Adaptive System for Streetlights in the Shopping Center Area of Purwakarta Region using Fuzzy Logic Method

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Received: October 18, 2023; **Accepted**: November 27, 2023

***Abstract*—Streetlight systems generally use time condition as the *parameter*, which set the lights to be always on during specified period. This way, the system has flaws in its inefficiency and ineffectiveness. The system designed in this research considers the intensity of surrounding lights and passing pedestrians as the parameters, and fuzzy logic to get fuzzier output of the luminosity level for the streetlight. From the results of testing and analysis, it can be concluded that the design in this research has been successfully built as the results obtained are in accordance with the previously set fuzzy logic universe of discourse. By implementing an adaptive street lighting system in this study can help streamline light energy, because the street lighting lights can adjust themselves depending on the presence or absence of pedestrians passing by using a PIR sensor and the level of light brightness in that place using an LDR sensor.**

***Keywords*—Streetlight systems, surrounding lights, passing pedestrians, fuzzy logic**

I. Introduction

Streetlight systems generally use time condition as the parameter. This set the lights to be always on during the specified period [1]. When in reality, there is no street with fixed frequency of passing pedestrians. For example, the numbers of pedestrians passing through shopping centers in Purwakarta, Yogyakarta, Bandung, Jakarta, and other big cities in the afternoon will certainly be different from the number of pedestrians in the evening or early in the morning. The lights are constantly illuminating with the same power and intensity during high or low frequency of pedestrians, although the demand for luminance is different in these conditions. As a result, some energy is unused and wasted when there's low frequency of pedestrians or no pedestrians at all [2]. Therefore, it is necessary to adjust the luminosity level according to the frequency of pedestrians, and the intensity needed according to the standard (SNI No. 04-6262-2000) [3], [4].

Shopping centers are among the favored places to visit that are always crowded [5]. Therefore, the shopping center area requires special management and setting of the streetlight systems, especially in the pedestrian area along the road. Besides paying attention to the efficiency and effectiveness of the technology usage, this setting also considers the aesthetic and comfort factors of visitors, which in this case is the right level of luminance [6]. The lights produced by the streetlight system in the shopping center area must provide comfort to visitors. Luminosity level that is either too faint or too bright will make visitors feel uncomfortable. Lighting system without management can be seen in figure 1.

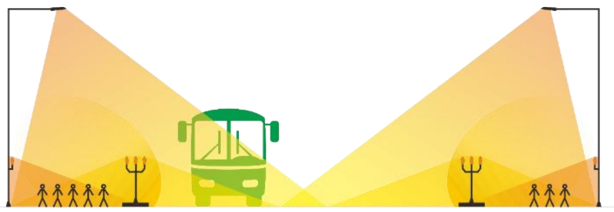

Fig. 1. Unmanaged Lighting System

One of the methods to manage a streetlight system to be in accordance with standards and comfort is to adjust the level of the brightness or dimness, often referred to as dimming [7], [8]. The luminosity value (dimming profile) is set according to the needs of the pedestrians and the current brightness in the surrounding environment (ambience light). Streetlight systems in shopping center areas in big cities can be derived from several lamps such as high mounting poles, antique poles, tree spotting poles, and wall mounted poles. However, the brightness intensity level management is only focused on the wall mounted pole lamp. Setting the intensity level of wall mounted pole lights requires adaptivity and semanticity, which can be obtained by using fuzzy logic [9].

Fuzzy logic is an alternative to boolean logic that only consists of 0 or 1 as its binary membership values. This way, the values can be defined as fuzzier values [10]. The values can later be processed by a computer to apply a way of thinking that is more similar to the way humans think. Various technologies in various fields have widely applied fuzzy logic, such as washing machines, refrigerators, and air conditioners [11]. In this research, fuzzy logic is used to define the output of luminosity level based on the pedestrian availability and the intensity of the surrounding lights.

The bottom line is that general streetlight systems don't consider the intensity of surrounding lights and passing pedestrians resulting in bad efficiency and effectiveness. The prototype in this research was designed specifically for that reason.

II. METHODS

This research will design a prototype of an adaptive street light system based on the surrounding lights and pedestrians. The method used in the design of this prototype is a waterfall methodology. Waterfall methodology is one of the SDLC (System Development Life Cycle) methods with a systematic and sequential approach, which means that the design of this prototype is carried out in stages and sequentially [12]. The flowchart of this waterfall methodology can be seen in the figure below.

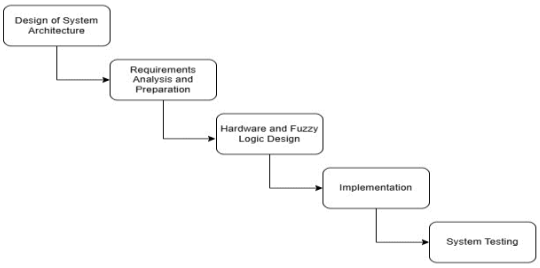

Fig. 2. Waterfall Methodology Flowchart

A. *Design of System Architecture*

This first stage is where the system architecture for the prototype in this research is designed. The steps of the system architecture design are presented in flowchart form in figure below.

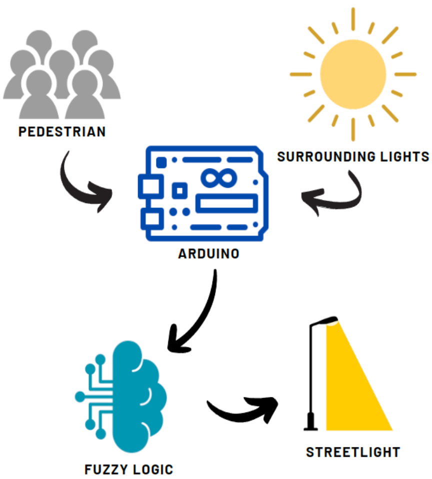

Fig. 3. System Architecture Flowchart

As presented in figure 2, the system starts from acquiring surrounding data of available pedestrian and light intensity. The data will be acquired by the sensors (PIR sensor for the pedestrian availability and LDR sensor for the lights intensity), which then will be used to calculate the luminosity level for the streetlight through a fuzzy logic calculation.

B. *Requirements Analysis and Preparation*

The components required for the prototype are presented in table 1.

TABLE I. HARDWARE COMPONENTS

No	Components Name
1	Arduino Uno R3
2	PIR Sensor
3	LCD 16x2 (I2C Module)
4	IRFZ44N Mosfet
5	12-volt LED
6	Project Board
7	24-volt Power Adapter Variable
8	Jumper Cable
9	Arduino Cable
10	USB Power Adapter

C. *Hardware and Fuzzy Logic Design*

This is where the hardware will be designed according to the previously described requirements and architecture, and where the fuzzy logic universe of discourse will be designed. The hardware is designed through an online circuit simulator, Autodesk TinkerCAD, and can be seen in figure 4.

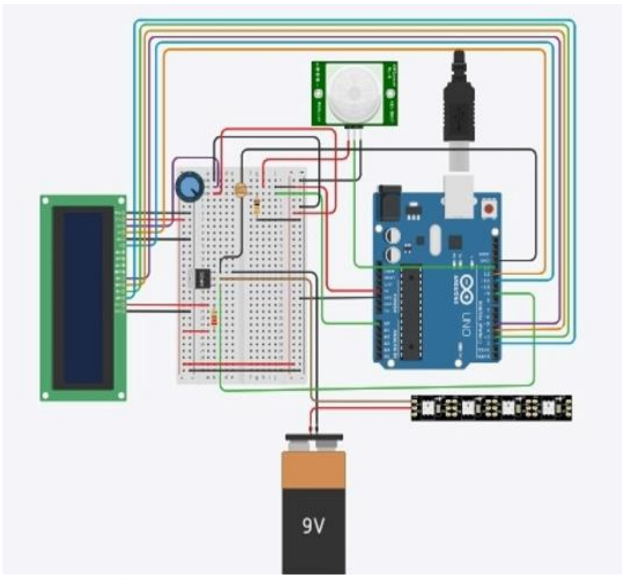

Fig. 4. Hardware Design

As presented in the figure above, the LCD, PIR sensor, and LDR sensor are connected and use the power from Arduino. Whereas the LED is using the power from the power adapter variable (the simulator uses battery because of unavailability issue), and is connected through the IRFZ44N mosfet to have the output calculated from fuzzy logic.

As previously explained, the fuzzy logic is used instead of boolean logic to get the light intensity setting based on the passing pedestrian (PIR sensor) and surrounding luminosity level (LDR sensor) [13]. The universe of discourse and rules can be seen in tables below.

TABLE II. FUZZY LOGIC UNIVERSE OF DISCOURSE

	Variable	Set	Interval
Input 1	PIR	Very Bright	600, 800, 800, 1023
		Bright	400, 600, 600, 800
		Dim	300, 400, 400, 600
		Dark	0, 0, 300, 400
Input 2	PIR	Present	0.4, 0.6, 1, 1
		Absent	-0.4, 0, 0.4, 0.6
Output	LED	Off	-2, -1, 0, 0.01
		Dim Light	1, 20, 20, 40
		Bright Light	40, 70, 70, 90
		Very Bright Light	95, 100, 100, 100

TABLE III. FUZZY LOGIC RULES

If		Then
PIR	***LDR***	***LED***
Present	Very Bright	Off
Present	Bright	Dim Light
Present	Dim	Bright Light
Present	Dark	Very Bright Light
Absent	Very Bright	Off
Absent	Bright	Off
Absent	Dim	Dim Light
Absent	Dark	Bright Light

D. System Testing

Once all the designs have finished, it is mandatory to do system testing. The tests consist of two types of testing, white box testing and black box testing.

1) Black Box Testing

In the black box testing, hardware functionality will be tested opaquely (without knowing how it works internally). For example, the prototype is tested whether it will function properly and accordingly, or will it need to be fixed, without knowing the internal structure and coding [14].

2) White Box Testing

White box testing is the opposite of black box testing, whereas the prototype will be tested transparently (involve testing the internal components and coding) [15].

After all the tests needed are done, the streetlight system prototype is ready for data acquisition. The data acquisition is conducted according to all the fuzzy set and rules.

III. RESULTS AND DISCUSSIONS

In the data collection process, the first step is the system testing stage. Adaptive street lighting system in the shopping center area in Purwakarta is performed using MATLAB software as a reference for the final value of fuzzification calculation so that the final value of fuzzification calculation can be compared. As a reference for the final value of the fuzzification calculation so that the final value of the lamp output can be compared with the fuzzification calculation process in MATLAB. Testing is done by running the tool and trying sensors under certain conditions, then the value read by the LDR and PIR sensors is entered into MATLAB input and a comparison is taken by looking at the fuzzification of the lamp output in MATLAB and the results of the LCD display tool.

After all the circuits are designed in the design of a street light lighting control system in a shopping center in the Purwakarta area using fuzzy logic, the system can be tested with several conditions. The circuit that has been designed and formed in a mockup as shown in the figure 5.

Fig. 5. Street lighting adaptive system mockup

A. Testing in very bright conditions

The very bright state of this system is analogized during the day with a light intensity value of the LDR of > 600 lux. While the PIR value = 1 indicates movement or the presence of pedestrians, if the PIR value = 0 then there are no pedestrians passing by. At the time of testing the LDR value displayed by the LCD is 688, the PIR sensor = 1 then the lamp output is dim as shown in figure 6.

Fig. 6. Testing using the LDR = 688 and PIR = 1 condition tool

The results of the test values in figure 6 will be entered into MATLAB software for comparison of design and testing as shown in figure 7.

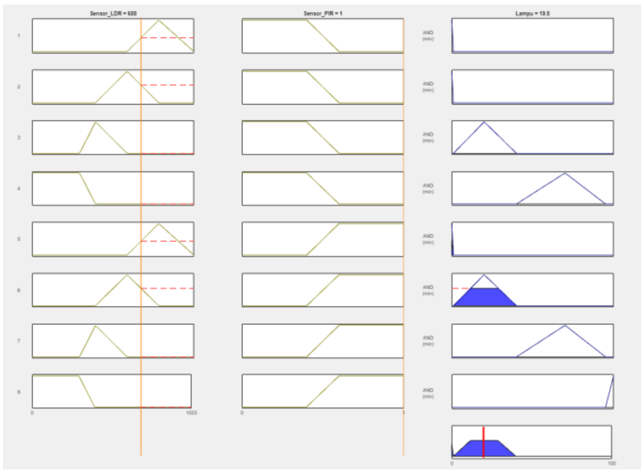

Fig. 7. Test rule state of LDR = 688 and PIR = 1 lights on dimly using MATLAB GUI

Furthermore, when testing the LDR value displayed by the LCD is 685, the PIR sensor = 0 then the light output is off as shown in figure 8.

Fig. 8. Testing using the LDR = 685 and PIR = 0 condition tool

The results of the test values in figure 8 will be entered into MATLAB software for comparison of design and testing as shown in figure 9.

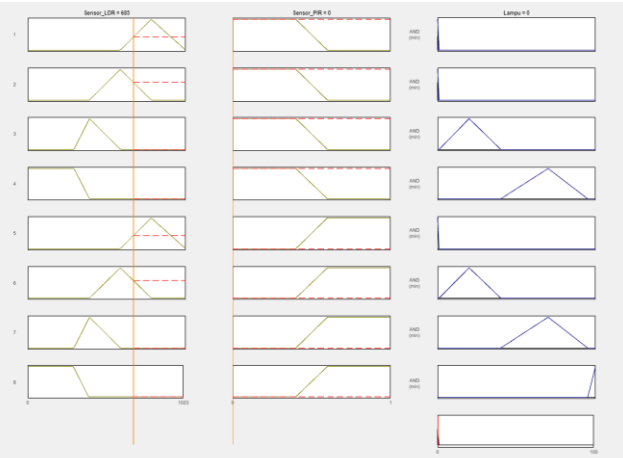

Fig. 9. Test rule state of LDR = 685 and PIR = 0 lights off using MATLAB GUI

B. Testing in bright conditions

Testing in bright light conditions has an LDR light intensity value > 400 lux. While the PIR value = 1 indicates the movement or presence of pedestrians, if the PIR value = 0 then there are no pedestrians passing by. At the time of testing the LDR value displayed by the LCD is 408, the PIR sensor = 1 then the lamp output is dim as shown in Figure 10.

Fig. 10. Testing using the LDR = 408 and PIR = 1 condition tool

The results of the test values in figure 10 will be entered into MATLAB software for comparison of design and testing as shown in figure 11.

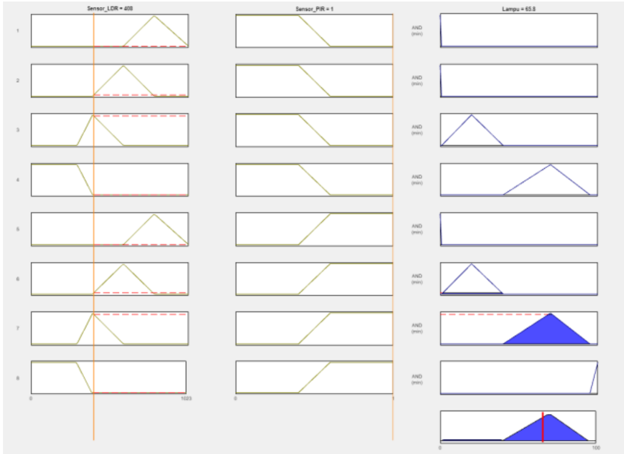

Fig. 11. Test rule state of LDR = 408 and PIR = 1 lights on brightly using MATLAB GUI

Furthermore, when testing the LDR value displayed by the LCD is 423, the PIR sensor = 0 then the light output is dim as shown in figure 12.

Fig. 12. Testing using the LDR = 423 and PIR = 0 condition tool

The results of the test values in figure 12 will be entered into MATLAB software for comparison of design and testing as shown in figure 13.

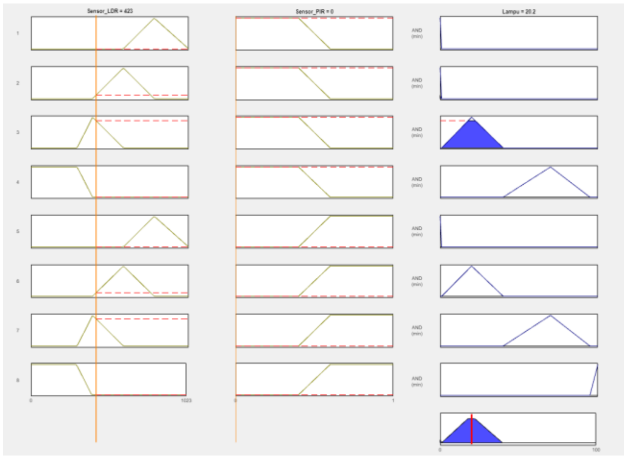

Fig. 13. Test rule state of LDR = 423 and PIR = 0 lights on dimly using MATLAB GUI

C. Testing in dim conditions

Testing in bright light conditions has an LDR light intensity value > 200 lux. While the PIR value = 1 indicates the movement or presence of pedestrians, if the PIR value = 0 then there are no pedestrians passing by. At the time of testing the LDR value displayed by the LCD is 210, the PIR sensor = 1 then the lamp output is very bright as shown in Figure 14.

Fig. 14. Testing using the LDR = 210 and PIR = 1 condition tool

The results of the test values in figure 14 will be entered into MATLAB software for comparison of design and testing as shown in figure 15.

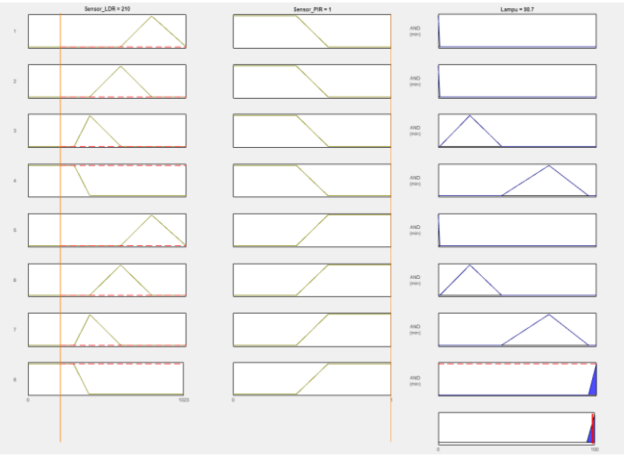

Fig. 15. Test rule state of LDR = 210 and PIR = 1 lights on very brightly using MATLAB GUI

Furthermore, when testing the LDR value displayed by the LCD is 200, the PIR sensor = 0 then the light output is bright as shown in figure 16.

Fig. 16. Testing using the LDR = 200 and PIR = 0 condition tool

The results of the test values in figure 16 will be entered into MATLAB software for comparison of design and testing as shown in figure 17.

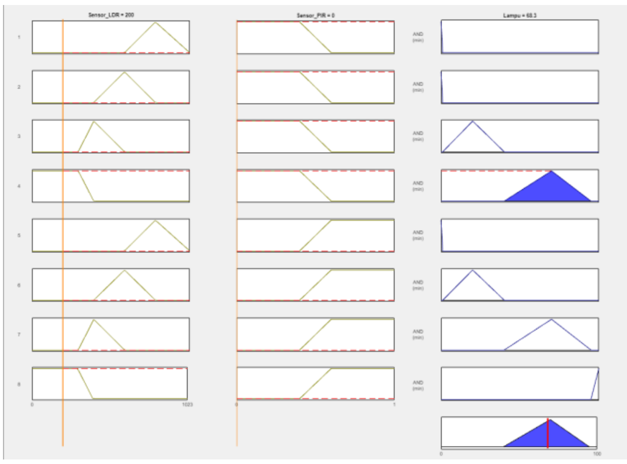

Fig. 17. Test rule state of LDR = 210 and PIR = 1 lights on brightly using MATLAB GUI

D. Testing in dark conditions

Testing in dark light conditions (night time) has an LDR light intensity value > 0 lux. While the PIR value = 1 indicates the movement or presence of pedestrians, if the PIR value = 0 then there are no pedestrians passing by. At the time of testing the LDR value displayed by the LCD is 1, the PIR sensor = 1 then the lamp output is very bright as shown in Figure 18.

Fig. 18. Testing using the LDR = 1 and PIR = 1 condition tool

The results of the test values in figure 18 will be entered into MATLAB software for comparison of design and testing as shown in figure 19.

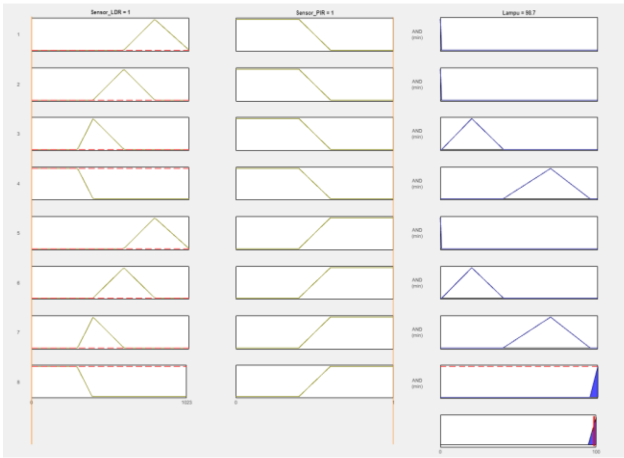

Fig. 19. Test rule state of LDR = 1 and PIR = 1 lights on very brightly using MATLAB GUI

Furthermore, when testing the LDR value displayed by the LCD is 2, the PIR sensor = 0 then the light output is bright as shown in figure 20.

Fig. 20. Testing using the LDR = 2 and PIR = 0 condition tool

The results of the test values in figure 20 will be entered into MATLAB software for comparison of design and testing as shown in figure 21.

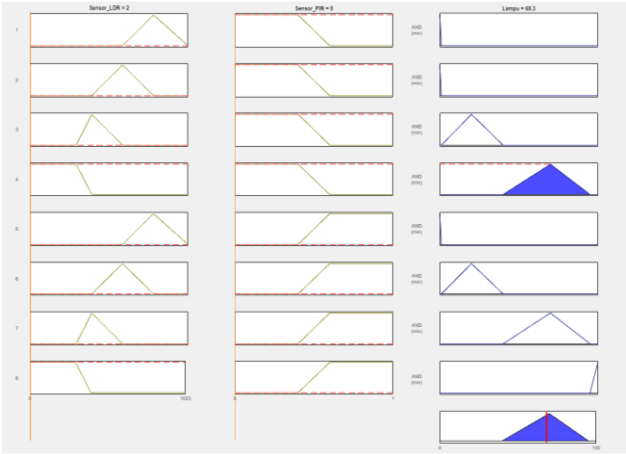

Fig. 19. Test rule state of LDR = 2 and PIR = 0 lights on brightly using MATLAB GUI

Based on testing with several categories of conditions such as very bright, bright, dim and dark conditions, it shows that the LDR and PIR values are in accordance with the fuzzification design or in accordance with the predetermined lux value range. The test results are in accordance with the system design made and the data obtained from the test can be seen in the summary table of test results below.

TABLE IV. FUZZIFICATION RESULT

Ambient light conditions	LDR sensor value (lux)	PIR sensor value	The meaning of PIR	Lights (%)	Lights
Dark	1	1	There is a pedestrian	98.7	Very bright lights
	2	0	None	68.3	Bright lights
Dim	210	1	There is a pedestrian	98.7	Very bright
	200	0	None	68.3	Bright lights
Bright	408	1	There is a pedestrian	65.8	Bright lights
	423	0	None	20.2	Dim lights
Very Bright	688	1	There is a pedestrian	19.8	Dim lights
	685	0	None	0	Off

Fuzzy logic consisting of fuzzier values makes it very efficient compared to boolean logic which only consists of 0 1. The comparison of using fuzzy logic and boolean logic can be seen in the table below (note that the voltage used in fuzzy logic is volatile but the results are more or less accurate).

TABLE V. COMPARISON OF FUZZY LOGIC AND BOOLEAN LOGIC

Condition	Logic	Ampere and Voltage	kWh	Efficiency Difference
Dark and there is no pedestrian	**Boolean**	24 V 3 A	0.07 2	Fuzzy is 19% more efficient
	Fuzzy	16.3 V 3 A	0.04 9	
Dark and there is a pedestrian	**Boolean**	24 V 3 A	0.07 2	Same efficiency (more or less)
	Fuzzy	24 V 3 A	0.07 2	
Bright and there is no pedestrian	**Boolean**	24 V 3 A	0.07 2	Fuzzy is 67% more efficient
	Fuzzy	4,8 V 3 A	0.01 4	
Bright and there is a pedestrian	**Boolean**	24 V 3 A	0.07 2	Fuzzy is 21% more efficient
	Fuzzy	15,6 V 3 A	0.04 7	

IV. CONCLUSIONS

From the results of testing and analysis, it can be concluded that the design of an adaptive street lighting system in the Purwakarta area shopping center area using fuzzy logic methods has been successfully built. With the Purwakarta regional shopping center area made in a mockup, then the adaptive street lighting system is made using an arduino uno R3 microcontroller, a PIR sensor as a pedestrian detector, and an LDR sensor as a detector of the brightness of the light in that place. In addition, the fuzzy logic method has been successfully applied to this prototype, the results obtained are in accordance with the universe of fuzzy logic. the test results on the tool compared to MATLAB GUI are also in accordance with the rules of fuzzy logic. Designing an adaptive system for street lighting in the Purwakarta shopping area can make the use of light energy more effective, because street lighting can adjust depending on pedestrians passing by and the level of light brightness in the area.

REFERENCES

[1] F. Marino, F. Leccese, and S. Pizzuti, “Adaptive Street Lighting Predictive Control,” Energy Procedia, vol. 111, pp. 790–799, Mar. 2017, doi: 10.1016/j.egypro.2017.03.241.

[2] G. Gagliardi et al., “Advanced Adaptive Street Lighting Systems for Smart Cities,” Smart Cities, vol. 3, no. 4, pp. 1495–1512, Dec. 2020, doi: 10.3390/smartcities3040071.

[3] A. A. Hafiz, “Implementasi Metode Fuzzy Logic Pada Intensitas Lampu di Laboratorium Berbasis Arduino,” J. SAINTIKOM J. Sains Manaj. Inform. Dan Komput., vol. 19, no. 2, p. 36, Jul. 2020, doi: 10.53513/jis.v19i2.2422.

[4] C. T. S. Manik, “Quality Analysis of Street Lighting Protocol of Pematang Siantar City,” J. Sci. Technol. JoSTec, vol. 1, no. 1, pp. 21–28, Dec. 2019, doi: 10.55299/jostec.v1i1.48.

[5] Hamdard University, Karachi and S. Nasim, “CONSUMER BEHAVIOR TOWARDS SHOPPING MALLS: A SYSTEMATIC NARRATIVE REVIEW,” IBT J. Bus. Stud., vol. 14, no. 1, pp. 81–94, 2018, doi: 10.46745/ilma.jbs.2018.14.01.07.

[6] G. Turesna, Z. Zulkarnain, and H. Hermawan, “Pengendali Intensitas Lampu Ruangan Berbasis Arduino UNO Menggunakan Metode Fuzzy Logic,” J. Otomasi Kontrol Dan Instrumentasi, vol. 7, no. 2, p. 73, Jan. 2017, doi: 10.5614/joki.2015.7.2.2.

[7] K. Arun Bhukya, S. Ramasubbareddy, K. Govinda, and T. Aditya Sai Srinivas, “Adaptive Mechanism for Smart Street Lighting System,” in Smart Intelligent Computing and Applications, vol. 160, S. C. Satapathy, V. Bhateja, J. R. Mohanty, and S. K. Udgata, Eds., in Smart Innovation, Systems and Technologies, vol. 160. , Singapore: Springer Singapore, 2020, pp. 69–76. doi: 10.1007/978-981-32-9690-9_8.

[8] A. Avotins, L. R. Adrian, R. Porins, P. Apse-Apsitis, and L. Ribickis, “Smart City Street Lighting System Quality and Control Issues To Increase Energy Efficiency and Safety,” Balt. J. Road Bridge Eng., vol. 16, no. 4, pp. 28–57, Dec. 2021, doi: 10.7250/bjrbe.2021-16.538.

[9] G. Oltean and L.-N. Ivanciu, “Implementation of a fuzzy logic-based embedded system for temperature control,” in 2017 40th International Spring Seminar on Electronics Technology (ISSE), Sofia, Bulgaria: IEEE, May 2017, pp. 1–6. doi: 10.1109/ISSE.2017.8001006.

[10] M. Rahman, A. Shahriar, and E. Islam, “Power Saver: Intelligent Streetlight Systems Using Fuzzy Logic”.

[11] S. Kambalimath and P. C. Deka, “A basic review of fuzzy logic applications in hydrology and water resources,” Appl. Water Sci., vol. 10, no. 8, p. 191, Aug. 2020, doi: 10.1007/s13201-020-01276-2.

[12] E. B. Kristanto and S. Andrayana, "Application of Waterfall SDLC Method in Designing Student's Web Blog Information System at the National University," vol. 4, no. 36, 2020.
[13] "Fuzzy Logic Toolbox User's Guide".
[14] C. Henard, M. Papadakis, M. Harman, Y. Jia, and Y. Le Traon, "Comparing white-box and black-box test prioritization," in Proceedings of the 38th International Conference on Software Engineering, Austin Texas: ACM, May 2016, pp. 523–534. doi: 10.1145/2884781.2884791.