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Real-Time Lighting Control System for Smart Home Applications

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ABSTRACT

The use of pervasive computing in the context of home automation equipment will greatly facilitate life. Several buildings still use manual switch to turn on or turn off the lighting system. It becomes ineffective if the house has a lot of lights and a high level and sometimes forget to turn off. Hence, the real-time control system for automatic lighting processing is desirable. An automatic control system will allow to control the illumination and it will be decrease the energy costs. In this paper, the Fuzzy logic system-based Mamdani style is used to adjust the intensity of the lights. Based on simple algorithm the controller board is working in a real-time condition. As a result found, the implementation is successfully to control the lighting system with good performance. Thus, the fuzzy system can be built smart home concept that facilitate the human life.

Keywords: pervasive computing, fuzzy mamdani, lighting control, smart home

1. INTRODUCTION

Smart home is a building equipped with high technology that allows various systems and devices to communicate with each other. As digital technologies are converging, the field of home automation is expanding. Various smart home control system has been developed including the control system with Blue-tooth [1-6], internet [7-9], and short message service [10]. Bluetooth capabilities are good equipment with low prices, and it can reduce the cost of the system. However, by using Bluetooth the range of environment is limited, and it is not feasible solution to implement. The Wi-Fi based home automation have proposed with good result [11]. It uses a PC (with built in Wi-Fi card) based web server that manages the connected home devices. The users can manage and control the system locally (LAN) or remotely (internet). The system supports a wide range of home automation devices like power management components and security components [12]. Other papers proposed internet controlled systems based on web server, database and a web page for interconnecting and managing the devices [13-20]. However, a PC is used as a server that increases the cost and power consumption while others require web page hosting that adds up the extra cost.

Moreover, several approaches used to provide optimal control to process the communication of all equipment in smart home. The supervisory control based models on renewable energy systems and evolutionary algorithms are used to obtain the optimal settings [3]. Min-max optimization technique to overcome demand response problems is proposed, especially during peak load conditions where electricity consumption and peak power usage in a building must be controlled [4]. The predictive control system is utilized to control temperature in buildings [4] [5], then similar studies using fuzzy predictive control [7] and neural network models [8]. Dynamic programming approach also develop for building cooling systems [9]. But, in the controller algorithm design, the computational complexity must be important to analysis before it implement. Due to all the system in smart home will operate in real-time condition.

In the smart home application, to control the lighting system is important, due to the efficiency of electricity consumption. To turn on and turn off the lights in the home always use the conventional switch. It is not effective, especially if the building has many levels that are light on each floor. Lighting contributed as much as 20-60% of the total consumption of electric power consumption [21], therefore it would be a waste of energy if the lights are forgot to turn off. Therefore, the lighting control system is needed to overcome such condition. The tasks become easier and produce an effective way. Lighting control in a smart home system is a computer-aided system that takes place automatically and programmed by computer, in a building or residence [22]. The control commands can be done by simply pressing a button on the gadget, or through automated systems that can detect the environment by itself [23]. Remote monitoring technology used allows the user to monitor the state of the house in real-time [24][25]. However, the algorithm must be in simple process with good results, due to it works in the real-time condition. In addition, the algorithm must be robust with the uncertainty, and imprecision because several sensors are used as an input parameters.

2. SYSTEM DESIGN

2.1 SYSTEM ARCHITECTURE

In order to run automatically, the lighting system need some sensors to control the illumination of each lamp, to regulate the lamp condition (on or off) and to detect the situation out of the home. However, the sensor always produce imprecision when it measures the condition. In the real world, there are many natural conditions that will affect the sensor readings such as in the morning, noon, night and when it rains and overcast. It means the controller must compensate the dynamic environment, it becomes an uncertainty parameter. To overcome the computational complexity and robust with the uncertainty and imprecision in the real time, the Fuzzy Logic system is proposed with Mamdani style. The fuzzy logic system work and produce good performance under uncertain and imprecision situation [26]. In this paper, the decision control about the lighting system is designed based on the Fuzzy Mamdani style [26].

The system architecture of lighting system including control and monitoring system are created by using a server computer and Android mobile devices (see Figure 1). To support communication between the microcontroller and computer servers USB Serial Interface is utilized. The system works in three conditions, automatic, manual and with timer. Each condition defines the method of control to adjust the lights. For automatic condition, the system will apply the fuzzy system with Mamdani style to determine lights where input will be obtained from the two light sensors placed inside and outside the room. For the manual condition, the lights will be set by the

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user through the interface android. Users can adjust the lighting become off, fair or on. As for the condition of the timer, lights will be set off or on at certain time according to the user wishes. The benefits that can be obtained that can facilitate control of the lights in the house and provide security and comfort in light control, even from far away.

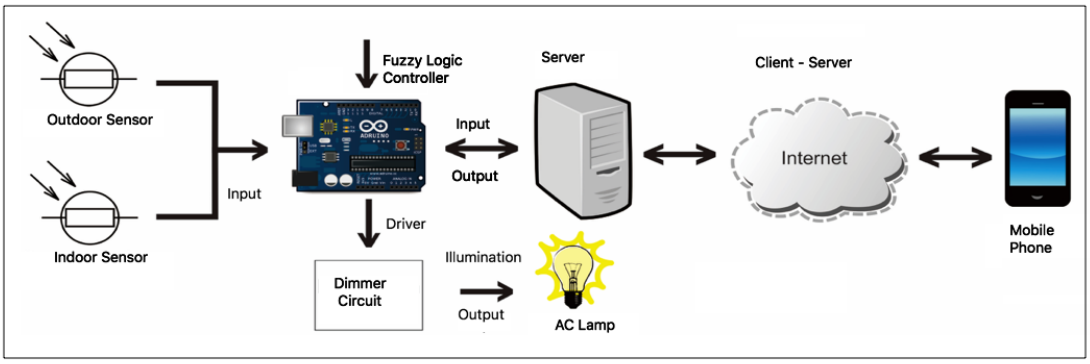

FIGURE 1. Topology design

2.2 CONTROL BOARD SYSTEM

The hardware device of control board is contained arduino microcontroller, LDR sensors, Triac and Dimmer, lights, PC and mobile phone. The arduino Uno is a microcontroller board based on the ATmega328. This board has 14 digital Input/output pins, with 6 analog inputs, and 16 MHz crystal oscillator. The sensor system for detecting the environmental condition is based-on LDR is a resistor that has resistance depends on the intensity of light that surrounds the surface. In this research, the MOC3020 Triac is used as drivers using optical isolation (optocoupler). Triac is a semiconductor component that is composed of four layers of structured PNPN diode with three PN junction [5]. Triac will be connected (on) when in quadran 1 that when a small positive current to pass through the gate terminal MT1, MT2 and higher polarity than MT1. At the time of the triac is connected (on) then fell forward voltage between terminals MT1 and MT2 are very small ranging from 0.5 volts to 2 volts. AC dimmer circuit serves to adjust the level of light intensity incandescent lamp lighting. All the hardware connection can be seen in Figure 2.

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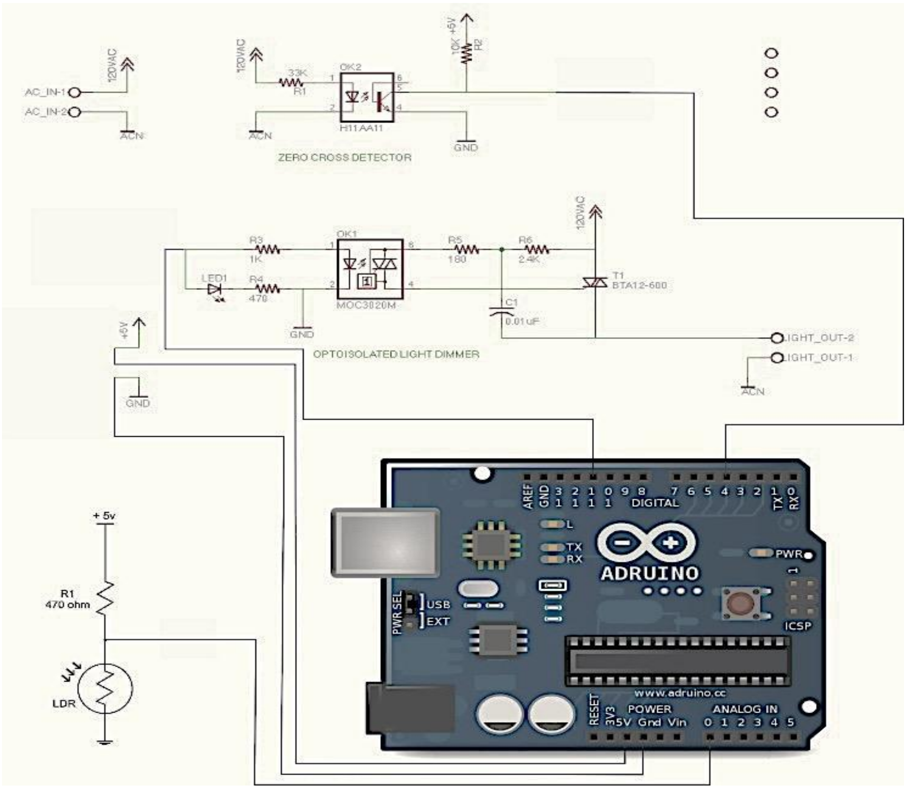

FIGURE 2. The control board with adruino

2.3 CLIENT-SERVER

In this paper, the webserver used to bridge between the user and the microcontroller. The command from the user will be entered into a server and it processed back to the microcontroller, and vice versa. A server is a running instance of an application (software) capable of accepting requests from the client and giving responses accordingly. Servers can run on any computer including dedicated computers, which individually are also often referred to as "the server".

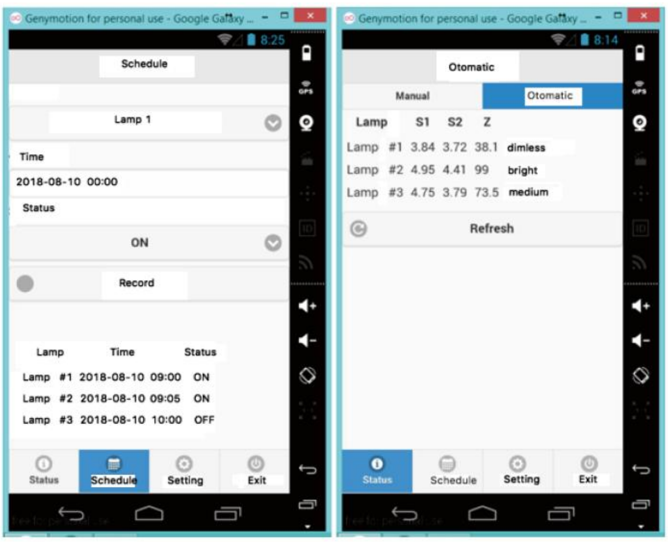

FIGURE 3. User interface

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The mobile phone is used as an interface for the user/client. Users can control or monitoring of the condition of the lights using its Android mobile devices. The program has two main window is divided into screen mode automatic / manual and timer mode. In automatic mode / manual, if the slide is selected in the automatic mode, the screen will display the status of each - each lamp and illumination conditions. While in manual mode, the user can adjust the lights as you wish. The visual of the process can be seen in Figure 3, for the timer mode the user can set the date and time to determine the status of the lamp.

3. THE FUZZY REAL-TIME CONTROL DESIGN

This section will be made a software to build a system to work as expected. System software includes a microcontroller, android php server and client.

3.1 FUZZY MAMDANI MODELS

Mamdani Fuzzy method used for producing good accuracy in the crisp output, due to it works in a real-time situation with environmental change every time. In this paper Arduino microcontroller is utilized to process the input and to create an automated system of the lights. Determination of the variables used in this study, shown in Table 1.

TABLE 1.
Range area for each variable

Function	Variable	Range Area
Input	Outdoor Sensor	[0,5]
	Indoor Sensor	[0,5]
Output	Ilumination	[0,128]

Fuzzy association along with the membership function (MFs) of the variable external and internal sensors. The fuzzy linguistic the sensor output is intensity are represented in the following: the outside sensor variables defined three fuzzy sets, such as Small, Medium, and Big. The fuzzy MFs set for variable intensity is defined based on the equation as follows;

$$\mu Small = \begin{cases} 1\ ;\ x \le 3{,}5 \\ \frac{(3{,}9-x)}{(3{,}9-3{,}5)}\ ;\ 3{,}5 < x \le 3{,}9 \\ 0\ ;\ x > 3{,}9 \end{cases} \quad (1)$$

$$\mu Medium = \begin{cases} 0\ ;\ x \le 3{,}7 \\ \frac{(x-3{,}7)}{(4{,}1-3{,}7)}\ ;\ 3{,}7 < x \le 4{,}1 \\ \frac{(4{,}5-x)}{(4{,}5-4{,}1)}\ ;\ 4{,}1 < x \le 4{,}5 \\ 0\ ;\ x > 4{,}5 \end{cases} \quad (2)$$

$$\mu Big = \begin{cases} 0\ ;\ x \le 4{,}3 \\ \frac{(x-4{,}3)}{(4{,}7-4{,}3)}\ ;\ 4{,}3 < x \le 4{,}7 \\ 1\ ;\ x > 4{,}7 \end{cases} \quad (3)$$

Illumination is obtained based on the fuzzy set lux values are represented using fuzzy sets. In variable illumination defined five fuzzy sets, ie Dim, Dim Less, Medium, Light Less, Bright. The fuzzy MFs set for variable illumination is defined based on the equation as follows:

$$\mu Dim = \begin{cases} 1\ ;\ x \leq 21{,}3 \\ \frac{(42{,}6-x)}{(42{,}6-21{,}3)}\ ;\ 21{,}3 < x \leq 42{,}6 \\ 0\ ;\ x > 42{,}6 \end{cases} \quad (4)$$

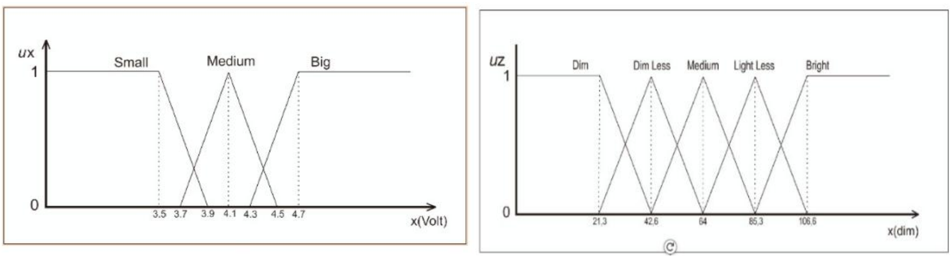
$$\mu DimLess = \begin{cases} 0\ ;\ x \leq 21{,}3 \\ \frac{(x-21{,}3)}{(42{,}6-21{,}3)};\ 21{,}3 < x \leq 42{,}6 \\ \frac{(64-x)}{(64-42{,}6)}\ ;\ 42{,}6 < x \leq 64 \\ 0\ ;\ x > 64 \end{cases} \quad (5)$$

$$\mu Medium = \begin{cases} 0\ ;\ x \leq 42{,}6 \\ \frac{(x-42{,}6)}{(64-42{,}6)};\ 42{,}6 < x \leq 64 \\ \frac{(85{,}3-x)}{(85{,}3-64)}\ ;\ 64 < x \leq 85{,}3 \\ 0\ ;\ x > 85{,}3 \end{cases} \quad (6)$$

$$\mu LightLess = \begin{cases} 0\ ;\ x \leq 64 \\ \frac{(x-64)}{(85{,}3-64)};\ 64 < x \leq 85{,}3 \\ \frac{(106{,}6-x)}{(106{,}6-85{,}3)}\ ;\ 85{,}3 < x \leq 106{,}6 \\ 0\ ;\ x > 106{,}6 \end{cases} \quad (7)$$

$$\mu Bright = \begin{cases} 0\ ;\ x \leq 85{,}3 \\ \frac{(x-85{,}3)}{(106{,}6-85{,}3)}\ ;\ 85{,}3 < x \leq 106{,}6 \\ 1\ ;\ x > 106{,}6 \end{cases} \quad (8)$$

From the fuzzy MFs in equation (1) to (8), can be described in a graph are shown in Figure 4 (a) and 4 (b). The horizontal axis represents the 2 values, such as the variable input sensor (indoor sensor and outdoor sensor) of intensity and the output of illumination, while the vertical axis represents the fuzzy degree of memberships.



(a) Fuzzy input (b) Fuzzy output

FIGURE 4. Membership functions

The formation of fuzzy sets, then carried after the fuzzification process. The rules established to express the relation between input and output. Each rule is an

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implication. Operators are used to connect between the two inputs is the AND operator, and which maps between the input-output is IF-THEN. IF the proposition that follows the so-called antecedents, while the proposition that follows THEN is called the consequent. Based grouping illumination, it can be deigned the fuzzy rules, all rules can be shown in Table 2 as follows:

TABLE 2.
Rules determining illumination lamp

		Outdoor Sensor		
		Small	Medium	Big
Indoor Sensor	Small	Dim	Dim less	Medium
	Medium	Dim less	Medium	Light less
	Big	Medium	Light less	Bright

3.2 CLIENT-SERVER SYSTEM

This is a phase to process the interfacing between the microcontroller and the end user. The server will read the status of the microcontroller and will provide monitoring results to the user device. Likewise, when there is a command from the user, then the server will give the command to be executed on a microcontroller. The response and command the microcontroller can be seen in the Table 3.

TABLE 3.
The response and command from microcontroller

Input	Output	Information
A	A A	Lamp 1 On, Mode Manual
B	A B	Lamp 1 Medium, Mode Manual
C	A C	Lamp 1 Off, Mode Manual
D	B A	Lamp 2 On, Mode Manual
E	B B	Lamp 2 Medium, Mode Manual
F	B C	Lamp 2 Off, Mode Manual
G	C A	Lamp 3 On, Mode Manual
H	C B	Lamp 3 Medium, Mode Manual
I	C C	Lamp 3 Off, Mode Manual
J	D A	Lamp 1 On, Mode Timer
K	D B	Lamp 1 Off, Mode Timer
L	E A	Lamp 2 On, Mode Timer
M	E B	Lamp 2 Off, Mode Timer
O	F A	Lamp 3 On, Mode Timer
P	F B	Lamp 3 Off, Mode Timer
Q	G A	Mode Manual / Timer
R	G B	Mode Automatic
S	H A	Status Information

4. RESULTS AND DISCUSSION

4.1 INITIAL SETTING

In this paper, there are two phase of testing such as initial and automatic testing. When it processes in the initial setting phase, all lamps are set manually by the user for initial setting. The test results are as follows: Input from the server ie "A" where the microcontroller will respond with an output of "A A" to be received by the server, which means the status Lamp 1 turned into on conditions. It setting for several values conditions. The sample status output in parameter voltage can be seen in Figure 5.

FIGURE 5. Response servers, lamp and light, voltage when input A

All inputs are repeat for setting in initial experiment to produce the input data of fuzzy controller (lamp 1, lamp 2 and lamp 3). For example, if the server send variable "E", the microcontroller will respond with an output of "B and B" to be received by the server. It means the status Lamp 2 is turned into medium condition. Input from the server is "H" where the microcontroller will respond with an output of "C and C" to be received by the server. It means the status Lamp 3 is turned into off condition. The setting for making the input data base, all values are summarized in Table 3.

4.2. AUTOMATIC MODE

The other stage is automatic mode after initial setting. In such process, it will be tested on the condition of each lamp that set automatically by the microprocessor based on the sensor values. Testing is done by taking the data sampling device conditions at every hour for 24 hours.

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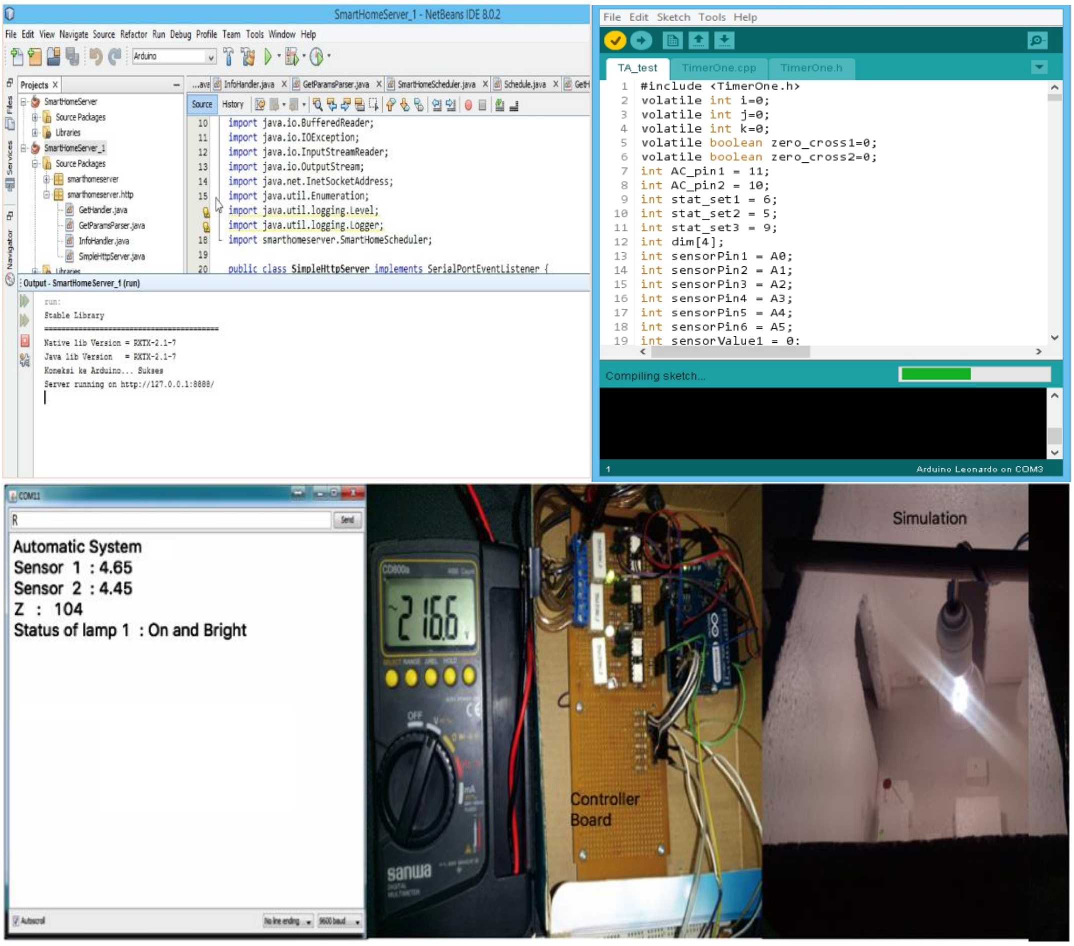

FIGURE 6. Automatic system experiment with client-server process

The process sampling of data captured includes affairs sensor voltage, the voltage sensor in, the voltage at the output of the lamp and the values calculated by fuzzy on the program. All external sensors placed on an open space in in door and out door. The fuzzy controller works on the automatic mode, when it regulates the illumination of each lamp (see Figure 6). By using 2 LDR sensors, the value of intensity is converted into voltage. Due to the controller only receive the digital value. After the fuzzy control is proceed the output in form of voltage, it converts again to the lamp state in the illumination value. All response of fuzzy controller can be seen in Table 4.

From the data in Table 4, we can make a graph the controller response when it controls the lighting system. It can be described in Figure 7 (a) show about the intensity response and Figure 7 (b) show about the illumination output from the controller. From Table 4 and Figure 7, there is a relationship between fluctuations in the external sensors and in the determination of the value of illumination. Out-door sensor values have range of 3.41 V - 4.98 V, and the in-door sensor have range between 3.61 V - 4.45 V. The difference occurs because the sensor range in addition to outdoor light, the sensor will be affected also by the intensity of the light in the room. The most dominant value fluctuations occur when switching afternoon - evening or vice versa ie at 5:00 a.m. to 08:00 and at 15:00 to 18:00. By looking at the values in the table and the graph above, it can be seen that the relationship between the outer and inner sensor for the determination of the fuzzy output value is the value of illumination has been going well.

TABLE 4.
The real-time fuzzy lighting system responses

No	Time	Outdoor Sensor Value	Indoor Sensor Value	Ilum	Output Voltage	Lamp State
1	08.00	3,84 V	3,72 V	38,1	3,8 V	Dim less
2	09.12	3,81 V	3,71 V	33,2	3,8 V	Dim less
3	10.04	3,62 V	3,68 V	18,2	5,3 V	Dim
4	11.06	3,56 V	3,62 V	17,5	3,9 V	Dim
5	12.01	3,41 V	3,61 V	17,4	3,2 V	Dim
6	13.07	3,48 V	3,64 V	17,7	4,5 V	Dim
7	14.00	3,59 V	3,68 V	18,2	5,3 V	Dim
8	15.03	3,87 V	3,70 V	39,2	83,8 V	Dim less
9	16.05	4,23 V	3,73 V	45,8	97,8 V	Dim less
10	17.11	4,75 V	3,79 V	73,5	142,1 V	Medium
11	18.02	4,89 V	4,02 V	85,3	184,8 V	Light less
12	19.05	4,95 V	4,41 V	99	208,4 V	Bright
13	20.08	4,96 V	4,43 V	101	216,7 V	Bright
14	21.03	4,97 V	4,44 V	103	221,5 V	Bright
15	22.12	4,96 V	4,43 V	101	216,7 V	Bright
16	23.01	4,98 V	4,45 V	104	228 V	Bright
17	00.07	4,96 V	4,42 V	100	211,2 V	Bright
18	01.21	4,98 V	4,43 V	101	216,7 V	Bright
19	02.10	4,97 V	4,43 V	101	216,7 V	Bright
20	03.25	4,98 V	4,45 V	104	228 V	Bright
21	04.09	4,97 V	4,43 V	101	216,7 V	Bright
22	05.14	4,96 V	4,44 V	103	221,5 V	Bright
23	06.01	4,82 V	3,80 V	74,6	149 V	Medium
24	07.04	4,03 V	3,77 V	50	106,4 V	Dim less

Determining the value of illumination is not based on the value of the sensor in the sensor must be greater than the outside in order to get a great illumination value, but by using the fuzzy controller, the calculation of the value of the sensor outside and inside is conducted at the real-time condition. This can be seen from the data 1 and the data 12 in Table 4, both have value in a larger sensor than the sensor outside but different illumination output. In the data 1, the outside sensor has a value of 3.84 V which are included in the category of the input fuzzy set small and medium while the sensor has a value of 3.72 V which are included in the category of fuzzy set small and medium input. The output of illumination is obtained in the data 1 is about 38.1 with a rather dim light status. In contrast to the data 12, the outside sensor has a value about 4.95 V which are included in the category of large input fuzzy set while the sensor has a value of 4.41 V which are included in the category of medium and large fuzzy set. Illumination output the data obtained at 12 is 99 with the status of bright lights. For the relationship between the output voltage value and the illumination of the lamp can be seen that the increase in value would illumination linearly proportional to the increase in output voltage.

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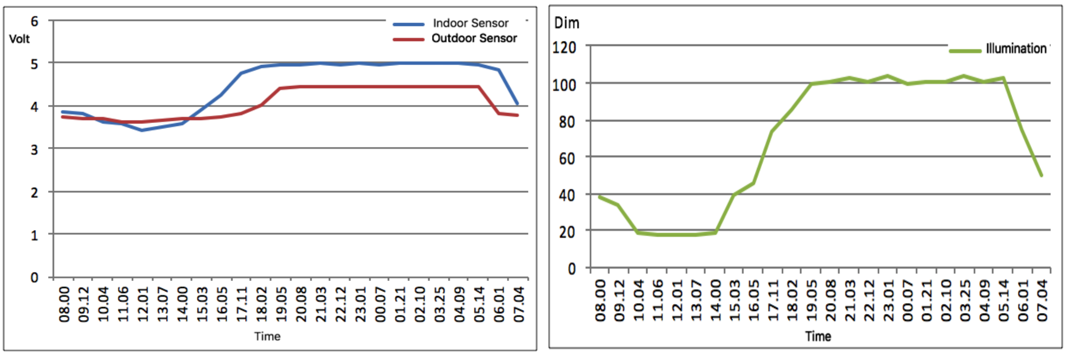
Moreover, it can be seen in Table 4, for the data 5 when the illumination value of 17.4, the output voltage will be small in the amount of 3.2 V. In the data 20 when a large illumination value is 104, the value of the output voltage will also be large in the amount of 228 V. Relationship between time and status lights have been going well. Shown in Table 4 when the lighting conditions require the status lights are on the light conditions. And when it does not need to be lighting the lamp status in dim conditions. On the other lamp status, the system will adjust according to lighting conditions received by the sensor.



(a) Outdoor and indoor sensor (b) Illumination

FIGURE 7. Input and output from the controller board based-on fuzzy mamdani

5. CONCLUSION

Based on the results found, it concludes that the LDR sensor is able to respond to environmental conditions respond well to the sensor or sensors in the outer, visible from the fluctuating value of the voltage sensor to changes in light intensity received. Determining the value of illumination has been done with fuzzy calculation of the value of the sensor inputs and external sensor. Large illumination value linearly proportional to the magnitude of the output voltage of the lamp, which means that the greater the value of illumination, the value of the output voltage will also increase. By setting the intensity of the lights swallow goes well according to the environmental conditions when the lighting conditions require the system will adjust the intensity of the light as needed. The real-time application is successfully implemented in lighting system with Fuzzy Mamdani Style with good performance, in terms of speed of controller response to control dynamically of the lamp illumination when the intensity change every-time.

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