Modeling of Fuzzy Logic Control System for Controlling Homogeneity of Light Intensity from Light Emitting Diode

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***Abstract*—The use of Light Emitting Diode (LED) as the lighting device becomes popular due to its energy-efficient characteristic. However, LED has radiation angle that is relatively smaller than other types of lighting device. This results in heterogeneity of light intensity that received by particular point near the LED. To obtain homogeneity of light intensity, this paper proposes a model of fuzzy logic control system to control illumination of LEDs lamp in a room. This model involves several components, namely LEDs lamp, LED driver, illumination sensor, microcontroller, and a differential transceiver RS-485. The fuzzy logic control system that used in this model uses error of illumination and delta error of illumination as input parameter. As output, this control system will change duty cycle of Pulse Width Modulation (PWM) that used to control illumination of LEDs lamp. Based on experiment result, when expected light intensity is set to 150 Lux, homogeneity of light intensity can be achieved with error less than 2%. In addition, the control system also can reduce energy consumption up to 40% under the experimental environment.**

Keywords-component; modelling; fuzzy logic; light intensity control

I. INTRODUCTION

Rapid advancement of technology has enabled production of energy-saving devices, including many types of lighting device ranging from fluorescent lamp to Light Emitting Diodes (LEDs) lamp. The LEDs lamp has been widely used as lighting device because of its energy-efficient feature [1, 2]. On an equivalent level of energy consumption, LEDs lamp can produce higher illumination than other types of lamp such as fluorescent or incandescent lamp [3]. Another advantage is the LEDs lamp can be operated at a fairly wide range of currents. This allows setting of LED illuminations on wide range of illumination level [2].

The use of LEDs lamp that combined with energy management system will result a significant improvement of energy-efficiency. With the energy management system, energy wastage can be reduced by adjusting the room illumination as needed. There are two methods of illuminations control in a room, namely ON/OFF control [4] and dimming control [2, 5]. The ON/OFF control can turn off and turn on lamp as needed, while the dimming control is not only able to turn off and turn on the lamp, but also able to adjust illumination level of the lamp.

The illumination control is not only about how to reduce energy consumption. It also has to maintain homogeneity of light intensity in a room. It is because the homogeneity of light intensity will affect the level of human comfort when doing activity in the room.

II. BACKGROUND OF PROBLEM

The use of LEDs lamp may become energy-efficient lighting solutions. However, the LEDs lamp has problem of light intensity heterogeneity [6]. This problem is occurred due to the small radiation angle of LEDs when compared with other types of lamps. So that light intensity that received on the particular side of the LED will vary depending on direction of the LED radiation. The LED also has non linear characteristic of V-A and temperature that causes every LED has different radiation pattern [7]. Moreover, external light radiation becomes another factor that also affects homogeneity of light intensity.

The homogeneity of light intensity can be achieved by placing a number of LEDs lamps in a room. By this manner, dark point near of an LED lamp can be covered by illumination from another LEDs lamp. This method requires a control system to adjust illumination of every LEDs lamp so that the homogeneity of light intensity can be achieved. To measure the light intensity, a number of illumination sensors need to be placed in a room. The illumination sensors measures light intensity of the room, and send the light intensity information as feedback for control system. The control system manages homogeneity of light intensity by adjusting illumination of the LEDs lamp.

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III. RELATED WORK

Research on indoor illuminations control [2, 4, 5, 8] has implemented artificial intelligent in the control system. Research that conducted by the Matta [5] involves external lighting to control indoor illuminations by using venetian blind angle. However, this system requires a complex mechanical system that is hard to be implemented.

Researches to improve homogeneity of light intensity from LEDs lamp have been carried out by Kay Yang [1] and Liu Ye [6]. Kay studied the distribution of LED radiation mathematically in order to find homogeneity of light intensity from LED. In his research, Liu proposed a technique for configuring LED arrays so that the homogeneity of light intensity can be improved. Liu also used lens to enlarge distribution of LED radiation to illuminate a wider area.

Research in [4, 5, 7, 9], found that energy efficiency in lighting system can be achieved by implementing energy management system. Various control methods can be used in energy management system. However, using artificial intelligent control system can provide more energy efficiency than traditional ON-OFF control system.

In several previous studies [8] [9] [10], fuzzy logic has been chosen as method of artificial intelligent control for indoor illuminations. The studies proved that the fuzzy logic control system is more reliable compared with ON - Off control or PID control [4]. Research by Chen Y [10] has improved performance of fuzzy logic control by using double loop, but it increase complexity of the control system. Using a single control loop will simplify the fuzzy logic control system. In addition, using single control loop can provide level of accuracy that meet the standard error of less than 2% in its implementation.

Various communication systems have been developed in the indoor illuminations control applications [2,11]. These communication systems include the use of wire and wireless medium. In wireless systems, visible light communication technology and CDMA produces a pretty good performance. However, the use of wireless medium suffers from the problems of noise and SNR which can reduce system performance. Due to this reason, the use of wired medium for serial communication is more feasible to be implemented.

In this paper, a model of fuzzy logic control system for controlling homogeneity of light intensity is proposed. By using arrays of LED lamps and illumination sensor, the model of control system is expected able to maintain homogeneity of light intensity in a room.

IV. MODEL OF FUZZY LOGIC CONTROL SYSTEM

A. System Configuration

This model is design for controlling homogeneity of light intensity where external light affect illumination in a room. In this model, illumination of LEDs lamp will be adjusted by considering illumination from external light. In general, the model of control system consists of five components, namely LEDs lamp, LED driver, illumination sensor, controller, and transceivers. Diagram block of system configuration is illustrated in Figure 1.

There are two types of controller that used in this configuration, namely master controller and slave controller. The master controller has main task to run the fuzzy logic control in order to manage the homogeneity of light intensity, while the slave controller measure light intensity by using illumination sensor and send the measurement result to master controller. The master controller process the measurement result and adjust illumination of LEDs lamp through a Pulse Width Modulation (PWM) LED driver.

In this model, communication between the master and slave is performed through the Recommended Standard 485 (RS485) that currently managed by the Telecommunications Industry Association (TIA). RS485 communications system enables communication of multi transceiver using bus topology. With this topology, each slave controller can send data to master controller in turn based on requests from the master controller.

B. Fuzzy Logic Control System

The control system works as closed loop where feedback input is received from illumination sensor. In every single loop, master controller will request light intensity data from particular sensor (slave controller). After receiving the request from the master controller, slave controller will perform measurement of light intensity and send the measurement result to master controller. In master controller, the light intensity data is processed by fuzzy logic control system. The fuzzy logic control system will output value of duty cycle that will be given to LED driver that associate with the sensor. Then, the LED driver will adjust LED illumination based on the value of duty cycle.

In the next single loop process, the master controller will request light intensity data from another illumination sensor and process the data to output duty cycle for LED driver that associates with the sensor. The control system will measure and process light intensity data from all of illumination sensors in turns. Then, the control system will adjust illumination of all LED lamps in order to achieve homogeneity of light intensity.

In simple words, the fuzzy logic control system works as follows. It will increase duty cycle of PWM when the actual light intensity is smaller than expected light intensity (set point). That means the LED lights will be brighter when actual light intensity still lower than set point. Otherwise, the duty cycle of PWM will be reduced when actual light intensity exceeds set point. This will dim the LEDs illumination. The duty cycle value will be constant set point is reached with error less than 2%.

Design of the fuzzy logic control system has two inputs and one output. The two inputs are intensity error and delta intensity error. The intensity error is defined as the difference between actual light intensity that measured and set point of light intensity, while delta intensity error is defines as the difference between current intensity error and previous intensity error. Intensity error and delta intensity error is calculated in preprocessing step. The fuzzy logic control system involves five steps, namely: preprocessing, fuzzification, inference, defuzzification, and postprocessing.

In fuzzification step, intensity error and delta intensity error are classified into five fuzzy input membership functions as shown in Figure 2. The membership functions are Negative Large (NL), Negative Small (NS), Zero (Z), Positive Small (PS), and Positive Large (PL). The Zero membership functions has error value ±2%.

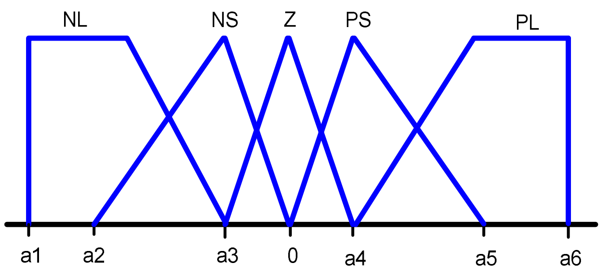

Figure 2. Membership functions of Fuzzy input.

This control system uses Mamdani method in its inference engine. This method maps the two fuzzy inputs to membership of fuzzy output based on Fuzzy Associative Memories (FAM) as shown in Table 1. Similar to fuzzy input, the fuzzy output also consist of five membership functions.

Defuzzification process uses weight average method. This method obtains crisp value by taking the centroid of the fuzzy output. The crisp output may have negative or positive value. In postprocessing step, the negative crisp value will decrease duty cycle of PWM to reduce illumination of LED. Meanwhile, positive crisp value will increase duty cycle of PWM to increase illumination of LED.

TABEL 1: FUZZY ASSOCIATIVE MEMORIES (FAM)

Intensity error	Delta intensity error				
	NL	**NS**	**Z**	**PS**	**PL**
NL	PL	PL	PL	PL	PL
NS	PS	PS	PS	PS	PL
Z	PS	PS	Z	NS	NS
PS	NS	NS	NS	NS	NL
PL	NL	NL	NL	NL	NL

V. EXPERIMENT AND RESULT

A series of experiments have been conducted to test performance of the proposed model of control system. The experiments carried out using 4 units of LEDs lamps and 2 units of illumination sensor. The LEDs lamps are made using 33 LEDs that consumes about 4 watts of power. To measure light intensity, integrated circuit BH1750FVI is used as illumination sensor. The sensor outputs light intensity in unit of Lux through inter integrated circuit (I2C) interface.

The LED Lamp is placed in a room that has windows on one of its side. It aims to give the effect of external light into the control system. Every illumination sensor associates with two LED lamps. The illumination sensors are mounted in the middle of the two LED lamps that want to be controlled. Placement of components in the room is illustrated in Figure 3.

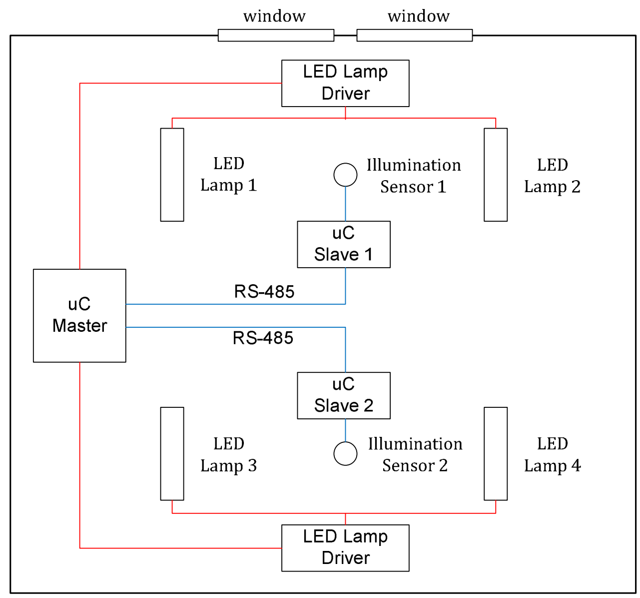

Figure 3. Placement of components.

In this experiment, every single loop of the control system takes about one second. That means, this control system needs one second to perform light intensity measurement, process the measurement data, and output duty cycle of PWM to LED driver. Since this experiment uses two illumination sensors, thus light intensity from each sensor will be measured and processed every two seconds.

Experimental procedure is conducted as follows. Firstly, expected light intensity in the room is set 150 lux. In first step, external illumination is reduced by closing window's curtain. When the control system is started, it will increase duty cycle of PWM that drives LEDs lamp illumination. This will increase illumination of the LED lamp to achieve expected light intensity. When external illumination is increased, the control system will reduce duty cycle of PWM that drives the LEDs lamp. This will reduce illumination of the LED lamp to achieve expected light intensity.

Graph in Figure 4 shows stability of light intensity under variation of external illuminations. In steady state condition, the graph shows error of light intensity is below 3 Lux or 2 percent of set point.

Besides to observe the stability of light intensity, the experiments are also conducted to measure energy efficiency of the LED lamp when using fuzzy logic control system. When expected light intensity is set to 150 Lux, the graph on Figure 5 shows that energy consumption can be saved from 20% to 40% when using fuzzy logic control system. This because the control system has reduced duty cycle of PWM up to 40% in order to achieve 150 Lux of light intensity. Therefore, the control system can reduce the energy consumption.

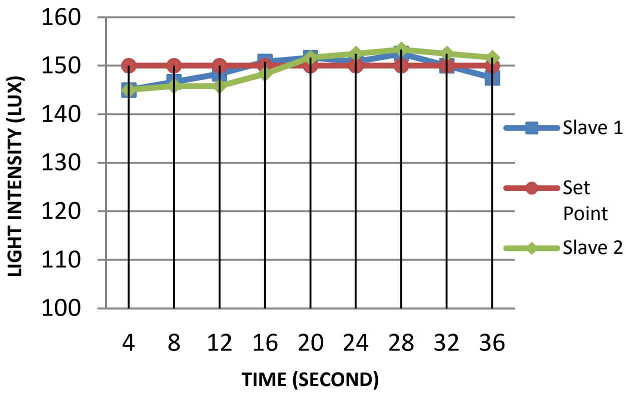

Figure 4. Stability of light intensity.

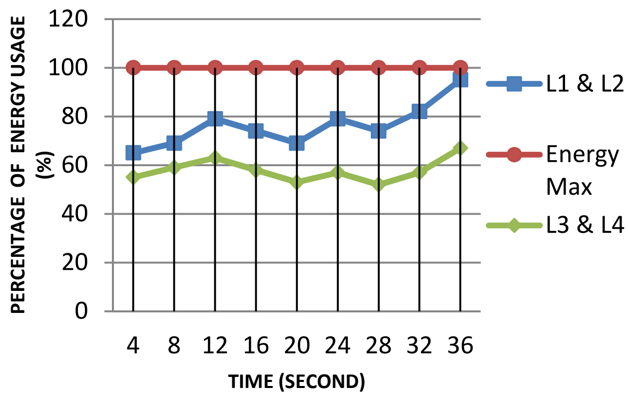

Figure 5. Energy usage of LED lamp 1 (L1), LED lamp 2 (L2), LED lamp 3 (L3), and LED lamp 4 (L4).

VI. CONCLUSION

This paper proposed a model of fuzzy logic control system for controlling homogeneity of light intensity from Light Emitting Diode (LED). This model is intended to address the heterogeneity issue of light intensity of LED due to its small radiation angel. This control system continuously measures light intensity through arrays of illumination sensor. Based on the measurement result, the control system will adjust illumination of LED by changing duty cycle of Pulse Width Modulation (PWM). The control process will be repeated until expected light intensity is achieved. Using this model of fuzzy logic control system, the homogeneity of light intensity in a room is expected can be achieved with error less than 2%. In addition, under the experimental condition, this control system can reduce energy consumption up to 40%.

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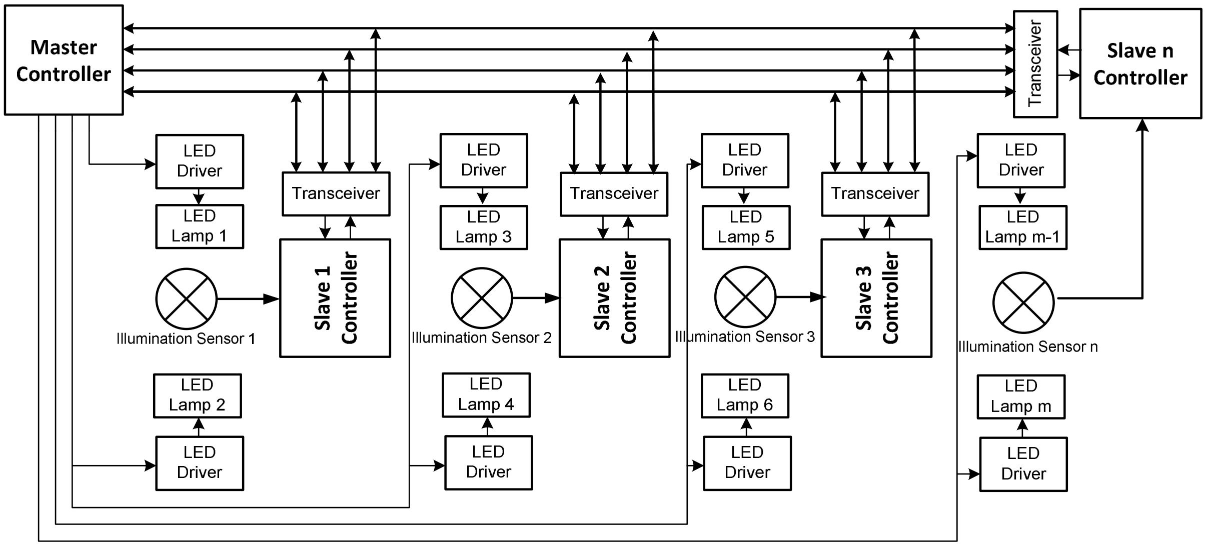

Figure 1. Diagram block of system configuration.