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Alternating Current Input LED Lighting Control System using Fuzzy Theory

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Abstract
In this study, we constructed several scenarios that are required for LED lighting, and we designed and implemented an LED lighting control system to operate these scenarios to confirm their behavior. An LED lighting control system is a hybrid control board that is designed by combining LED controllers and SMPS, consisting of an AC/DC power supply part that converts AC 220 V into DC 12 V, and a drive and control part that controls the scenario and color of the LED module. Conventional LED light controllers have an input power of DC 12 V, so when using the input AC 220 V, the SMPS must be connected to the LED light controller. To eliminate this inconvenience, a hybrid LED lighting control system was configured to combine LED lighting controllers and SMPS into one control system. Furthermore, we designed a control system to represent the most appropriate color according to the input of the distance and illumination using a fuzzy control system to conduct computer simulations.

Index Terms: Action scenario, Fuzzy control system, Illumination, LED lighting, Membership

I. INTRODUCTION

To use the advantages of LEDs as much as possible, LED lighting is being recommended in the US, Japan, Europe, and South Korea, or legislation is being prepared or implemented to replace existing incandescent and fluorescent lighting. Because LEDs have been used as the main source of light, the function of light sources is expanding beyond simply lighting darkness to provide aesthetic satisfaction or to induce sensibility. It is expected that various emotional effects will be derived by dynamically changing the brightness, color, and purity of lighting. On this basis, the potential to create market demand that may lead to opportunities for new product development is recognized. That is, an increasing number of areas are aiming to utilize the chromatic properties of lighting as design elements.

The existing LED light controller has an input power of DC 12 V, so when using the input AC 220 V, the SMPS must be connected to the LED light controller. To eliminate this inconvenience, a hybrid LED lighting control system was studied to combine LED lighting controllers and SMPS to form a single control board, so as to share the functions of LED lighting control and SMPS. This configuration allows the input to operate with AC 220 V as a combined LED light controller that can function with one hybrid light controller, without having to purchase LED light controllers and SMPS separately. The input of conventional pseudo-LED light controllers is DC 12 V, but the hybrid lighting control system in this study is characterized by AC 220 V input.

The configuration characteristics of the LED lighting con-

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trol system in this study are four channels; thus, four RGB LED colors can be controlled simultaneously, each exchanging the terminals of the RGB LED module to create more emotional lighting, and 10 color control directing scenarios, including mode and speed. It is compatible with the use of all existing RGB LED modules and bars, and offers the advantage of using many RGB LED connections with the large current capacity design of each channel terminal.

II. FUZZY CONTROL SYSTEM

A. Fuzzy Theory

Fuzzy theory was presented in 1965 by Lofti Zedeh, who was a professor at the University of Berkeley. Fuzzy theory is a theory based on fuzzy logic and an extension of Boolean logic, thereby forming a classical collective theory. In set theory based on Boolean logic, a particular object belongs to or does not belong to an element in a given set. However, in fuzzy set theory based on fuzzy logic, the extent to which this object belongs to a particular set as a component is represented by a number between 0 and 1, which is known as the degree of belonging. This allows fuzzy logic to address uncertain concepts in humans as well as features that can represent uncertain concepts in human mathematical representations of physical numbers and amounts [1, 2].

B. Fuzzy Controller Configuration

Fuzzy theory can represent uncertain feelings, as they define the values of the appropriate language.

Fig. 1 presents the structure of a basic fuzzy controller, which requires an IF-THEN form of an inference rule to make a fuzzy inference, which is known as the “Fuzzy IF-THEN rule.” The main points to be determined when designing a fuzzy controller are summarized as follows [3, 4].

① Determination of the input and output variables of the fuzzy controller and their fuzzy values:

Given the control target, the input and output variables are determined first, following which the language values of the input and output variables and their affiliation functions are determined.

② Knowledge base design:

The knowledge that is required for control can be expressed on a rule-based basis, where the if clause is referred to as the first half or the pre-construction part, and the then clause is used to describe the control rule as a fuzzy application, which is known as the second half or post-construction part.

③ Determination of the fuzzy method of the numerical input variable values:

Because the value of the input variable is numerical and cannot be used directly in the inference process, the value of the input variable must be converted into a fuzzy value.

④ Determination of fuzzy inference methods:

Inference methods include reasoning based on infinite logic and reasoning based on fuzzy logic. Reasoning methods that are based on infinite logic can be classified by synthesis, as well as the methods of Tsukamoto, and Takagi and Sugeno. Synthetic reasoning includes the methods of Zadeh, Mamdani, and Larsen.

⑤ Determination of the defuzzification method of the output fuzzy value:

The amount of control that is the input of the process must be numerical, thereby requiring a process of converting the fuzzy inference results into numerical real values. This function is performed through a defuzzifier, max criterion method, mean of maximum method, and centroid of gravity method.

Fig. 2 depicts the internal structure and computational process of the variable structure of a fuzzy system.

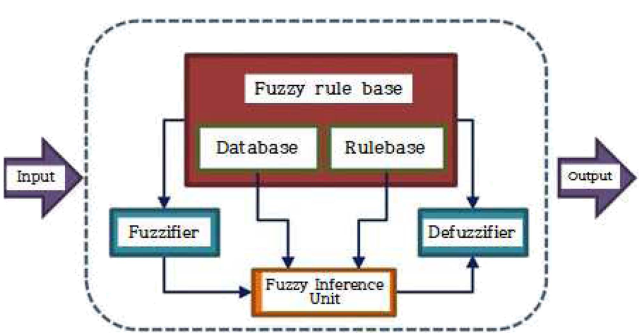

Fig. 1. Structure of fuzzy controller.

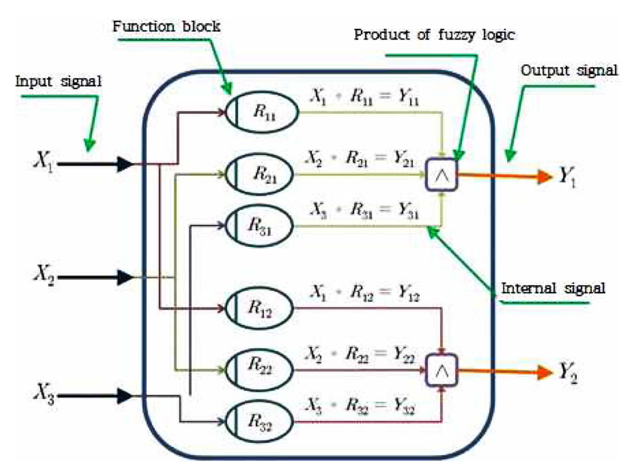

Fig. 2. Block diagram of variable structure of the fuzzy system.

III. DESIGN OF LED LIGHTING CONTROL SYSTEMS

We describe the design of LED lighting control systems using fuzzy theory.

A. Configuration of Fuzzy Algorithms

A fuzzy algorithm transforms the quantified inputs into linguistic variables. The measured datum in the control system is a practical value and the fuzzy controller is based on fuzzy set theory; therefore, the quantified values need to be fuzzy [5, 6]. In this study, the values that were entered into the microprocessor were two variables: illumination and distance. This variable then derived the value of the LED illumination color using a fuzzy operation. Fig. 3 presents an approximate block diagram of the fuzzy control system used in this study.

The settings of the input/output language variables used in the fuzzy inference in this study are displayed in Table 1.

B. Fuzzy Membership Function

Each class of input and output variables was divided into five classes and assigned a membership function accordingly.

The illumination was divided into five classes: very dark (VD), dark (D), proper (P), bright (B), and very bright (VB). The standard of adequacy was set to 25 lx and had a range of 50 lx per class. Fig. 4 shows the set illumination membership functions.

In the case of "very dark,' if the illumination was less than 0 lx, it had a membership of 1. In the case of "proper," it had a membership of 1, and a triangular membership between 0 and 50 lx. The reading method of the fuzzy membership function values was as follows: if the illumination was 12.5 lx, the fuzzy membership function of "proper" was 0.5, the fuzzy membership function of "dark" was 1, and the fuzzy membership function of "very dark" was 0.5.

Next, we assigned a fuzzy membership function by dividing the range of distance values into five parts: very far (VF), far (F), reasonable (R), close (C), and very close (VC), depending on the language variable setting with respect to the distance. Fig. 5 presents the set distance membership function.

In the case of "very close," if the distance was less than 0 cm, it had a membership of 1. In the case of "proper," it had a membership of 1 and a triangular membership between 0 and 50 cm.

This was the allocation of membership functions to the inputs. According to the language variable settings for the LED outputs, we assigned fuzzy membership functions by dividing the range of LED output values into at least (L), few (F), ordinary (O), many (M), and peak (P). The range of fuzzy membership functions was the same as that shown in Fig. 6.

Based on the above RGB LED output fuzzy membership function, the RGB LED output range according to the illumination and distance inputs was added to produce consistent output due to illumination and distance changes. When outputting the above function fuzzy membership to the LEDs of

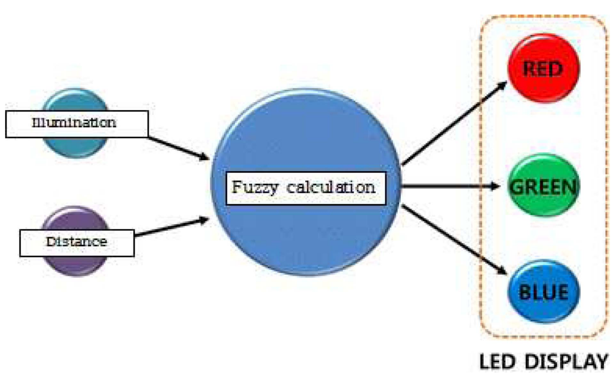

Fig. 3. Block diagram of fuzzy system.

Table 1. Setting the language variables of fuzzy inference

Illumination input	Distance input	LED output
very bright (VB)	very far (VF)	least (L)
bright (B)	far (F)	few (F)
proper (P)	reasonable (R)	ordinary (O)
dark (D)	close (C)	many (M)
very dark (VD)	very close (VC)	peak (P)

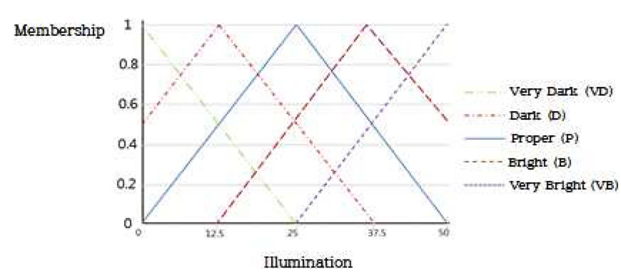

Fig. 4. Function of illumination membership.

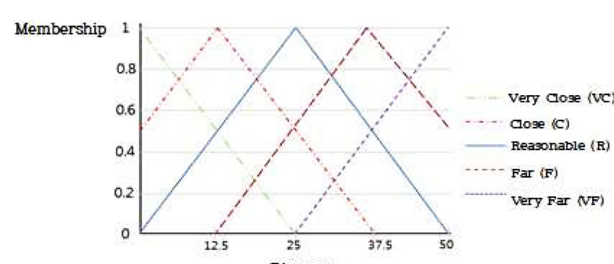

Fig. 5. Function of distance membership.

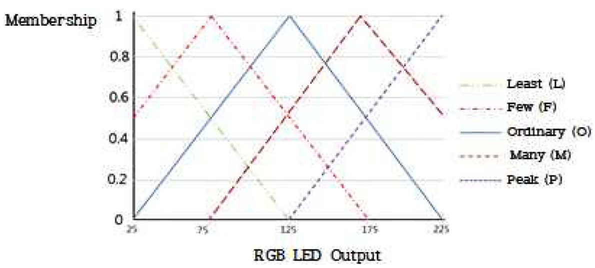

Fig. 6. Function of RGB output membership.

red, green, and blue, the three colors were mixed to produce pulse width modulation (PWM). Based on the above RGB output, 13 colors were produced: RED, YELLOW, GREEN, CYAN, BLUE, PURPLE, LIGHT PINK, ORANGE, GREEN YELLOW, LIGHT CYAN, DODGER BLUE, MAGENTA, and VIOLET. The output ranges for each color are listed in Table 2.

C. Fuzzy Control Rule Settings

An important aspect of fuzzy algorithms is the establishment of rules, which are of paramount importance in deriving results using input variables. Rules should be prepared with the advice of experts or by matters that are generally recognized as true. That is, fuzzy logic control systems can be understood as mimicking expert judgment behavior, so fuzzy logic control systems are practical applications of system control, and to implement fuzzy logic control systems, the empirical knowledge of experts must first be described [7].

With sufficient learning, experts with the knowledge that is required to control the system can describe their control rules qualitatively and linguistically rather than mathematically and quantitatively. In particular, the IF-THEN format is used most often because it is convenient to express empirical knowledge; thus, this format is also used in this study.

The lighting system had two inputs, with five classes for each input, and one class for the output. This is why the number of rules could also be large. Fuzzy logic is the most ideal system when all rules are established, because more rules result in greater sophistication and accuracy. The number of rules was limited in this study owing to the long time required for processing and complicated computation.

Each value of the RGB output was represented. The resulting rule table is presented in Table 3.

D. Defuzzification Course

The fuzzy value that was calculated in the previous section could not be used as a direct output (the operating value of the LED display). Therefore, it needed to undergo a defuzzification process to convert it into actual available figures.

Table 2. LED fuzzy and crisp output color values

	Color	Fuzzy Output	Crisp Output
1	Red	Red: P Green: L Blue: L	R = 255, G = 0, B = 0
2	Yellow	Red: P Green: P Blue: L	R = 255, G = 255, B = 0
3	Green	Red: L Green: P Blue: L	R = 0, G = 255, B = 0
4	Cyan	Red: L Green: P Blue: P	R = 0, G = 255, B = 255
5	Blue	Red: L Green: L Blue: P	R = 0, G = 0, B = 255
6	Purple	Red: O Green: L Blue: O	R = 128, G = 0, B = 128
7	Light Pink	Red: P Green: M Blue: M	R = 255, G = 182, B = 193
8	Orange	Red: P Green: M Blue: L	R = 255, G = 165, B = 0
9	Green Yellow	Red: M Green: P Blue: L	R = 173, G = 255, B = 47
10	Light Cyan	Red: P Green: P Blue: P	R = 224, G = 255, B = 255
11	Dodger Blue	Red: L Green: O Blue: P	R = 30, G = 144, B = 255
12	Magenta	Red: P Green: L Blue: P	R = 255, G = 0, B = 255
13	Violet	Red: P Green: O Blue: P	R = 238, G = 130, B = 238

There are several defuzzification methods, but the centroid of gravity method was used in this study.

E. Configuration of LED Lighting Control System

An LED lighting control system is a hybrid control board that is designed by combining LED controllers and SMPS, consisting of an AC/DC power supply part that converts AC 220 V into DC 12 V, and an LED display part that controls the scenarios and colors of the LED modules.

Existing LED light controllers have an input power of DC 12 V, so when using the input AC 220 V, the SMPS must be connected to the LED light controller. To eliminate this

Table 3. Fuzzy rules table

Distance \ Illumination	VD (~ 10 lx)	D (~ 20 lx)	P (~ 30 lx)	B (~ 40 lx)	VB (~ 50 lx)
VC (~ 10 cm)	Purple (R:128,G:0,B:128) RED: O GREEN: L BLUE: O	Magenta (R:255,G:0,B:255) RED: P GREEN: L BLUE: P	Cyan (R:0,G:255,B:255) RED: L GREEN: P BLUE: P	Dodger Blue (R:30,G:144,B:255) RED: L GREEN: O BLUE: P	Blue (R:0,G:0,B:255) RED: L GREEN: L BLUE: P
C (~ 20 cm)	Light Pink (R:255,G:182,B:193) RED: P GREEN: M BLUE: M	Violet (R:238,G:130,B:238) RED: P GREEN: O BLUE: P	Light Cyan (R:224,G:255,B:255) RED: P GREEN: P BLUE: P	Cyan (R:0,G:255,B:255) RED: L GREEN: P BLUE: P	Dodger Blue (R:30,G:144,B:255) RED: L GREEN: O BLUE: P
R (~ 30 cm)	Yellow (R:255,G:255,B:0) RED: P GREEN: P BLUE: L	Green Yellow (R:173, G:255, B:47) RED: M GREEN: P BLUE: L	Green (R:0,G:255,B:0) RED: L GREEN: P BLUE: L	Light Cyan (R:224,G:255,B:255) RED: P GREEN: P BLUE: P	Cyan (R:0,G:255,B:255) RED: L GREEN: P BLUE: P
F (~ 40 cm)	Orange (R:255,G:165,B:0) RED: P GREEN: M BLUE: L	Yellow (R:255,G:255,B:0) RED: P GREEN: P BLUE: L	Green Yellow (R:173,G:255,B:47) RED: M GREEN: P BLUE: L	Violet (R:238,G:130,B:238) RED: P GREEN: O BLUE: P	Magenta (R:255,G:0,B:255) RED: P GREEN: L BLUE: P
VF (~ 50 cm)	Red (R:255,G:0,B:0) RED: P GREEN: L BLUE: L	Orange (R:255,G:165,B:0) RED: P GREEN: M BLUE: L	Yellow (R:255,G:255,B:0) RED: P GREEN: P BLUE: L	Light Pink (R:255,G:182,B:193) RED: P GREEN: M BLUE: M	Purple (R:128,G:0,B:128) RED: O GREEN: L BLUE: O

inconvenience, a hybrid LED lighting control system was configured to combine LED lighting controllers and SMPS into one control system [8, 9].

F. Configuration of Action Scenarios

To verify the behavior of the LED lighting control systems that were implemented in this study, we constructed scenarios in various cases, as follows. Note that the behavior checking of various scenarios confirms the behavior by constructing it in practice, as shown in Figs. 7 and 8.

Switch 1. 16-color panorama with switching method
Switch 2. 16-color change with one step on
Switch 3. Dimming color moving to front and back with 16 colors
Switch 4. 16-color panorama with dimming method
Switch 5. All on and switching with 16-color change
Switch 6. Each on moving with 16-color change
Switch 7. Color moving to front and back with 16 colors
Switch 8. All the same color change with 16 colors

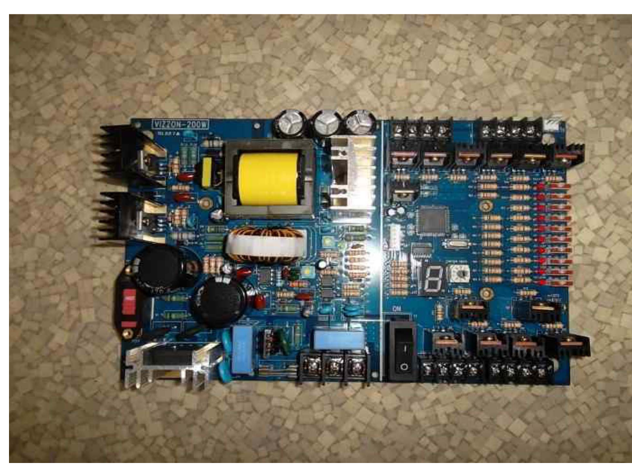

Fig. 7. Hardware of 4CH LED controller.

Switch 9. Color storage with 16 colors
Switch 10. Each dimming and switching with 16 colors

Fig. 8. Operating photograph of four-channel LED lighting control system.

IV. IMPLEMENTATION AND COMPUTER SIMULATION OF LED LIGHTING CONTROL SYSTEM

A. Implementation of LED Lighting Control System

The actual manufactured board with an alternating current of 220 V input four-channel LED lighting control system was the same as that depicted in Fig. 7. The CPU used an ATmega128 and FET to control the current signals. To run the CPU, DC 12 V was converted into DC 5 V using a 7805 regulator. A heat shield was used to remove heat because the FET was heat generated by hanging the load. The SMPS capacity of the manufactured control board consisted of 200 W, and the load capacity of each four-channel LED module could reach up to 50 W.

A four-channel LED lighting control system was manufactured, as shown in Fig. 8, and various scenario actions were identified by operating them as manufactured products. The behavior of each scenario could be selected through the on/off of the selection switch and the operation speed of the motion scenario was adjusted from the slowest 0 to the fastest 9 with a separate speed adjustment switch that was represented numerically in seven segments. Photographs of the product behavior of the AC 220 V input LED lighting control system are provided in Fig. 8.

B. Computer Simulation of LED Lighting Control Systems

We designed an LED lighting control system to represent the color of the fuzzy rules in Table 3 according to the inputs of the distance and illumination to conduct computer simulations with crisp control and fuzzy control.

Table 4 presents the results of fuzzy control simulation based on fuzzy rules.

V. CONCLUSIONS

In this study, we have constructed several scenarios that are required for LED lighting, and we designed and implemented an LED lighting control system to operate those scenarios to confirm their behavior.

The hardware of the control system consists of power, AVR control, CLCD output, LED control, a scenario selection switch, and operating speed display parts, and is built on four channels. The CPU uses an ATmega128 and FET to control the current signals. To operate the CPU, DC 12 V is converted into DC 5 V using a 7805 regulator, and a radiator is used to remove the heat generated by the FET. Furthermore, the SMPS capacity is configured to fit a four-channel controller with a total of 200 W. We combined the LED light controller and SMPS to form a single control board to combine the functions of LED light control and SMPS, so as to form an LED light control system that enables the input to operate at AC 220 V.

Furthermore, we designed a control system to represent

Table 4. RGB fuzzy output results according to input of arbitrary illumination and distance values

	Illumination (lx)	Distance (mm)	Fuzzy Output	Color Output
No. 1	5	111	R = 147, G = 58, B = 136	Purple
No. 2	8	113	R = 145, G = 55, B = 135	Purple
No. 3	11	152	R = 176, G = 105, B = 159	Purple
No. 4	21	122	R = 192, G = 75, B = 225	Magenta
No. 5	24	144	R = 137, G = 117, B = 225	Violet
No. 6	32	211	R = 170, G = 225, B = 189	Light Cyan
No. 7	7	281	R = 225, G = 211, B = 66.2	Yellow
No. 8	22	312	R = 147, G = 225, B = 25	Green Yellow
No. 9	29	378	R = 143, G = 225, B = 25	Green Yellow
No. 10	3	321	R = 225, G = 204, B = 25	Yellow
No. 11	41	391	R = 195, G = 124, B = 225	Violet
No. 12	26	311	R = 107, G = 225, B = 25	Green Yellow
No. 13	33	19	R = 25.1, G = 175, B = 225	Dodger Blue
No. 14	37	233	R = 101, G = 225, B = 152	Green Yellow
No. 15	23	384	R = 176, G = 225, B = 25	Green Yellow
No. 16	1	344	R = 225, G = 200, B = 25	Green Yellow
No. 17	36	412	R = 203, G = 169, B = 143	Light Pink
No. 18	44	222	R = 89, G = 182, B = 225	Cyan
No. 19	31	123	R = 85, G = 208, B = 225	Cyan
No. 20	22	431	R = 211, G = 207, B = 25	Yellow
No. 22	47	327	R = 97, G = 149, B = 225	Dodger Blue
No. 23	16	356	R = 202, G = 203, B = 25	Yellow
No. 24	19	211	R = 216, G = 147, B = 188	Light Pink
No. 25	21	51	R = 185, G = 65, B = 225	Magenta
No. 26	4	22	R = 125, G = 25, B = 125	Magenta
No. 27	27	118	R = 97, G = 148, B = 225	Cyan
No. 28	49	32	R = 25, G = 51, B = 225	Blue
No. 29	13	112	R = 161, G = 66, B = 163	Magenta
No. 30	42	234	R = 103, G = 196, B = 225	Light Cyan

the most appropriate color according to the inputs of the distance and illumination using a fuzzy control system to conduct computer simulations. As a result, given the resulting values and output colors under fuzzy rules, we can observe that fuzzy logic, unlike conventional crisp logic, does not require the storage of input values of many data, and is even efficient in representing many output values with simple fuzzy rules.

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