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Design and Development of Smart Pedestrian Lighting System In UNITEN

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ABSTRACT

This project addressed energy wastage from continuous lighting in university walkways. Electrical energy is wasted particularly during low traffic after 10 pm where the lights are still turned on. A Smart Pedestrian Lighting System that integrates an Arduino microcontroller, sensors, and an Internet of Things (IoT) cloud system is proposed to reduce the wastage. The lights operated under various predetermined conditions from 7 am to 7 am the next day. Two prototypes namely Pro1 and Pro2 were developed and evaluated. All data collected was transmitted to the IoT cloud via the UNITEN Wifi for real-time monitoring and evaluation. The results showed that Pro2 is more reliable, effectively addressing high energy consumption and carbon emissions. Stark contrast in energy usage and CO_2 emission was obtained as compared to the existing setup. The Smart Lighting System can contribute to the university effort to become a Smart Campus, providing a potential positive step towards energy saving strategies and achieving UNSDG.

1. Introduction

Lighting systems are one of the main contributors to energy consumption worldwide, and they tremendously affect human beings' physical, psychological, and emotional well-being [1-2]. However, lighting systems continuously contribute to 15% of electricity consumption and 5% of greenhouse gas emissions worldwide [3]. The energy consumed in buildings is significantly attributed to lighting. Specifically, lighting constitutes 17% of the total energy consumed in commercial office buildings in the United States, 21% in commercial buildings across the United Kingdom, and between 20% to 40% of the overall electricity usage in large buildings in China [4].

The conventional lighting system draws its electrical energy from the grid, leading to continuous energy consumption throughout the night. This results in higher energy wastage and costs, thus making it not energy efficient. Such operation always results in elevated operational expenses. The inefficiency of the traditional lighting system not only leads to increased energy costs but also amplifies utility bills. Moreover, the heightened energy consumption contributes to a rise in carbon dioxide emissions from electricity production as the demand for energy grows. Therefore, efficient

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smart pedestrian streetlight systems are essential for mitigating energy consumption, reducing costs, and minimizing carbon emissions [5].

On the other hand, energy-efficient street lighting systems have been widely researched to reduce the energy consumption caused by streetlights. Past research includes the autonomous adjustment of brightness for streetlights, which is adopted by sensing pedestrians and vehicles [6], the inclusion of an adaptive control mechanism for the benefits of energy-saving and ease of maintenance for the smart street lighting system [7] and using the Clean Development Mechanism to estimate greenhouse gas emissions reductions [8]. Another research project involving PV powered outdoor lighting system that was incorporated with camera functionality but meant for household applications [9].

Saputra and Surapati research conducted in Jakarta involved smart streetlight using ESP 32 microcontroller and remotely controlled using web-based platform demonstrated a notable energy efficiency with an average of reduction in power consumption of 13.77 watts and an efficiency increase in 42.67% [10]. In another project conducted in Korea, Widartha et al developed a smart lighting system consisting of low-cost sensor and third-party Application Programming Interface (API), together with a prototype application. The results obtained indicated that by applying both sensor and daylight data appropriately, energy consumption reduction can be achieved effectively with the application of rule-based algorithm. The prototype application was designed to be able to provide real-time monitoring functionality, thus contributing to overall energy optimization [11].

A smart lighting system is an intelligent lighting system that integrates various devices and technologies such as sensors, internet connectivity, and automation to provide efficient and customized lighting solutions. The smart system is designed to reduce electricity consumption, carbon emissions, stress, and time by automating the lighting functions in a building or a specific area [12]. Smart lighting systems have emerged over the years in commercial and industrial environments, with a focus on energy saving [13-15].

In addition to the smart lighting system, the efficient utilization of natural daylight can also contribute to sustainable architectural design. Specifically, the design of skylights or light wells in low-lateral-area, deep-depth structures are important. Notably, as the lighting factor of the building increases from 3% to 6%, there is an annual decrease of 3% in CO_2 emissions [16]. In a separate study, the research showed that 60% energy savings, totalling 350 MWh in a year, can be achieved by retrofitting fluorescent lights with LEDs and occupancy sensors. This energy savings translates to a reduction of 62.4 tonnes of CO_2 emissions per year [17]. Furthermore, Widartha et al. reported that a combination of sensor and daylight data could effectively reduce energy consumption, and the rule-based algorithm further optimized energy usage [18].

The IoT is an innovative technology involving a range of devices, “things,” that communicate with each other and share information as part of a large network [19]. These objects and devices exhibit heterogeneity in their nature, are intelligent and distributed, and establish connections with the work environment, thereby facilitating interaction [19]. This technology captures state-of-the-art research in architectures, technologies, and applications of the IoT, opening the door to new interactions between things and humans [20]. It not only allows humans to control these objects but also provides regular and timely updates on their status [21-22].

Currently, Universiti Tenaga Nasional (UNITEN) is using a traditional Light-Emitting Diode (LED) lighting system, which sources its electricity from the grid throughout the night regardless of the traffic of along the pathways and time. This would yield a lot of wastage in terms of electrical energy during low traffics when it is late into the night. This project proposed to design and implement a smart lighting system in UNITEN that will reduce energy waste while ensuring adequate lighting for daily activities such as walking or jogging at night.

With the understanding that smart lighting will continue to become the foundation for smart cities and homes, driven by both "efficiency" and "quality of light." [23], this project was carried out with a few objectives such as to design, develop and implement a smart lighting system that can operate independently. Another objective of the project is to provide real time data on the electricity consumption through IoT technology, and to determine of amount of electricity consumption as well as carbon emission of both systems.

2. Methodology

The methodology is categorized into THREE major phases namely: -

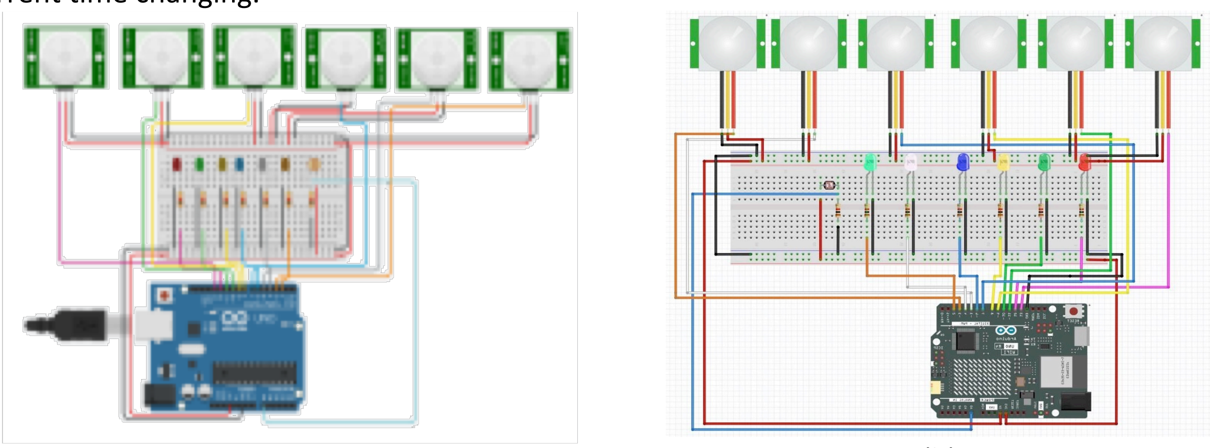
a. Phase 1 Product Design Specifications Identification
b. Phase 2 Product Development and Implementation
c. Phase 3 Data Collection, Analysis and Presentation

2.1 PHASE 1: Product Design Specifications Identification

The study began in Phase 1 with the Literature Review on the various available smart systems and relevant devices. The literature review also extended into gathering of information about electricity consumption of traditional LED lighting systems and electricity tariffs, available IoT system and the internet connection availability within the campus. Site visits to identify potential applications of the smart lighting system were also conducted around UNITEN campus.

Once the required information was available, the study then proceeds to determine the project scope and limitations. With the availability of scopes and limitations, the project enters the last phase of Phase 1 which was the design and simulation of the smart system in the software environment using TinkerCAD and Fritzing. The project then proceeded to Phase 2 once a successful simulation of the smart system was obtained, otherwise, the project requirement and specifications need to be redefined until a successful one is obtained. Figure 1 illustrates the smart lighting system setup designed and simulated using TinkerCAD.

The simulation setup consists of 6 different colours of LEDs which are red, green, yellow, blue, white, and orange to ease data evaluation. Each LED was paired with six different PIR motion sensors. PIR motion sensor will be utilized when there is motion from 10 pm to 7 am. One photoresistor was placed in the setup to light up LEDs automatically when there is no light. Six resistors were placed in the setup to avoid the LEDs from breaking down. This simulation applies a data set to simulate the current time changing.



(a) (b)

Fig. 1. Smart Lighting Setup and Simulation in TinkerCAD for (a) Pro 1 and (b) Pro2

The identified predetermined conditions for simulation of the smart lighting system are presented in Table 1.

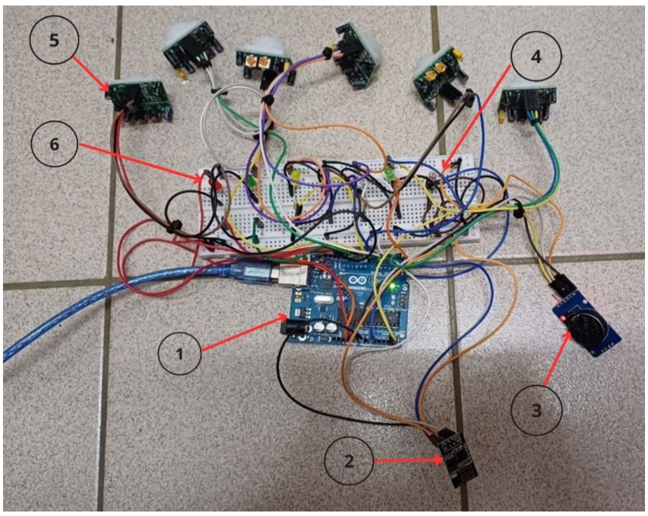
Table 1
Identified Predetermined Conditions for Smart Lighting System

From 7.00 pm – 10.00 pm		
Light	**Movement**	**LED Status**
No	Yes	On
No	No	On
Yes	Yes	On
Yes	No	On
From 10.00 pm – 7.00 am		
No	Yes	On
No	No	Off
Yes	Yes	Off
Yes	No	Off
From 7.00 am – 7.00 pm		
No	Yes	On
No	No	On
Yes	Yes	Off
Yes	No	Off

2.2 PHASE 2: Product Development and Implementation

The second phase of the project was dedicated to the creation of prototypes for smart lighting systems. Two distinct prototypes, named Pro1 and Pro2, were developed during this phase. Pro1 and Pro 2 were designed to cater for the different needs and specifications of the Wireless Fidelity (Wifi) connection availability on the campus and pathway. Both Pro1 and Pro2 designs met the requirements for smart lighting systems. The performance of Pro1 and Pro2 were compared later to determine its effectiveness in reducing electricity power consumption and Carbon Dioxide (CO_2) emissions.

The images and workflow diagrams of these prototypes are depicted in Figure 2 and Figure 3 respectively. Additionally, Figure 4 provides a visual representation of the potential application areas for the smart lighting system within the UNITEN Putrajaya Campus.



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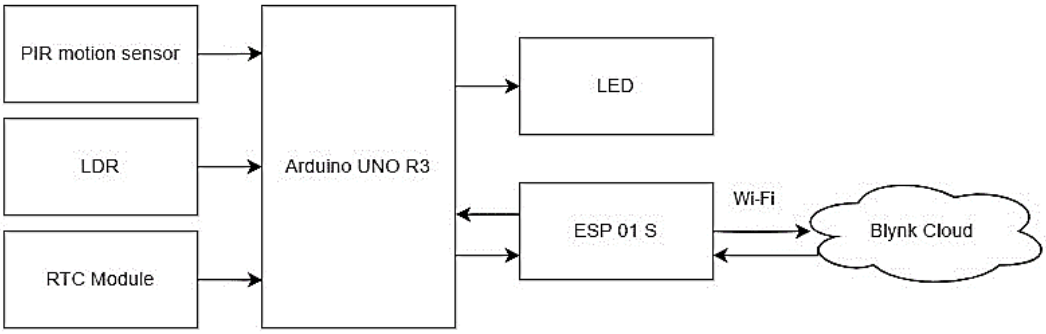


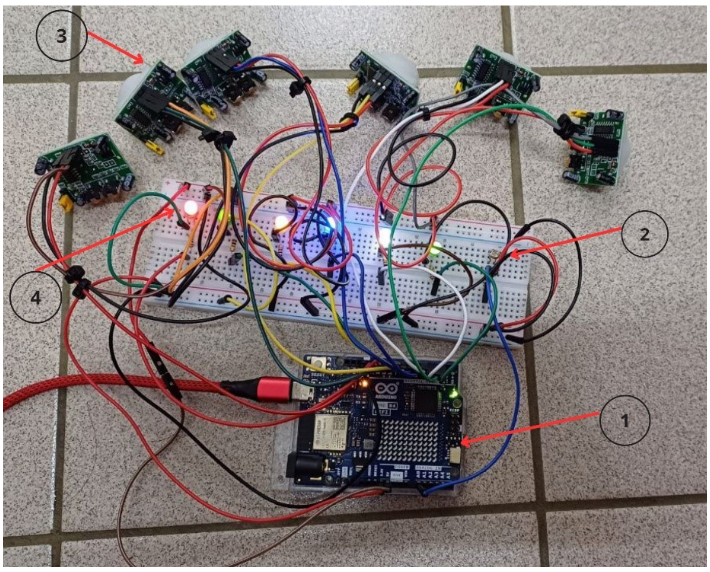
(b)

Fig. 2. (a) Picture of Prototype and (b) Workflow Diagram of Pro1

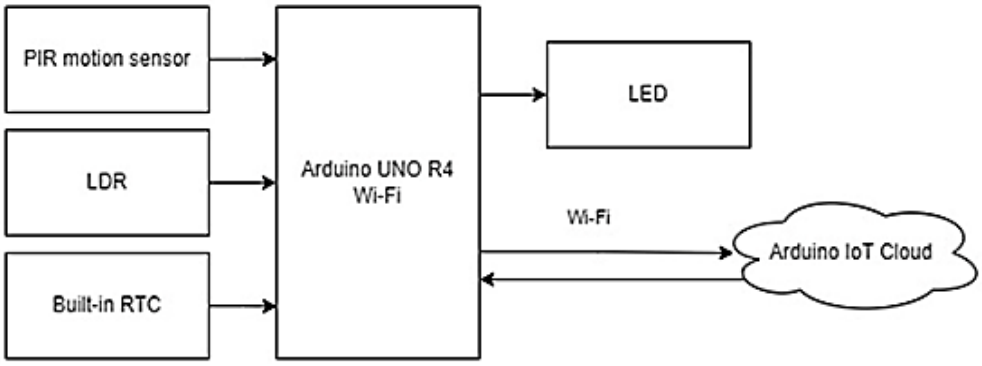
To understand the functionality of these prototypes, Tables 2 and Table 3 have been provided. These tables contain detailed information about the components used in Pro1 and Pro2, and their respective functions. This information is crucial in understanding the operation of the prototypes and their potential applications in enhancing the lighting system of the campus.

Table 2
Functionality of Components in Pro1

Label	Component	Function of Component
1	Arduino UNO R3	Microcontroller to control the smart pedestrian streetlight
2	ESP8266 ESP-01S	Provide Wi-Fi connectivity to Arduino UNO R3
3	RTC module	Provide real time clock for Arduino UNO R3
4	LDR	To detect and respond to variations in light intensity levels.
5	PIR sensor	To detect motion of pedestrian
6	LED	To represent the pedestrian light in prototype setup



(a)



(b)
Fig. 3. (a) Picture of Prototype and (b) Workflow Diagram of Pro2

Fig. 4. Identified Potential Locations of Smart Lighting System Application

Table 3
Functionality of Components in Pro2

Label	Component	Function of Component
1	Arduino UNO R4 Wi-fi	Microcontroller to control the smart pedestrian streetlight and provide connection to UNITEN Wi-Fi
2	LDR	To detect and respond to variations in light intensity levels.
3	PIR sensor	To detect motion of pedestrian
4	LED	To represent the pedestrian light in prototype setup

There are 48 LED lights installed and operating daily along this pathway. This pathway was selected because it is used by many UNITEN students who go to the gym, the swimming pool located at Dewan Seri Sajana in Location 1 as well as UPTEN food court at Location 2 to obtain food and drinks in the evening and nighttime. The Smart Lighting system will be installed and tested at one of the locations to collect the data at Dewan Seri Sarjana.

Table 4 illustrates the current LED lighting system specification applied in the studied locations.

Table 4
LED Lighting System in UNITEN Pathway

Component	Specification
Power consumption (W)	9
Voltage (V)	220-240
Frequency (Hz)	50/60
Length (mm)	600
Brightness (Lm)	800
Current(mA)	70

2.3 PHASE 3: Data Collection, Analysis and Presentation

Phase 3 of the project entailed the installation of the Smart Lighting systems at one of the pre-identified locations. This phase also included the collection and subsequent analysis of all relevant data. The Smart Lighting System was set up and operated continuously for a period of seven days, during which real-time data was systematically collected.

Theoretical calculations were carried out using the following equations, and a comprehensive performance comparison was completed to determine the energy consumption of the prototype as well as the current system, using the details of the current system and Pro1 and Pro2 parameters.

Energy consumption for single light per day: -

$$E = \frac{P \times t}{1000}\ (kWh) \tag{1}$$

E= Energy consumption (kWh)
P=Power (W)
T=Operating hours (h)

The energy consumption for every light in pathway per day: -

$$E = \frac{P \times t}{1000} \times number\ of\ lights\ (kWh) \tag{2}$$

The carbon dioxide equivalent ($kgCO_2e$) by current lighting system: -

$$Carbon\ dioxide\ equivalent\ (kgCO_2e) = Energy\ consumption\ (in\ kWh) \times Carbon\ Intensity\ factor\ for\ electricity\ in\ Malaysia\ (in\ \frac{kgCO_2e}{kWh}) \tag{3}$$

The raw data obtained was processed for:

- A comparison of the energy consumption between the current lighting system, Pro1 and Pro2,
- An estimation of the carbon dioxide equivalent emissions produced by the current lighting system, Pro 1 and Pro2.

Based on the results obtained and the subsequent analysis, appropriate conclusions were drawn, and recommendations were made. These findings provided the basis for future improvements and modifications to the Smart Lighting systems.

3. Results and Discussion

The energy consumption for both current and smart lighting systems was determined. The current lighting system for one unit was calculated. The calculation was done for three hours duration (9 pm to 12 am) as the current system lights will remain on during that duration to determine the energy consumption for the current system. This 3-hour slot for continuous seven days of data collection was chosen to comply with the security requirements of the university.

For Pro1 and Pro2, the real time value for one unit of each was collected for the same period for a specific location. In this project, the location selected is location 2 where the Dewan Seri Sarjana is located. This location was chosen because students would walk past here to get to the student accommodation. However, it should be noted that for 9 pm – 10 pm the smart lighting system will be on throughout the period. From 10 pm – 12 am, the smart lighting systems will only be activated whenever there is activation by students passing by. Using the data collected and calculations were performed, the results are illustrated in Table 5. For current lighting systems, energy consumption 0.142591Wh from day 1 to day 7. Figure 5 illustrates the energy consumption comparison of Pro1, Pro2 and current system.

Table 5
Energy Consumption Comparison for Different Systems

Day / Systems	Current System (Wh)	Pro1 (Wh)	Pro2 (Wh)
Day 1	0.1426	0.1382	0.1343
Day 2	0.1426	0.1009	0.0977
Day 3	0.1426	0.0908	0.0922
Day 4	0.1426	0.0965	0.0971
Day 5	0.1426	0.1054	0.1040
Day 6	0.1426	0.1147	0.1112
Day 7	0.1426	0.0889	0.0888

The results illustrated that the total weekly energy consumption of the current system surpasses that of Pro1 and Pro2. This disparity is attributed to the consistent illumination provided by the LEDs in the setup, leading to continuous energy consumption over time.

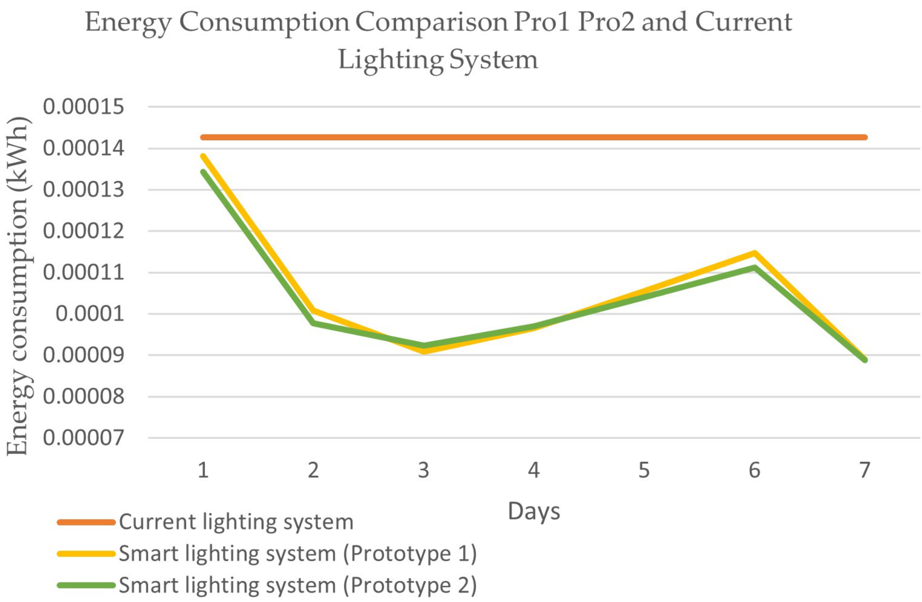


Fig. 5. Energy Consumption Comparison for Pro1, Pro2 and Current Lighting System

Both Pro1 and Pro2 displayed variable energy consumption patterns. This variability was due to events that took place in the Sports Arena at Location 1 and Dewan Seri Sarjana at Location 2. The influx of students returning to their accommodation between 9 pm and 12 am influenced the readings of the PIR motion sensors installed in these areas.

The carbon emission for all 3 systems were also determined using Equation 3. As illustrated in Figure 6, the current lighting system shows the highest Carbon Dioxide Equivalent when compared to both Pro1 and Pro2. This suggests that both Pro1 and Pro2 are more environmentally friendly, offering a sustainable solution for lighting needs.

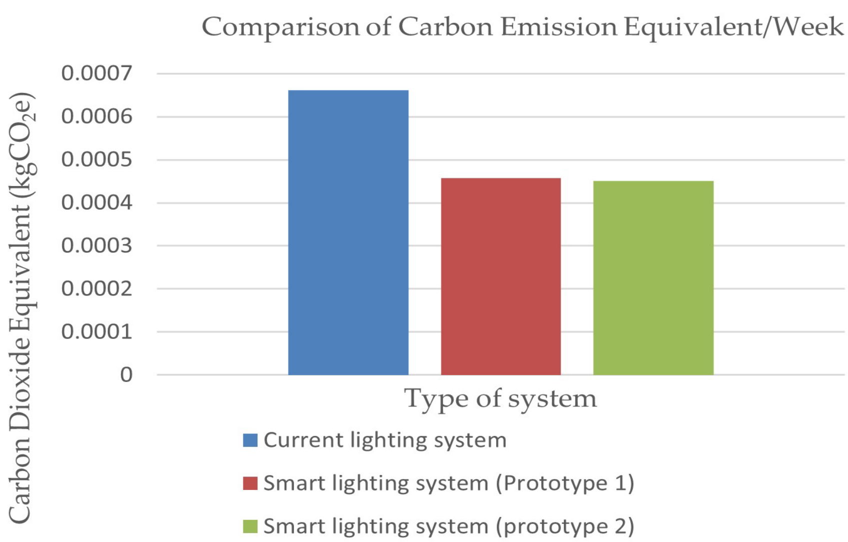


Fig. 6. The Carbon Emissions equivalent for Pro1, Pro2 and Current Lighting System

The actual number of pedestrians or group of pedestrians was counted and recorded manually. The activation readings from Pro1 and Pro2 were compared to determine the percentage of errors of the smart lighting systems developed. Both Pro1 and Pro2 consist of 6 LEDs paired with PIR sensors that detect motion for activation. These LEDs are in Red (R), Green (G), Yellow (Y), Blue (B), White (W) and Light Green (LG). Whenever motions are detected by a particular PIR sensor, the related LED will light up and record. Table 6 illustrates the detected motion by Pro1 and Pro2 as well as the manual recorded real passerby or group of passersby. Table 7 on the other hand illustrates the percentage of errors by Pro1 and Pro2 respectively.

Table 6
Number of activations detected by each PIR sensor compared with actual number of passersby detected manually

Day	Real No	Pro 1						Pro 2					
		R	G	Y	B	W	LG	R	G	Y	B	W	LG
1	80	101	93	112	113	118	118	89	96	97	114	102	108
2	25	21	28	28	34	37	39	34	25	16	21	24	37
3	17	19	13	13	8	9	9	20	16	9	11	15	16
4	28	28	20	30	19	25	18	22	26	28	23	21	29
5	42	43	36	6	31	71	47	38	42	49	35	38	35
6	60	48	67	59	64	62	65	46	61	64	47	57	53
7	7	10	8	9	5	6	8	7	7	7	7	7	7

Table 7
Percentage of Error by Pro1 and Pro2 respectively

Day	Prototype	Red (%)	Green (%)	Yellow (%)	Blue (%)	White (%)	Light Green (%)	Average (%)
Day 1	Pro1	26.00	16.00	40.00	41.00	48.00	48.00	36.50
	Pro2	11.00	20.00	21.00	43.00	28.00	35.00	26.33
Day 2	Pro1	16.00	12.00	12.00	36.00	48.00	56.00	30.00
	Pro2	36.00	0.00	24.00	16.00	4.00	48.00	21.33
Day 3	Pro1	12.00	24.00	24.00	53.00	47.00	47.00	34.50
	Pro2	18.00	6.00	47.00	35.00	12.00	6.00	20.67
Day 4	Pro1	0.00	29.00	7.00	32.00	11.00	36.00	19.17
	Pro2	21.00	7.00	0.00	18.00	25.00	4.00	12.50
Day 5	Pro1	2.00	14.00	86.00	26.00	69.00	12.00	34.83
	Pro2	10.00	0.00	17.00	17.00	10.00	17.00	11.83
Day 6	Pro1	20.00	12.00	2.00	7.00	3.00	8.00	8.67
	Pro2	23.00	2.00	7.00	22.00	5.00	12.00	11.83
Day 7	Pro1	43.00	14.00	29.00	29.00	14.00	14.00	23.83
	Pro2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The results in Table 7 indicated that Pro2 exhibited lower error throughout the 7-day period. Potential sources of these errors include variations in pedestrian pathways, minimal delay on the PIR sensor, heightened sensitivity of the sensors, the positioning and location of the prototype, as well as human errors in tallying pedestrian numbers or groups.

The data presented in this study underscores the significant potential of smart lighting systems in reducing energy consumption and carbon emissions. The comparison between the current lighting system and the Pro1 and Pro2 prototypes reveals a stark contrast in energy usage patterns. The current system, with its constant illumination, leads to continuous energy consumption, while Pro1 and Pro2 both exhibited variable energy consumption, adapting to the presence and activities of students in the area. Pro2 illustrated the best performance in terms of energy consumption, CO_2 emissions and errors comparatively.

Moreover, the lower carbon dioxide equivalent of the smart lighting systems, as shown in Figure 6, highlights their environmental benefits. This is a critical aspect in today's world, where there is an urgent need to adopt sustainable practices to mitigate the impacts of climate change. The findings of this study provide compelling evidence for the adoption of smart lighting systems, not just within the confines of the UNITEN Putrajaya Campus, but potentially in other similar environments as well such as retrofitting the heritage buildings with energy efficient components and systems [24]. This could lead to significant energy savings and a reduction in carbon emissions, contributing to global sustainability efforts.

4. Conclusions and Recommendations

The Smart Pedestrian Lighting System in this project was simple and easy to design and develop. It had undergone rigorous testing in the selected location. Between the prototypes, Pro2 distinguished itself as an exceptional solution, adeptly tackling both economic and environmental challenges. The data collected and analyzed during this study unequivocally demonstrate a significant reduction in energy consumption by Pro2 compared to the existing pedestrian lighting infrastructure.

This reduction in energy consumption is not merely a theoretical concept but translates into tangible benefits such as decreased energy costs. Furthermore, the environmental implications are profound, with a consequential decrease in carbon emissions. This aligns with global sustainability goals, reinforcing the importance and potential of implementing smart lighting systems. The findings of this study underscore the transformative potential of smart technologies in creating a sustainable and energy-efficient future.

There were a few limitations identified in this project. The project received no research fundings thus very limited instruments were utilized. In this case pedestrians detection system was not included. Another limitation was the number of data that could be collected. The data collection involved activity late night for a prolonged period and thus required approval from university management. Such activity raised security concerns and must be avoided at all costs. Thus 7 days of data collection are acceptable under such circumstances. It is recommended that to include a fully automated pedestrian counting system onto Pro2 if there is sufficient funding available. This would solve the problem of the manual recording of pedestrians whilst improving the reliability of the data collected. It also allows the collection of more experimental data for prolonged periods and also into late night without raising security concerns.

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