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Adaptive Lighting System for Presence Detection and Indoor Room Brightness Control

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Abstract – According to the survey, 10% of the electricity used is for lights. Adaptive lighting is a term used to describe innovations that reduce energy consumption for lighting. Generally speaking, adaptive lighting is a highly developed system built with built-in sensors to react automatically without the assistance of the people to make a decision. The research aims to develop an adaptive lighting system with two main functions presence detection and fuzzy logic implementations for automatic brightness adjustments. Increased sensitivity in detecting the presence and movement of items, monitoring the lighting conditions in the room, and consideration of the system's energy efficiency, which was not the main emphasis of the previous study, are some improvements over earlier studies. The device was tested for five days to calculate the energy consumption efficiency of a 4.5 W bulb for 10 hours in total. With a 98.4 % accuracy rate, the adaptive lighting system has proven 74% more efficient than regular lighting.

Keywords *– Adaptive lighting; energy consumption; fuzzy logic; light-dependent resistor; lighting*

I. Introduction

Energy-saving is a never-ending topic in the electrical engineering field. The benefit of energy-saving is that it could help sustain the power source for a longer time and would cost less for daily usage. Building energy efficiency has sparked broad interest since it is the most energy-intensive industry, accounting for more than half of global power and one-third of total energy consumption [1]. Lighting is a component whose primary purpose is electricity use [2], [3]. Based on [4], [5], [6] it is a significant energy consumer in buildings, representing about one-third of the electricity needs in commercial buildings and even more in office buildings. Many research and developments have been invented to help maintain a device's efficiency regarding how to save energy as much as possible while still maintaining its functionality. The benefit of energy-saving is that it could help sustain the power source for a longer time and would cost less for daily usage.

It uses the basic concept of an automatic lighting system while adding a microcontroller integrated with several sensors, such as motion and photo sensors. The motion sensor detects a person's occupancy, and photo-sensors are used to monitor the room's lighting situation and outside the room to decide the condition [7]. The concept is then supported using a fuzzy logic system to create the dynamic output value of the light intensity. For example, if the light from the outside is detected bright enough, usually due to daylight, the photo-sensor will give input to the microcontroller continuing with the fuzzy logic to decide to turn off, dim, or make it bright, which in this case would be to turn off the light.

Many technologies have been implemented to improve the automatic lighting system and adaptive lighting [8], [9]. In order to improve the performance and uniqueness of this research, the authors have learned five journal articles with a similar concept for comparison.

In 2015, Sihaloho [10] introduced the lighting brightness control system using fuzzy logic with Lab-View's supporting software. The author uses a similar design system by using multiple sensors to detect the intensity of the light, and with the help of a fuzzy logic controller, the lighting output will result in a dynamic value. The author specifically discussed the lighting system, the dimmer circuit configuration, and testing it by simulating the condition via LabView software. The author uses the Lux sensor and LDR to detect the light intensity and the current sensor to monitor the current flows to calculate the power consumed.

In the same year, Turesna et al. [11] also proposed a similar concept of lighting intensity control using a microcontroller Arduino and multiple sensors using the Fuzzy logic method. The author discussed using a pulse width modulation (PWM) concept to manipulate the signal of the light voltage. The author also mentioned that the work used a power supply with a driver circuit. The author mentioned that it also uses a PIR sensor to detect the presence of a person inside a room, but it does not discuss it further.

In 2017, Pardede et al. [12] proposed another lighting control system implementation using similar concepts. The author discussed the design specifications

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using Arduino combined with a fuzzy logic method. It uses 1 LDR sensor to detect the light intensity value that will be inserted into the Arduino later than managed by fuzzy logic to create a dynamic output of lighting brightness. The work did not use any motion sensors nor discuss energy consumption in-depth. In 2018, Putra et al. [13] proposed an intelligent lamp control system for smart-home android-based purposes. The background for this work is slightly different, as it focuses more on the connectivity and network field. However, the research offers a similar concept: to control the intensity of light using a fuzzy logic method. The main component for this work will be a smartphone, even though the author also used a lux sensor to detect the light input. Using an Arduino UNO and a Dimmer circuit, the author then designs automatic lighting that can be controlled from a user's smartphone. The primary purpose is to create a device that can control all the components inside the house, as it is leaning towards more for smart-home development.

Lastly, in 2019, Setiawan et al. [14] proposed another lighting control system in a room using a fuzzy logic method. In this research, the author uses PLC as the micro-controller instead. It uses a similar concept to using LDR sensors to detect the light input, which will be passed to the PLC, and using the fuzzy logic, the data will then be calculated to create a dynamic output of light brightness. The author uses three conditions, bright, dim, or dark, as the output, implemented to a light bulb. The author uses 2 LDR sensors to detect the inside and outside light conditions. The work is tested using an experiment by creating a prototype room to observe the data. It did not use motion sensors to detect the presence inside the room.

The occupancy or motion sensor will be in charge of the microcontroller to give the final output for the light. If the photo-sensor detects that the outside light is dark; however, there are no people in the room, the occupancy sensor will give input for no detected presence inside the room and prevent the light from turning on. Based on the background above, then conclude to bring up this topic of automatic lighting to improve the previous research to reduce the energy consumption of lighting.

This work aims to create an automatic lighting system to reduce energy consumption by developing adaptive lighting and a MATLAB modeling system to control the intensity of a lighting bulb output using multiple sensors. This system can detect a static human presence inside a room and adjust the automatic brightness light, which intends to improve the previous research. Furthermore, this research also evaluates the energy consumption effectiveness of using typical lighting methods and adaptive lighting methods.

II. Research Method

A. Literature Study Related to Previous Research

One of the purposes of this research is to develop the existing system design that has been researched previously. To sum up the comparison between this research with the previous journals that provided similar concepts for the automatic lighting system, then we summarize it in the form of comparison as illustrated in Table 1.

Table 1. The comparison summary with the prior research

Paper	Detection Sensor	Implementation	Energy Efficiency Purpose
[9]	• Presence detection sensor:- • Light detection sensor: Lux & LDR	LabView Simulation	NO, Current Monitoring
[11]	• Presence detection sensor: PIR • Light detection sensor: 1 LDR	Device Testing using a Flashlight	YES
[12]	• Presence detection sensor: - • Light detection sensor: 1 LDR	Various Output of Light Intensity	NO, Light Intensity Monitoring
[13]	• Presence detection sensor: - • Light detection sensor: 2 Lux	Simulation Prototype	NO, Smart-home Building
[14]	• Presence detection sensor: - • Light detection sensor: 1 LDR	Simulation Prototype	NO, Light Detection Accuracy
This paper	• Presence detection sensor: PIR and Sound • Light detection sensor: 2 LDR	Real-Time Simulation	YES

Table 1 shows that several improvement focuses have been carried out in this study to complement the previous research. PIR sensors and sound as presence detection and 2 LDR as light detection sensors aim to increase the system's sensitivity in detecting object movement. In addition, this study also considers the energy efficiency produced by the system, which has not been the focus of research in previous journals.

B. Overall System Design

The Adaptive lighting system is divided into three main parts: the Input system, Processing System, and the Output System. The overview of the system, in general, is structured in a block diagram that can be seen in Figure 1.

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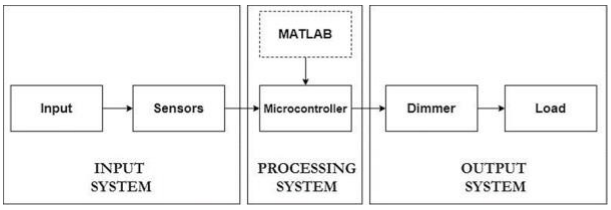

Figure 1. Adaptive lighting system block diagram

The input system includes the input variables, which are the parameters that will affect the output value of the system. The parameters are categorized into two types by their functions: light input and presence input, which each sensor will detect. These input data are then transmitted into the microcontroller Arduino UNO, leading to the next system, Processing System. Using the method of fuzzy logic systems implemented into the Arduino UNO by coding the fuzzy logic program with Arduino IDE, the output data then are sent into the light bulb load as a command of brightness adjustments for the load, which consists of values within the set from the fuzzy logic output function.

Fuzzy logic is an improvement over Boolean logic, which has similarities with partial truth. Fuzzy logic deals with inequalities, uncertainties, and partial truths, and it can help determine the values between 0 and 1 [15]. The design of the fuzzy logic system itself, such as the membership functions, the output functions, and the fuzzy rules, are created beforehand using a MATLAB toolbox software called Fuzzy Logic Toolbox, which is then decoded into a programming language written for Arduino IDE to compile the code into the Arduino UNO. The last system of the device is the Output System, where the output results are transmitted to the AC dimmer to set a specific value of the PWM duty cycle that will be sent into the light bulb as a command of brightness adjustments. In short, motion and sound within the coverage area inside the room will transmit a motion input and sound input data that will be received by the HC-SR501 passive infrared sensor and the KY-038 sound sensor, which will then transfer the digital output data into the Arduino UNO as a form of presence detection.

Figure 2 depicts the flow of how the system device flowchart system operates. A light source within the coverage area inside the room will radiate a light input received by the light-dependent resistors, transmitting an analog input into the microcontroller Arduino UNO as a form of lighting intensity value input. These input data are processed by the Arduino UNO and using the method of fuzzy logic systems; the output data are then sent into the light bulb load as a command of brightness adjustments for the load, consisting of values within the set from the fuzzy logic output function.

Figure 2. Adaptive lighting system device flowchart

C. Room Design

This work is conducted in a real-scale room with 3.875 m x 3.08 m x 2.70 m with a total volume of 32.2 m2, and real-time testing for 9 hours, starting from 9.00 AM to 6.00 PM. The light sensors are placed near thewindow area to get a decent exposure of sunlights for a better result of input, as shown in Figure 3.

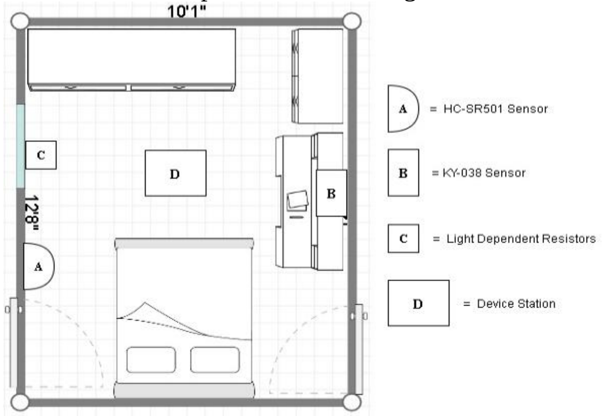

Figure 3. Two-dimensional overview of the restroom

The motion sensor HC-SR501 is placed in an area that is expected to have the most coverage for the passive infrared sensor to be able to detect a motion. The sound sensor KY-038 is placed near the work desk area for a better coverage of detecting a small sound such as keyboard-typing or mouse-clicking. There are four blocks representing each placement of the device within the room, as described in Figure 4.

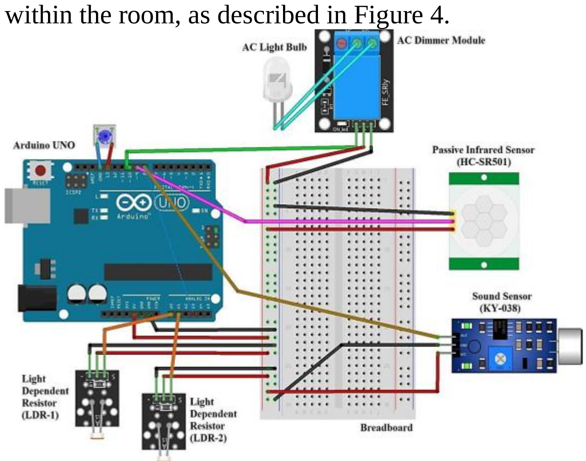

Figure 4. Schematic diagram of adaptive lighting

Block A represents the placement of the passive infrared sensor, block B represents the placement of the sound sensor KY-038, block C represents the placement of the light-dependent resistors, and block D represents the placement of the station, which consists of a light bulb and microcontroller as described on Figure 4, with the pin configuration of aech block as descibed in the Table 2.

Table 2. Adaptive lighting system pin configuration

Block	Pin Configurations	
LDR	LDR Sensor (OUT)	Arduino UNO
	VCC	5V – Power
	GND	GND – Power

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	DO	-	
	AO	A0 – Analog Pins	
	LDR Sensor (IN)	-	
	VCC	5V – Power	
	GND	GND – Power	
	DO	-	
	AO	A1 – Analog Pins	
PIR Sensor	PIR Sensor	Arduino UNO	
	VCC	5V – Power	
	OUTPUT	Pin 9 – Digital Pins	
	GND	GND – Power	
Sound Sensor	Sound Sensor	Arduino UNO	
	AO	-	
	GND	GND – Power	
	+	5V – Power	
	DO	Pin 8 – Digital Pins	
AC Dimmer Module	**AC Dimmer**	**Arduino UNO**	**Light Bulb**
	VCC	Pin 11 – Digital Pins	
	GND	5V – Power	
	Z-C	GND – Power	
	PWM		
	C-IN		AC 220V Power Source
			AC 220V Power Source
	LOAD		Light bulb
			Light bulb

D. Fuzzy Logic System Design

As shown in Figure 5, a fuzzy logic system's configura-tion consists of a fuzzifier, some fuzzy IF-THEN rules, a fuzzy inference engine, and a defuzzifier [16]. In this work, the solution proposed will be developing automatic lighting. It uses the concept of an automatic lighting system using microcontrollers integrated with motion and photo sensors. The concept is then supported using a fuzzy logic system to create the dynamic output value of the light intensity. For example, if the light from the outside is detected bright enough, usually due to daylight, the photo-sensor will give input to the microcontroller continuing with the fuzzy logic to decide to turn off, dim, or make it bright, which in this case would be to turn off the light. The situation also occurs and vice versa.

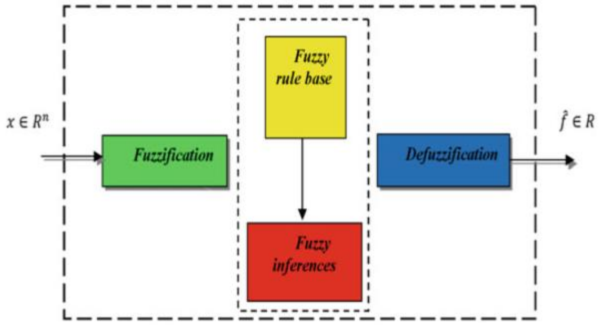

Figure 5. Fuzzy logic basic system configuration [16]

The process will start when the system reads the input values of LDRs. There are two LDRs used in the system. The first LDR sensor detects the brightness intensity inside the room, while the second LDR sensor detects the brightness intensity outside the room. Both LDR values will then be processed by the microcontroller using the fuzzy logic system by inserting the values into the membership functions. There are three ranges of input values based on the Light-dependent resistor bit value, consisting of 'Dark,' 'Neutral,' and 'Bright,' which can be seen in Table 3.

Table 3. Fuzzy rules for intensity of Adaptive Lighting

Status	**Dark (Outside)**	**Neutral (Outside)**	**Bright (Outside)**
Dark (Inside)	High	High	Dim
Neutral (Inside)	Dim	Dim	Low
Bright (Inside)	High	Dim	Low

The output values will also consist of three outputs: 'Low (~25%)', 'Dim (~50%)', and 'High (~100%)'. The system continues to evaluate the fuzzy rules inside the fuzzy logic inference based on the following nine different IF-THEN rules written in the linguistic form:

Rule 1: *If* (Out *is* Dark) *And* (In *is* Dark) *Then* (Output *is* High)
Rule 2: *If* (Out *is* Neutral) *And* (In *is* Dark) *Then* (Output *is* High)
Rule 3: *If* (Out *is* Bright) *And* (In *is* Dark) *Then* (Output *is* Dim)
Rule 4: *If* (Out *is* Dark) *And* (In *is* Neutral) *Then* (Output *is* Dim)
Rule 5: *If* (Out *is* Neutral) *And* (In *is* Neutral) *Then* (Output *is* Dim)
Rule 6: *If* (Out *is* Bright) *And* (In *is* Neutral) *Then* (Output *is* Low)
Rule 7: *If* (Out *is* Dark) *And* (In *is* Bright) *Then* (Output *is* High)
Rule 8: *If* (Out *is* Neutral) *And* (In *is* Bright) *Then* (Output *is* Dim)
Rule 9: *If* (Out *is* Bright) *And* (In *is* Bright) *Then* (Output *is* Low)

After evaluating the rules, the fuzzy logic system will then give the defuzzification output value to the primary system to be processed into the final output form of the device system, which is the intensity of the light bulb. Figure 6 shown the graph function plots of the first and the second LDR membership function, that tracks down the value of the light brightness from the outside sensor Figure 6 (a) and inside sensor Figure 6 (b).

As can be seen from Figure 6, the brightness range value from the inside room has a wider set due to the fact that the inside room's brightness intensity are

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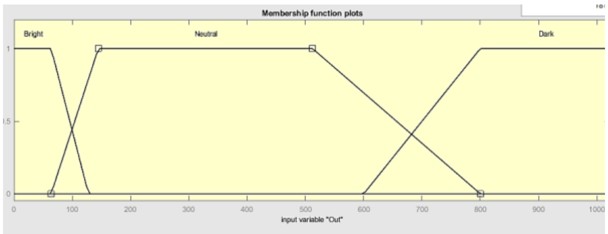
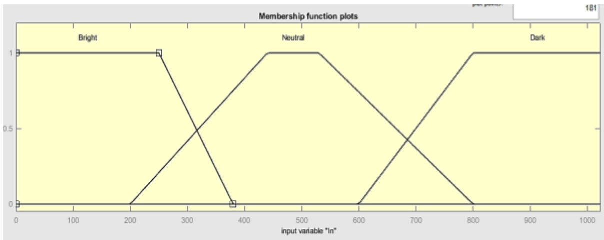
affected with more parameters, such as the light scattering from the outside light around the room and also the amount of objects inside the room that are not able to reflect back the light properly.



(a)



(b)

Figure 6. Membership function plots in MATLAB. (a) LDR-1 as outside sensor (b) LDR-2 as inside sensor

E. Automation Lighting

Due to the rapid advancement of sensing technology, recent lighting system control has utilized sensing-based methodologies as vital inputs to improve the performance of lighting systems in terms of energy efficiency and the visual comfort of building occupants [17]. The effectiveness of occupancy-based control strategies in terms of energy savings, as well as their performance and sensor placement techniques, are examined in various published publications. Various sensing technologies, including PIR, ultrasonic, RFID, and others, are also discussed [18], [19].

Adaptive lighting is a sophisticated system designed with some sensors integrated so that it is able to respond by itself in the current conditions without the need for the help of the users to make the decision. Common ways to manipulate the lighting output and control its brightness are done with the concept of Pulse Width Modulation (PWM). PWM is a method to manipulate the signal's width indicated in a periodic pulse waveform in a certain period (in seconds). The modulating signal is the signal that consists of the data of information to be sent or transmitted. PWM signals are divided into two main components; duty cycle (T-on) and period (Time) [20], as can be seen in Figure 7.

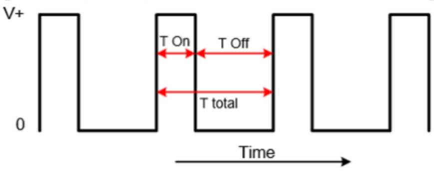


Figure 7. PWM signal form [11]

As shown in Figure 7, T-On represents the duty cycle associated with the High signal. In other words, the duty cycle is the part of the modulation signal that shows how many times the signal is high or on. The period is the exact definition of a general wave, representing the time of one wave to be 'on,' and 'off.' V+ is the signal's amplitude, or in this case, the light's voltage input.

E. Automatic Lighting Energy Consumption

Lighting consumes a large part of the global energy bill [21]. However, using intelligent control algorithms, light' waste,' i.e., lights that are on when no one uses them, can be reduced, leading to even more significant energy savings. This domain can roughly be divided between lighting for outdoors and indoors. In both cases, the goal is to balance energy consumption with other lighting requirements or parameters of user comfort.

For indoor lighting, there are roughly three strategies to save energy: daylight harvesting, occupancy sensing, or user demand [22]. Daylight harvesting involves strategies to transport light into buildings and dim lights when sufficient daylight is present. Occupancy sensing involves dimming or disabling lights when no user activity is detected. The energy consumption efficiency of an adaptive lighting method is expected to be more efficient than standard lighting. The efficiency rate can be calculated with the equation [23].

$$\eta = \frac{W_{out}}{W_{in}} x100\% \qquad (1)$$

Where:
η = energy efficiency (%)
$Wout$ = energy output (J)
Win = energy input (J)

The energy consumption in a given time from the light bulb may be calculated by multiplying the two factors: the essential power of the light bulb times the duration of the user based on the conversion from the basic equations that existed [24], as written in the following equation:

$$W = Pxt \qquad (2)$$

Where:
W = energy of the bulb (J)
P = power of the bulb (W)
t = duration of the use (s)

While the standard lighting method will use the equation above for the calculation, it is expected that the power output of the adaptive lighting given throughout the day will not be constant as the standard lighting considering some addition to the parameters that are going to affect the system, such as the presence of a person inside the room or the intensity of the light bulb itself.

The method to calculate the energy consumption is by adding the total power consumption used for each intensity in the average hour of the watt usage as

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adapted from the research [25] on energy consumption, which is written in the equation as follows:

$$W_{total} = P_{dark}\ x\ t_{dark} + P_{dim}\ x\ t_{dim} + P_{bright}\ x\ t_{bright} \quad (3)$$

However, before the energy consumption is calculated and its efficiency is defined, it is necessary to ensure that the given output data provided by the device is accurate. In order to fulfill the requirements, a calculation of the accuracy rate is necessary, which can be obtained by defining the error rate of the device data. The error rate is calculated by the following equation [26]:

$$error\ rate = \left|\frac{measuredvalue - standardvalue}{standardvalue}\right| x\ 100\% \quad (4)$$

$$Accuracy\ rate = 100\% - error\ rate \quad (5)$$

Where:
$Accuracy\ rate$ = the percentage of the data accuracy (%)
$error\ rate$ = the percentage of the data inaccuracy (%)
$measured\ value$ = the output value from the device
$standard\ value$ = the value provided by a standard trusted source

III. Results and Discussions

A. Observation Data Results

A tracking experiment is undertaken to improve accuracy for real-time circumstances in the room as part of this research. It is carried done by assessing the lighting situation within the space using two parameters, outside light and inside light. It is also done by using the Light Dependent Resistor, which will be used later in the research for lighting intensity value. The primary purpose of the tracking is to find a range of values that will be used for the fuzzy logic membership sets. In short, two tests are conducted with a slight difference in angle inside the room to achieve a better tolerance value of the range. The result of the tracking experiment is shown in Table 4.

The data is added to each input's fuzzy logic membership functions using the available information from the range of values set above. Afterward, all of the prepared program codes in the Arduino IDE are implemented into the Arduino UNO, followed by the subsequent experiment, which is gaining data for the lighting bulb power consumption throughout the day.

Table 4. Light dependent resistor tracking result

LDR Position	Status	Estimated Range (V)
Outside LDR	Bright	0 – 0.513
	Neutral	0.518 – 3.91
	Dark	3.914 – 5
Inside LDR	Bright	0 – 1.857
	Neutral	1.862 – 4.692
	Dark	4.696 – 5

The second experiment was tested for five days straight, measured from 09.00 AM to 06.00 PM with an hour addition for calculation simplicity purposes. The total experiment duration is 10 hours. The power consumption results are shown for each day of tests (measured in watts), observing the device's behavior responding to different conditions throughout the day. The parameters that affected the output are Presence Detection from motion and sound and the room's lighting conditions. Figure 8 shows the results of power consumption of the adaptive lighting device from Day-1 until Day-5, with each having a different weather condition from "Cloudy," "Sunny," or "Rainy".

The standard lighting variable is there to act as a comparison value for the constant power consumption in the usual regular lighting system. As can be seen from the graphs above, the adaptive lighting system behave differently depending on the current environment condition that day. The system also gave a different output according to the presence detection on the specific hour. Examples can be seen in the graph such as Day-1 at 09.00 AM and 05.00 PM, Day-2 at 10.00 AM, Day-4 at 01.00 PM, and Day-5 at 01.00 PM, where the adaptive lighting went "OFF" due to no presence status were detected inside the room, resulting the device to automatically turning off the light to reduce the unnecessary power consumption.

Another parameter that affects the system behavior is the room's lighting condition throughout the day, which is tracked by the light-dependent resistors. The Arduino UNO detects the presence of either motion or sound. The device then checks both light-dependent resistor input values before inserting them into the fuzzy membership functions to be grouped in three different categories provided depending on their values.

An example can be seen in graph on Day-1 until Day-5 at around 11.00 PM – 01.00 PM as described in Figure 8, where the system sets the lighting into the "Low" status due to both light-dependent resistor values are categorized on the "Bright" range according to the fuzzy systems, meaning that there was enough light exposure inside the room to set the light into a dimming mode for lower power consumption.

However, there were certain conditions where the usual sunlight exposure was reduced earlier than the regular hours. Take an example in the graph on Day-4 and Day-5 where the weather was rainy, and rain occurred at around 02.00 PM - 03.00 PM, decreasing the sunlight exposure quite significantly than average weather, resulting in the device automatically setting the lighting to a higher brightness intensity such as "Dim" or "High" depending on the fuzzy logic system output. The brightness intensity inside the room influences the outputs, controlled by how bright or dark the outside and inside lighting conditions are. These characteristics are tracked as input values into the system by the light-dependent resistors.

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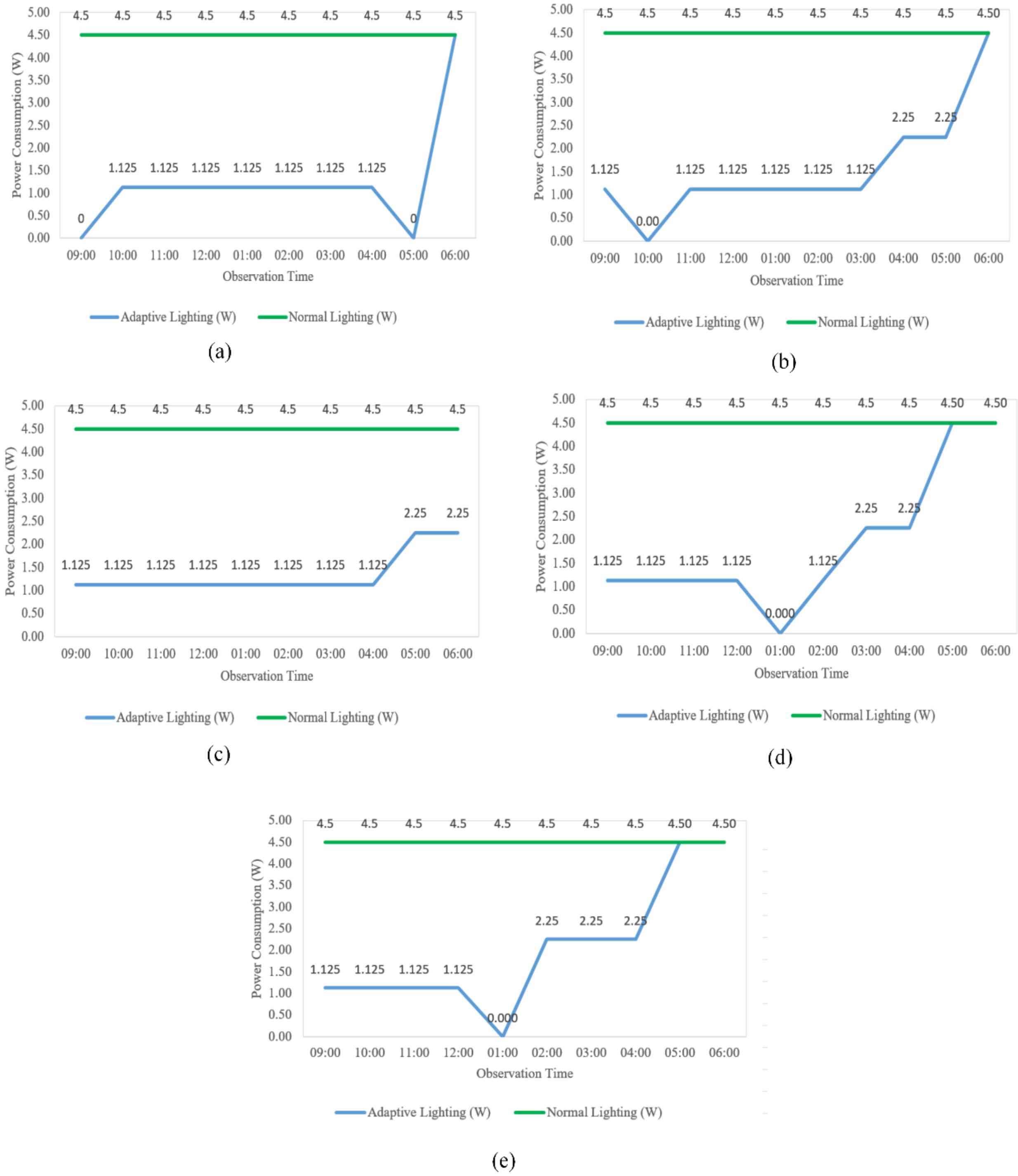

Figure 8. Lighting power consumption comparison graph (day 1 - day 5)

B. Testing and Comparing Data Results

The MATLAB viewing features provided the simulation preview of the output that will occur in a certain value of inputs. The feature also enables the user to test out various input values to show the outcome values of the lamp. These values are going to be the standard value that will be compared to the measured value for accuracy rate calculation that are going to be tested. The output overview of adaptive lighting in MATLAB for this work was represented by Figure 9.

After the results of the measured value from Arduino UNO for five days of observation from 09.00 AM to 06.00 PM, the values are compared with the MATLAB simulation results using the Fuzzy Logic Toolbox. This comparing is aims to test the accuracy rate of the device's output. The equation used to calculate the error rate is referenced from Equation 4:

Data day-1 at 10.00 AM:

$$error\ rate = \left|\frac{measuredvalue - standardvalue}{standardvalue}\right| x\ 100\%$$

$$= \left|\frac{31-30.6}{31}\right| x\ 100\% = 2.26\%$$

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$$Accuracy\ rate = 100\% - error\ rate$$
$$= 100\% - 2.26\% = 97.74\%$$

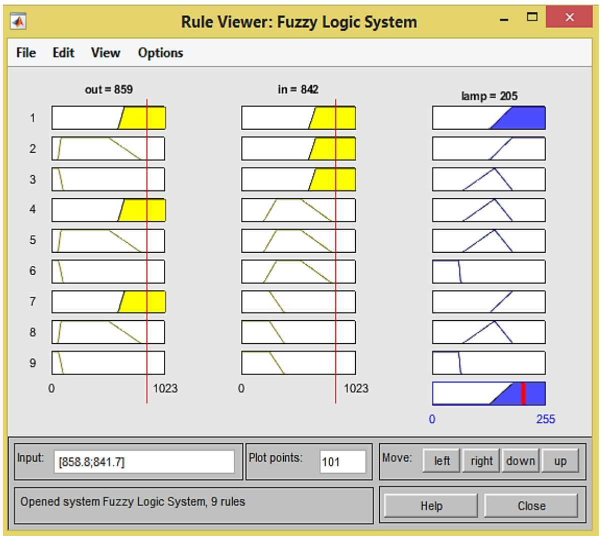

Figure 9. Output overview of adaptive lighting in MATLAB

Furthermore, similar computations were done for each of the five days of observation data, which covered the hours of observation from 09:00 AM to 06:00 PM. As a result, the output of the device and the reference value provided by MATLAB are roughly comparable and have an average accuracy of 98.4%. Therefore, it can be concluded that the value is valid and allowed to be used for calculation purposes.

C. Evaluation of Energy Consumption Efficiency

From all the data obtained and tested for accuracy, next is to summarize the total power usage for each day. The total energy consumption in kJ computed for each day from Day-1 to Day-5 is shown on the graph. The results also show the comparison of the energy consumption from the adaptive lighting and the standard lighting method as defined in Table 5.

Table 5. Summary for total hour consumption table

Light Status	Power Usage (W)	Time Duration (hour)				
		Day-1	Day-2	Day-3	Day-4	Day-5
OFF	0	2	1	0	1	1
LOW	1.125	7	6	8	5	4
DIM	2.25	0	2	2	2	3
HIGH	4.5	1	1	0	2	2

The varying energy consumption results are parallel with the previous data of the varying power consumption, following the system's behavior and output. This also shows that the device worked well with dynamic environments, lighting or weather conditions, and presence detection. The total energy consumption calculation results are compared and shown in Figure 10.

From the data shown in Figure 10, it is possible to calculate the average energy consumption by dividing the total energy consumption from Day-1 until Day-5 by the number of test days, using Equation 3 with the result $W_{avg} = 58.32kJ$ (Adaptive lighting). Since the energy consumption of the standard lighting method gives a constant value, therefore it can define the $W_{avg} = 162kJ$ (Normal lighting).

The efficiency of the energy consumption for using adaptive lighting is calculated with the energy efficiency using equation.1. As a result, that adaptive lighting uses an average energy consumption of 36% of the total standard lighting method. According to the findings above, it can be seen that energy consumption is adequate when adaptive lighting and a MATLAB modeling system are implemented to regulate the light bulb output's intensity using several sensors. The ability of the system to detect human presence in the room allows it to modify light intensity according to the situation automatically. As a result, compared to traditional lighting techniques, energy usage is more effective.

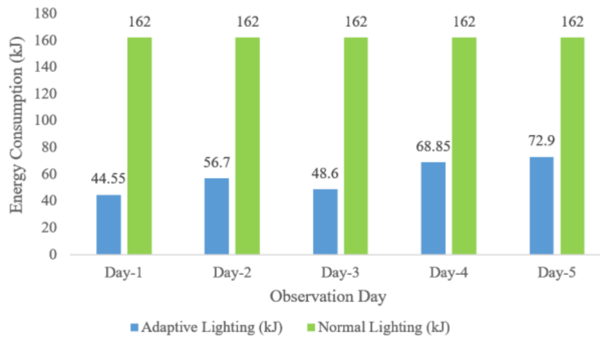

Figure 10. Lighting energy consumption data comparison graph

IV. Conclusion

As proposed in this study, the device's adaptive lighting technology performs effectively in dynamic situations. Several improvement focuses have been carried out in this study to complement the previous research. PIR sensors and sound as presence detection inside the room and 2 LDR as light detection sensors aim to monitor the lighting conditions in the room. This improvement aims to increase the system's sensitivity in detecting objects' presence and movement and monitoring the room's lighting conditions. In addition, this study also considers the energy efficiency produced by the system, which has not been the focus of research in previous research. As a result, the device system functioned satisfactorily with the fuzzy logic systems, producing a very accurate output result with a 98.4 % accuracy rate. Finally, it has been established that Adaptive Lighting uses an average energy consumption of 36% of the standard lighting method. Therefore, using an adaptive lighting method is proven to be more efficient, as it has lower energy consumption with a 74% efficiency compared to the normal lighting method. The improvement of this study compared to the previous study has been added in conclusion.

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REFERENCES

[1] Y.Cheng, C.Fang, J.Yuan dan L.Zhu, "Design and Application of a Smart Lighting System Based on Distributed Wireless Sensor Networks," *Applied Science*, vol. 10, no. 23, pp. 1-21, 2020.

[2] S.Z.Laikha, A.Adria dan A.Rahman, "Sistem Otomasi Lampu Rumah Adaptif Berbasis Artificial Neural Network," *Jurnal Komputer, Informasi Teknologi, dan Elektro (KITEKTRO)*, vol. 3, no. 2, pp. 68-75, 2018.

[3] M.Khairudin, S.Riyanto dan Z.Mohammed, "Development of Fuzzy Logic Control for Indoor Lighting Using LEDs Group," *Telecommunication, Computing, Electronics and Control (TELKOMNIKA)*, vol. 16, no. 3, pp. 1165-1173, 2018.

[4] W.R.Ryckaert, C.Lootens, J.Geldof and P.Hanselaer, "Criteria for energy efficient lighting in buildings," *Energy and Buildings*, vol. 42, no. 3, pp. 341-347, 2010.

[5] A.Motamed dan J.-L. S. L. Deschamps, "Eight-month experimental study of energy impact of integrated control of sun shading and lighting system based on HDR vision sensor," *Energy and Buildings*, vol. 203, 2019.

[6] G.Chiesaa, D.D.Vitab, A.Ghadirzadehb, A.H.M.Herrerab dan J.C.L.Rodriguezb, "A fuzzy-logic IoT lighting and shading control system for smart buildings," *Automation in Construction*, vol. 120, 2020.

[7] G.Cimini, A.Freddi, G.Ippoliti, A.Monteriù dan M.Pirro, "A Smart Lighting System for Visual Comfort and Energy Savings in Industrial and Domestic Use," *Electric Power Components and Systems*, vol. 43, no. 15, p. 1696–1706, 2015.

[8] A.Pandharipande dan D.Caicedo, "Smart Indoor Lighting Systems with Luminaire-based Sensing: A Review of Lighting Control Approaches," *Energy and Buildings*, vol. 104, pp. 369-377, 2015.

[9] C.P.Kurian, S.Kuriachan, J.Bhat dan R.S.Aithal, "An Adaptive Neuro-Fuzzy for the Prediction and Control of Light in Integrated Lighting Schemes," *Lighting Research and Technology*, vol. 37, no. 4, pp. 343-352, 2015.

[10] D. Sihaloho, "Kendali Kecerahan Lampu Menggunakan Fuzzy Logic Dan Monitoring Berbasis Labview pada Prototype Smart Building," Politeknik Negeri Batam, Batam, 2015.

[11] G.Turesna dan Z. H.Hermawan, "Pengendali Intensitas Lampu Ruangan Berbasis Arduino UNO Menggunakan Metode Fuzzy Logic," *Jurnal Otomasi Kontrol dan Instrumentasi*, vol. 7, no. 2, pp. 73-88, 2017.

[12] A.M.H.Pardede, Novriyenni dan S.Efendi, "Implementasi Pengendalian Lampu Otomatis Berbasis Arduino Menggunakan Metode Fuzzy Logic," *Jurnal Penelitian Teknik Informatika Universitas Malikussaleh (TECHSI)*, vol. 9, no. 2, pp. 164-177, 2017.

[13] L.A.Putra dan A.R.Hakim, "Sistem Kendali Lampu Cerdas Pada Smarthome Berbasis Android mengunakan Metode Fuzzy Logic Control," *Computer Science Research and Its Development Journal (CSRID)*, vol. 10, no. 1, pp. 33-43, 2018.

[14] A.B.Setiawan dan R.D.Puriyanto, "Pengatur Intensitas Cahaya Ruangan dengan Metode Fuzzy Logic Menggunakan PLC," *Buletin Ilmiah Sarjana Teknik Elektro*, vol. 1, no. 3, pp. 100-107, 2019.

[15] A. Mukti, O.D.Nurhayati dan E.D.Widianto, "Rancang Bangun Sistem Kontrol Robot Line Follower Menggunakan Lgika Fuzzy," *Jurnal Teknologi dan Sistem Komputer (JTsiskom)*, vol. 3, no. 4, pp. 536-543, 2015.

[16] A.T.Azar dan S.Vaidyanathan, "Advances in Chaos Theory and Intelligent Control," *Springer International Publishing*, Switzerland, 2016.

[17] K.R.Wagiman, M.N.Abdullah, M.Y.Hassan, N.H.M.Radzi, A.H.A.Bakar dan T.C.Kwang, "Lighting system control techniques in commercial buildings: Current trends and future directions," *Journal of Building Engineering*, vol. 31, 2020.

[18] C. Bakker, M.Aries, H.Kort dan A.Rosemann, "Occupancy-based lighting control in open-plan office spaces: a state-of-the-art review," *Building and Environment*, vol. 112, p. 308–321, 2017.

[19] K.R.Wagiman, M.N.Abdullah, M.Y.Hassan dan N. Radzi, "A review on sensing- based strategies of interior lighting control system and their performance in commercial buildings," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 16, no. 1, p. 208–215, 2019.

[20] S.A.E.Hamza dan A.Babiker.A, "The Common Use of Pulse Width Modulation "PWM" Technique in Power Electronics," *International Journal of Science and Research (IJSR)*, vol. 3, no. 11, pp. 2129-2132, 2014.

[21] H. a. M.Roser, "Energy Production and Consumption," Our World In Data, 2019. [Online]. Available: https://ourworldindata.org/energy-production-consumption. [Accessed 15 May 2022].

[22] S.Papantoniou, D.Kolokotsa, K.Kalaitzakis, D.N.Cesarini, E.Cubi dan C.Cristalli, "Adaptive lighting controllers using smart sensors," *International Journal of Sustainable Energy*, vol. 35, no. 6, pp. 537-553, 2014.

[23] J. B. a. C. Ross, Mechanical Engineering Principles, Abingdon, Oxon: Routledge, 2015, pp. 161-176.

[24] J. Bird dan C. T. Ross, Mechanical Engineering Principles (2nd ed.), London: Routledge, 2012, pp. 161-176.

[25] S. Escolar, J. Carretero, M. C. Marinescu dan S. Chessa, "Estimating energy savings in smart street lighting by using an adaptive control system," *International Journal of Distributed Sensor Networks*, pp. 1-17, 2014.

[26] A. I. Systems, "College Physics Labs Mechanics, "Measurements and Error Analysis"," The

Submitted: 7 April 2022; Revised: 15 April 2022; Accepted: 28 April 2022; Published: 30 April 2022

University of North Carolina at Chapel Hill, 2011. [Online]. Available: http://www.webassign.net/question_assets/unccolphysmechl1/measurements/manual.html.