing object in the camera field of view. By tracking the object locations on the frames, the movement is detected and the occupancy is discovered. For simplicity, this project has utilized a laptop Webcam for occupancy detection; it is Acer Crystal Eye webcam having a 1.3 megapixel CMOS lens, capable of up to a 1280 x 1024 resolution. This camera is capable of capturing images and videos with high accuracy and clarity. A photo for a laptop with Webcam is shown in Fi.

Fig. 3 Laptop with the webcam

Arduino Uno

Arduino Uno is an open-source programmable circuit board developed by Arduino and based on 8-bit ATmega328P microcontroller. It has 6 analog inputs, 14 digital input/output pins, a USB connection, a 16 MHz quartz crystal, a power jack, an ICSP header and a reset button. It also has an integrated development environment (IDE) for writing, compiling, and uploading codes to the microcontroller [21]. A photo of Arduino-UNO board is shown in Fig[22]. In the smart lighting system, the Arduino microcontroller controls operation of LED lamps based on feedback signals received from the PIR sensor and the camera.

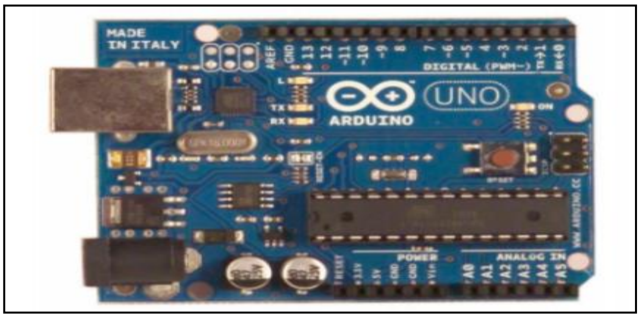

Fig. 4 Arduino Uno board

Principle of Operation

The operating principle of smart lighting system proposed in this paper is explained in Fig. 5. As indicated in the figure, controlling the LED on and off is done based on the occupancy status. Initially, when the webcam and the PIR sensor do not detect any occupancy, their OUT pins stay LOW. As the person enters the room, a detection occurs due to either the change in the scene in front of the webcam or due to the change in infrared radiation in front of the PIR sensor. As a result, the output of their pins becomes HIGH. These pins are connected to the inputs of the Arduino, and based on the code if either of the inputs is high, Arduino will send a signal to the MOSFET to turns on the LED. The occupancy is checked every seven seconds to make sure the occupant is still there to keep the LED in operation, otherwise the LED is automatically switched off.

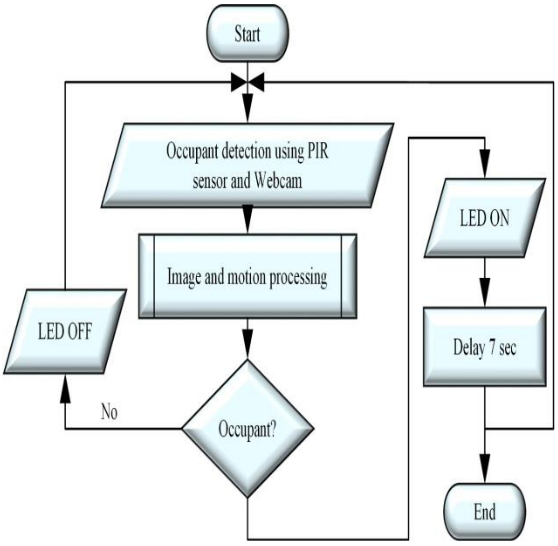

Fig. 5 Operating principle flowchart

Design of Experiment Setup

The schematic diagram and the photograph of the experimental prototype are shown in FigandFig, respectively. As shown in the figures, the main components of the prototype are Arduino Uno microcontroller, RIP motion sensor, LED and power semiconductor switches (Transistor and IGBT). Controlling the LED on and off is achieved through controlling the signals sent from the microcontroller to the MOSFET and transistor switches. The specification of the components used in the experiment are explained in Table.

Table. 2 Characteristics of hardware components used in the experiment

Component	Characteristics
Controller	Arduino Uno
Motion sensor	HC-SR501 RIP sensor
LED	10Watt, high power
Resistor	10 kΩ, 0.25 Watt
Camera	Acer Crystal Eye webcam, 1.3 megapixel

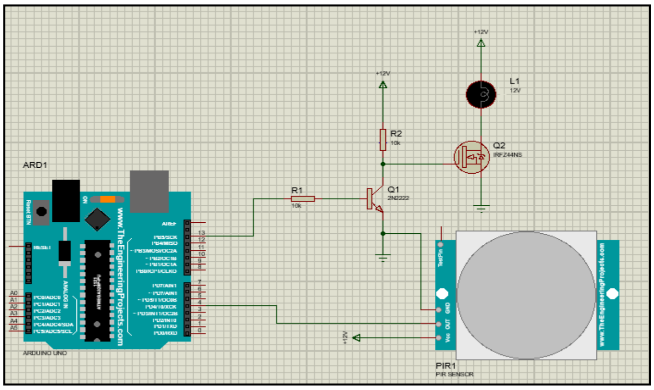

Fig. 6 Schematic diagram using Proteus

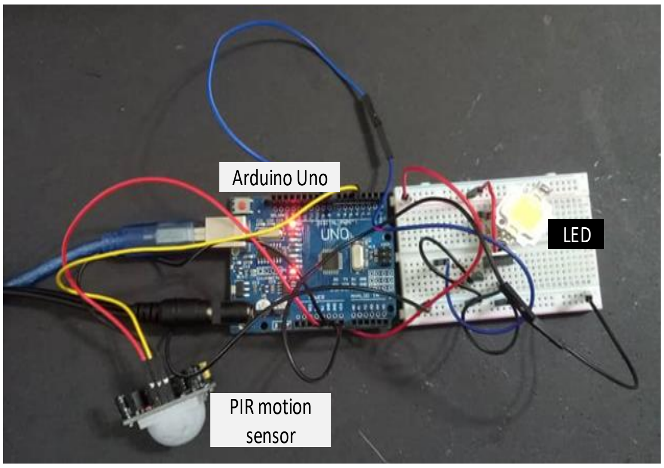

Fig. 7 Prototype wiring connection

III.RESULTS AND DISCUSSIONS

According to the goal set, the main idea of this paper is to implement a smart energy-saving lighting system.

This smart lighting system operates only if there is an occupant in the place and the lights remains lit as long as the occupancy continues. The lights automatically turn off if there is no occupancy for about 7 seconds, and this time delay can be changed as desired by the user and as programmed in the code. Four cases were tested in the experiment to check the performance of the proposed system. In the first and second cases, the system was tested by detecting the occupancy through the Webcam. A face was exposed into the Webcam in the first case, as shown in Fig(a). The system was able to detect the occupancy and switch on the LED. As soon as the face disappeared from the Webcam and after the 7 seconds specified delay, the LED was automatically switched OFF, as shown in Fig(b).

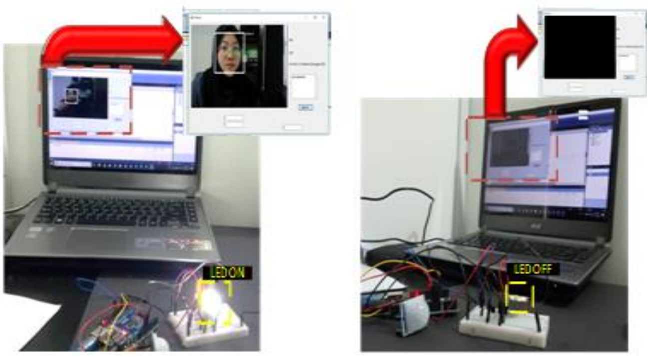

Fig. 8 (a) LED light ON when the camera detects faces, (b) LED light OFF when camera do not detect faces

In the third and fourth cases, the system was tested by detecting the occupancy through the PIR sensor. A motion was occurred in front of the sensor in the first case, as shown in Fig(a). The system was able to detect the occupancy and switch on the LED. As soon as there was no motion and after the 7 seconds specified delay, the LED was automatically switched OFF, as shown in Fig(b).

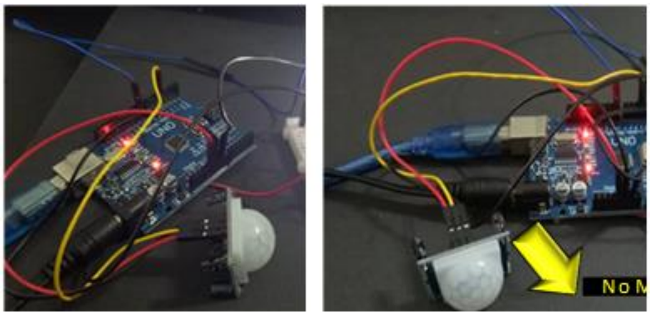

Fig. 9 (a) LED light ON when PIR sensor detects motion, (b) LED light OFF when PIR sensor does not detect motion

To quantify the effect of automatically switching lights on and off on energy-saving and carbon dioxide emission, simple calculations, based on equations (1) to (5), were carried out and summarized in Table. In the calculation, it was assumed that the room is occupied for only 5 hours in a day, thus the LED will switch on during this period and switch off during rest of the time. The table shows total saving under three different cases; when a conventional bulb is used, with uncontrolled LED, and with a smart lighting system. It is clear from the results that using smart lighting system not only reduces greenhouse gases emission, but it also reduces electricity bills. The calculated CO2 reduction is 68.75%, and the saved bill is RM17.465. All calculated results are per bulb. It is indeed environmentally and economically useful.

$$\text{Energy used (Wh/day)} = \text{Wattage/bulb} \times \text{Hours used/day} \quad \textbf{(1)}$$

$$\text{Energy consumption (kWhr/year)} = \frac{\text{Energy used}}{1000} \times 365 \quad \textbf{(2)}$$

$$\text{Cost of Electricity per bulb (RM/year/bulb)} = \text{(kWh/year)} \times \text{RM0.435} \quad \textbf{(3)}$$

$$\text{Energy Saving} = \frac{\text{Energy}_{\text{Before}} - \text{Energy}_{\text{After}}}{\text{Energy}_{\text{Before}}} \times 100\% \quad \textbf{(4)}$$

$$CO_2\,\text{(kg/year)} = \text{(kWh/year)} \times 0.536 \quad \textbf{(5)}$$

Table.3 Energy consumption per working day

Details	Conventional	LED	LED with sensors (PIR & Camera)	Total Saving
Wattage/bulb (W)	20	10	10	10W
Hours used/day	8	8	5	3hours
Energy used (Wh/day)	160	80	50	110W/hours
Energy consumption (kWh/year)	58.40	29.20	18.25	40.15kWh/year
Cost of electricity per bulb @ RM0.435sen (RM)	25.404	12.702	7.939	RM17.465
Energy saving (%)	-	50	68.75	68.75
CO2 emission (kg/year)	31.30	15.65	9.78	68.75

IV.CONCLUSION

The smart lighting system was proposed in the paper to assist in realizing the aims of maximizing energy savings and reducing economic and environmental impacts due to lighting energy misuse. The proposed smart lighting system utilized a motion sensor and a webcam to turn on and off the light depending on occupancy status. So, it automatically controls the light switching. The study has achieved the aims, through the successful design and implementation of the prototype that functions well according to the set aims. The proposed system contributes to reduction energy consumption by automatically switching off the lights when there is no occupancy.

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