Power Saving LED Luminance Fuzzy Control with IOT Network

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Abstract. To lower down illumination power consumption and enhance lighting effects, smart LED controller and luminance sensors were connected to a WIFI based IOT network, fuzzy luminance control was employed on the IOT net. The schematic topology of the IOT net was outlined. The smart LED controller used the dedicated IOT chip ESP 8266 as the main processor, which was connected to the WIFI network and drove LEDs with PWM signals. The luminance fuzzy control strategy was also implemented on ESP8266 in C language. The fuzzy control process was a typical feedback loop, which took the error (difference between the luminance measured value and the luminance set value) and error change as inputs and calculated the output (the PWM increment) according to fuzzy rules. To test system efficiency, step response experiment and power saving experiment were conducted, proving the system to have good control quality and capable of saving more power by means of intelligent control.

1. Introduction
LED has better luminous efficiency and is more power-saving than other light sources. In developed countries and southeast area of China, LEDs are widely used for illumination, but in other parts of China, luminous sources like fluorescent, incandescent lamps are still used in large quantity, pending to be replaced by LEDs.

To test the effect of LED illumination, we developed a WIFI based IOT [1][2][3] (internet of things) network, smart LED controller and illumination sensor were connected to the IOT network, fuzzy luminance control [4][5] was employed on the IOT net to save power and enhance lighting effect. Experiments were conducted which showed the system had very good control quality and power saving efficiency.

Detailed description and analysis of the system is as follows.

2. IOT topology for fuzzy luminance control
The IOT net used for LED control is composed of the main controller, the luminance sensor, and the smart LED controller. The main controller is a Linux router which connects all other IOT devices. The luminance sensor measures the environmental luminance and send it to the LED controller via IOT. The LED controller compares the measured luminance with the user set value, and regulates PWM outputs to drive LEDs using fuzzy logic feedback control. The IOT net can be connected to the
Using a smart android phone, users can control the LED luminance locally by Wifi or remotely through internet cloud. All communications are conducted using UDP protocol. The topology of the IOT network is shown in Figure.1.

**Figure 1. IOT network topology for LED luminance fuzzy control**

### 3. Smart LED controller hardware architecture
The smart LED controller is the centre of the fuzzy luminance control. It uses ESP8266 IOT MCU to communicate via WIFI with other devices (smart phone, luminance sensor) using UDP protocol, implementing the feedback fuzzy control in C language.

The outlining of the smart LED controller hardware structure is shown in Figure.2.

**Figure 2. Smart LED controller hardware structure**

#### 3.1. Power supply
The full bridge rectifier provides high voltage DC power supply for LEDs, and through a RC-buck, it also provides a 16V DC power supply to the constant current chip BP2838. The AC/DC generates a 5V DC voltage which powers up the kernel board.

#### 3.2. Kernel board
The kernel board consists of the ESP8266 MCU, 4M flash, power management unit and the Wifi antenna. Through Wifi based UDP communication, ESP8266 gets user commands from android phone, and set desired luminance level; it also gets measured environmental luminance value from the luminance sensor, it then implements a feedback fuzzy control strategy to regulate the PWM output,
which is fed to the constant current source (BP2838) input, each BP2838 drives a LED, in this way, the luminance is regulated.

3.3. Constant current source
The constant current source (BP2838) gets its input from ESP8266’s PWM output and regulates the LED current according to the PWM duty cycle. The luminance can be adjusted from 0% to 100% continuously. The source regulates current in a feedback way, the current precision can be as high as 2%.

4. Luminance fuzzy control algorithm

4.1. Control flowchart
The luminance fuzzy control algorithm flowchart is shown in Figure 3.

![Figure 3. Fuzzy control algorithm flowchart.](image)

The control process is a typical feedback loop [6][7]. The error and error change between luminance set value and measured value are two inputs of the fuzzy system, then fuzzy rules are applied to generate the output—the PWM duty cycle increment value. The current PWM duty cycle value is added to the increment value, the new duty cycle value is applied to drive the LED and regulates luminance. The system is a network-based control system, since the inputs (set value and measured value) are from the IOT net.

4.2. Fuzzy system
The fuzzy system has two inputs: error and error change, one output: PWM duty cycle increment. The membership functions of these 3 variables are shown in Figure 4 to Figure 6.

In these figures, terms NL, NB, NM, NS, ZO, PS, PM, PB, PL mean negative large, negative big, negative middle, negative small, zero, positive small, positive middle, positive big, positive large respectively.

![Figure 4. Luminance error membership function](image)
Based on these 3 membership functions, fuzzy rules are defined in Table 1

| EC:NB | EC:NS | EC:ZO | EC:PS | EC:PB |
|-------|-------|-------|-------|-------|
| E:NB  | DCI:PL| DCI:PB| DCI:PS| DCI:ZO|
| E:NS  | DCI:PB| DCI:PM| DCI:PS| DCI:ZO|
| E:ZO  | DCI:PM| DCI:PS| DCI:ZO| DCI:NM|
| E:PS  | DCI:PB| DCI:PM| DCI:NS| DCI:ZO|
| E:PB  | DCI:ZO| DCI:NS| DCI:NM| DCI:NL|

In Table 1, EC stands for error change, E stands for error, DCI stands for PWM duty cycle increment.

4.3. Algorithm realization
The algorithm is realized in C language in ESP8266 IOT MCU, it is a discrete control process and executes every 50 ms.

5. Experiments and analysis
After the establishment of the system, 2 experiments were conducted: step response experiment and power saving efficiency experiment. The former is to test the control quality, the latter is to test the power saving efficiency.

5.1. Step response experiment
Initial conditions: The PWM ran with a duty cycle of 85%, the luminance set value was 300 lx, the luminance measured value was 300lx.
Step response: Set value was changed to 320 lx. Within 500 ms, the measured luminance followed to 320 lx and stayed stable, the PWM duty cycle increased to 89% and also stayed stable. The transition
process was recorded and drawn in Figure 7. It can be seen there is almost no overshoot during the transition process, the transition was smooth, and the control quality was good.

![Figure 7. Luminance step response in fuzzy control](image)

5.2. Power saving efficiency experiment
To test the power saving efficiency of the luminance fuzzy control, three rooms in our office building with similar natural illumination situations were prepared: in Room-1 four common 36W T8 fluorescent tubes without luminance control were installed; in Room-2 four common 18W LED T8 tubes without luminance control were installed; in Room3 four 18W LED T8 tubes controlled by above mentioned IOT network were installed. All light sources were switched on from 6:00 in the morning to 20:00 in the evening. The experiments lasted for 5 consecutive days. Total consumption of electricity and average luminance in each room were measured and recorded, the results were summarized in Table 2.

| Room  | Light sources | Experiment condition | Measured total Electricity consumption (kWh) | Luminance control | Measure maximum luminance(lx) | Measure minimum luminance(lx) | Measured average luminance (lx) |
|-------|---------------|----------------------|---------------------------------------------|-------------------|-------------------------------|-------------------------------|-------------------------------|
| Room1 | Fluorescent   | Lights on from 6:00 to 20:00 each day. lasted for 5 consecutive days | 13.5                         | -                 | 313                           | 272                           | 291                           |
| Room2 | LED 4×18W     | Lights on from 6:00 to 20:00 each day. lasted for 5 consecutive days | 6.8                          | -                 | 378                           | 308                           | 345                           |
| Room3 | LED 4×18W     | Lights on from 6:00 to 20:00 each day. lasted for 5 consecutive days | 6.2                          | Fuzzy IOT control (set value: 320lx) | 317                           | 322                           | 319                           |

According to Chinese national standard [8] for office illumination, the luminance level should be above 300 lx in reading and writing circumstances. The following is our analysis of data in Table 2:

1) In Room1, fluorescent light sources could not provide required luminance, the average luminance was 291lx, below the national standard, and due to no control of luminance, the luminance level varied significantly from 272lx to 313lx, the power consumption was also the highest among the three rooms.

2) In Room2, LED sources were used but without luminance control. The power consumption was lowered by almost 50% compared with Room1, and the average luminance level raised greatly, exceeding the national standard by 15%, and it was too bright during noon hours. So if there was
no luminance control, it seemed to be a waste of energy. And the luminance level varied greatly in a day, it was not comfortable for users.

3) In Room3, with fuzzy luminance control, we got desired results. The luminance set value was set just a little above the national standard, and the measured luminance value followed the set value perfectly. The average luminance level was 319lx, and the variation of luminance was within 6lx. The illumination of the room was stable and users felt comfortable.

6. Conclusion
Intelligent IOT based LED fuzzy control can effectively maintain stable luminance level in office environment, saving power and giving users comfortable experiences. Users can control light sources locally and remotely, different scenario modes can be applied. The system build a basis for further cloud-based big data mining to optimize power saving strategy. If applied in large scale, energy saving effects can be enormous.

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