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Design Strategy of LED Landscape Lighting System Based on Light Intelligence Technology under Smart City Framework

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Abstract The continuous development of economic construction has put forward the requirements of green, environmental protection, energy saving and intelligent city construction. Traditional street lights are timed and controlled, simple control, but once the failure can not be controlled in real time, affecting the cityscape and the waste of electric energy resources. This paper takes LED landscape lighting as the research basis, combines urban planning, and designs the fuzzy controller according to the switching and intelligent dimming operation of street lights at different times of the day in different seasons. The minimum output power of LED street lights is taken as the control objective, and the optimised fuzzy control algorithm is introduced to achieve the design of LED landscape lighting system from both hardware and software aspects. Through the establishment of the fuzzy controller, MATLAB simulation and real-time data analysis, using the proposed lighting control strategy, the energy consumption of the system after stabilisation is reduced by about 40% compared with the maximum energy consumption of the traversing experiment, which greatly reduces the lighting energy consumption and improves the efficiency of energy use. It has certain practical significance and broad application prospects for sustainable urban development.

Index Terms urban planning, smart city, energy use efficiency, sustainable development, LED landscape lighting system

I. Introduction

China's urbanisation process is accelerating, in the economic development at the same time, people's quality of life has made a qualitative leap, the level of landscape lighting has also been steadily improved, landscape lighting design towards the direction of intelligent development [1]-[3]. Traditional lighting fixtures in terms of energy saving, environmental protection, colour and other aspects has been difficult to adapt to the needs of urban landscape lighting, by the LED light source to replace the traditional lighting fixtures in the landscape lighting in the position of the LED light source is a fluorescent lamp alternative products, can improve the traditional fluorescent lamps energy-saving effect, improve the utilization of energy, reduce energy loss [4]-[6].

LED technology is widely used in the control of urban landscape lighting process with its many technical advantages. One of the typical cases is the Water Cube in Beijing, which can emit fascinating sea-blue night light at night. The whole landscape lighting control process is displayed by LED street lights [7], [8]. At present, measures to control lighting reasonably are an important and basic way to save energy in landscape architecture [9], [10]. Therefore, it is necessary to control the brightness of traditional LED planning in strict accordance with the requirements of architectural environmental protection, and then with the help of traditional LED programming and brightness coordination technology to achieve the best effect of landscape lighting in art buildings [11], [12].

Overall, the control management system of LED intelligent landscape lighting system is mainly composed of two major parts: landscape intelligent lighting control and landscape equipment intelligent management [13], [14]. Among them, the landscape intelligent control system has many essential differences with other intelligent integrated control systems, which can be fully demonstrated through a set of standardised landscape lighting control strategies. The intelligent management of lamps and lanterns mainly includes intelligent remote control, online protection, intelligent diagnosis, alarm circuit setting and switching power lighting control circuit [15], [16].

In summary, more and more landscape intelligent lighting began to adopt the wheel management approach, using the system intelligent process control to maintain the normal operation process in a stable state, and through the continuous practice of technological innovation, more ideal results have been achieved [17], [18]. However, there are still some deficiencies in this approach, which need to be investigated by the relevant personnel and take appropriate measures to solve in a timely manner, give full consideration to the use of the season, the indoor environment and other relevant factors, and make the appropriate adjustments to better meet the needs of people in the garden building lighting industry [19], [20].

This paper innovatively combines intelligent control algorithms and advanced software and hardware technologies to design an LED landscape lighting system based on light wisdom technology, which reduces lighting energy consumption and improves energy use efficiency. First, the overall functional architecture design of the intelligent LED landscape lighting system, including the monitoring centre, wireless transmission network and gateway forwarding node, was carried out. Then, the functional design of the hardware structure of the lighting monitoring system was carried out, including the GPRS communication module, ZigBee node, perception module and gateway module, main control microcontroller system module, constant current driver and sensor module. Subsequently, the system software process design was carried out, including the design of the main function to achieve effective control of PID illuminance and Red and Green components and the design of the adaptive brightness intelligent control algorithm. Finally, the LED landscape lighting system function is subjected to system modelling and testing to verify its effective application in smart city construction.

II. Intelligent LED landscape lighting system under intelligent urban construction

A smart city is an urban construction concept and related technology system that comprehensively transforms the core system of a city by analysing and measuring it through information technology. Environmental protection, urban security, urban industrial and commercial activities and the use of new technologies to transform the city all belong to the scope of the smart city. In the process of smart city construction, lighting technology is an indispensable part of the smart LED lighting technology to promote the development of the smart city.

II. A. Smart City and Intelligent LED Lighting

II. A. 1) Smart Cities

(1) The components of a smart city include economic and social systems, infrastructure systems, natural resources and the natural environment. The smart city system can be constructed by building an intelligent platform and a basic framework for information, energy and logistics.

(2) The construction of a smart city is a long-term and systematic effort that needs to be implemented under the guidance of the national government, which will build the smart city by unifying the construction opinions of all parties and fostering an information-based mindset. The construction of smart cities will improve the pattern of the whole city and promote the progress of medical care, logistics, environmental protection and education. The basis of building a smart city is to meet the demand for social services and to provide strong assistance to people in their work, employment and study. Therefore, smart city construction needs to be carried out in conjunction with people's actual needs.

II. A. 2) Intelligent LED Light Smart Technology

Intelligent LED lighting technology is not only an important product of the high-speed development of modern information lighting technology, but also a core technology to promote the construction of smart cities. Intelligent LED lighting technology is the organic fusion of LED lighting technology and modern Internet of Things technology, is a new generation of intelligent lighting technology. Intelligent LED lighting technology consists of two parts: software and hardware. Intelligent LED lighting technology through the use of perfect software control protocols and hardware control and processing tools, with the help of good man-machine lighting interaction control system, can be at any time for automatic diagnosis and lighting fault alarm. Among them, the lighting hardware control system mainly adopts energy efficient wireless control technology, such as infrared wireless communication technology.

(1) Remote control: LED lighting equipment has good process controllability, and intelligent LED lighting technology combines the advantages of both intelligent lighting control technology and LED lighting technology.

(2) Green energy saving. Through the use of modern intelligent control technology, intelligent LED lighting technology can improve the urban ecological environment and extend the effective life of intelligent LED lamps and lanterns.

(3) Intelligent control. Intelligent LED lighting system is reliably connected with BA system, monitoring and alarm system, area control system and other systems to form the Internet of Things. The use of intelligent LED lighting technology significantly improves the control of lighting, which helps to improve the quality of lighting in people's daily lives and reduces lighting energy consumption.

II. A. 3) LED landscape lighting performance

Urban residents of the landscape lighting project requirements are also changing, now more pursuit of light through the change of form, to improve the richness of the theme and the content expressed, in order to achieve the embodiment of the different qualities of each scene of the city, against the convergence of the same and simple and crude means of design. In the development of smart city construction, we should combine advanced technology and equipment to optimise the urban landscape lighting project, improve the convenience of management through systematic control, rational planning of intelligent lighting system in the construction of the project, especially pay attention to the control technology of the system, from a scientific point of view, to solve the problems existing in the traditional urban landscape lighting project, to integrate the rational intelligent technology with the sensual art, to show the urban elegance.

(1) Application of intelligent lighting system in urban road lighting project

The use of intelligent lighting system can combine with the remote monitoring module to understand the operation of the lighting equipment in real time. System control and artistic lighting integration, the formation of artistic landscape lighting project, combined with system control in the construction of the project is the lighting and the overall landscape environment integration, combined with the points and lines in the light, the formation of a three-dimensional sense of space, in the form of system control to maximise the use of lighting effects, aptly demonstrated the artistic connection between the light and the landscape and the landscape according to the environment and traffic around the landscape to make adjustments, highlight the focus of the landscape, and show the city's style. According to the environment and traffic around the landscape to make adjustments, highlighting the focus of the landscape, so that the lighting project of the urban landscape is clearly distinguishable.

(2) The application of intelligent lighting system in urban architectural landscape lighting project

In the modern landscape lighting project, it is necessary to improve the technical means, but also to highlight the artistic atmosphere, to control the expression in the landscape lighting in the way of lighting management system, to increase the hierarchy of the landscape through flashing, colour change, light and dark change, etc., and to bake a pleasant atmosphere with the dynamic lighting change.

II. B.LED landscape lighting system based on light wisdom technology

II. B. 1) Intelligent landscape lighting programme design

Intelligent LED landscape lighting control method installs an intelligent controller terminal in each street light node to control the start and stop and brightness adjustment of each street light respectively, and each street light is equipped with a wireless communication module, which is responsible for the communication between the street light terminal and the upper level website. The main functions of the intelligent lighting monitoring system are as follows:

(1) Automatic/artificial dimming function

Under normal operation, when there are fewer vehicles driving on the road in the latter part of the night, the brightness of the streetlights will be adjusted downward so as to achieve the purpose of saving electricity, and the brightness of the streetlights can also be adjusted infinitely by the staff in the control center (single light in the system area) according to the actual needs.

(2) Single-lamp control

The system can realize the switching, timing, dimming control of any street light terminal, fault detection and positioning, such as short circuit fault, illuminator fault, fault occurrence time, remote alarm and other functions.

(3) Remote monitoring function

Staff can see the operation of each street light in the monitoring center, find out the faulty street light at any time and repair the faulty street light in time, and realize the “three remotes” of street light, remote sensing, telemetry and telecommunication functions.

(4) System maintenance and management functions

System time setting, database maintenance, data backup and recovery, historical data maintenance, log query and maintenance, system operation log management.

II. B. 2) LED intelligent landscape lighting control system framework

LED intelligent landscape lighting control system framework design, focusing on the effective application of ZigBee module, to ensure that the lighting system has a better automation and intelligence characteristics, can better achieve resource conservation, and meet people's lighting needs. At the same time, the LED intelligent lighting control system design itself, the application of LED dimmable constant current driver module, temperature sensor module and intelligent control module, to ensure that the system design has a high degree of intelligence characteristics to meet the needs of people's design.ZigBee in the application of the LED intelligent landscape lighting system, pay attention to the application of the Internet, the wireless communication technology and the Internet technology, LED intelligent landscape lighting system design. Internet technology, LED intelligent landscape lighting system for the organic combination, effectively achieve the control of the lighting system to meet people's lighting needs.

II. B. 3) Intelligent control terminal

The LED landscape lighting terminal of this system is mainly composed of intelligent controller, light sensor, and LED driving circuit. The signal flow of the intelligent street light energy-saving controller is shown in Figure 1. Intelligent street light energy-saving control system through the light sensor set up on the road will collect the light signal into the intelligent controller, after processing by the intelligent controller to determine whether the street light needs to be turned on. At the same time, the intelligent controller enters the timing stage to be timed after the end of the LED street lamp automatically reduces the brightness, at this time, the intelligent controller receives the signal from the radar speed detector, when the speed signal is detected, the system automatically opens the vehicle travelling in front of the 200-metre range of street lamps, and sends the speed signal to the intelligent controller to be fuzzy processed to obtain a time t (t that is, the next street lamp travelling in front of the road to brighten up the delay time, that is, the street lamp behind the vehicle darkens). (t is the delay time for the next street light in front of the vehicle to become bright, and the delay time for the street light behind the vehicle to become dark). This ensures that a certain range of lights in front of the vehicle driving to maintain a high level of brightness, while the vehicle driving through the street lamps will be dimmed again, to truly ensure that both the lighting needs, and achieve the purpose of energy saving.

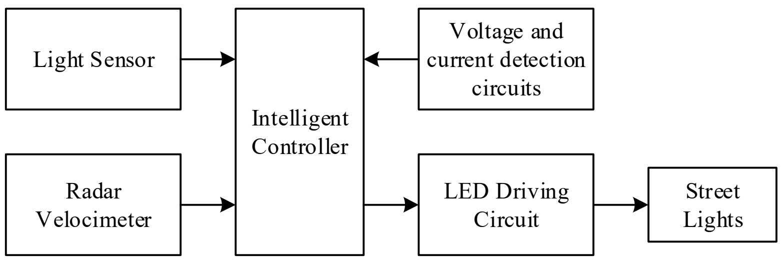


Figure 1: Intelligent street lamp energy-saving controller signal process

III. Hardware and software design of LED cityscape lighting system

III. A. Hardware System Framework Design

LED city landscape lighting system hardware module mainly includes: GPRS module, responsible for data transmission. ZigBee node and gateway module, responsible for street light data collection, uploading and transmission, etc [21], [22]. Main control microcontroller system, data core processing. LED constant current driver, street light system protection, improve the life of lamps. Sensor module, street light node data acquisition and upload. The overall design of the hardware system is shown in Figure 2. GPRS module mainly realises the remote control of the street light system, and the ZigBee system mainly realises all kinds of information collection and detection of LED street lights, remote switching of lamps and lanterns and intelligent control of lamps and lanterns light.

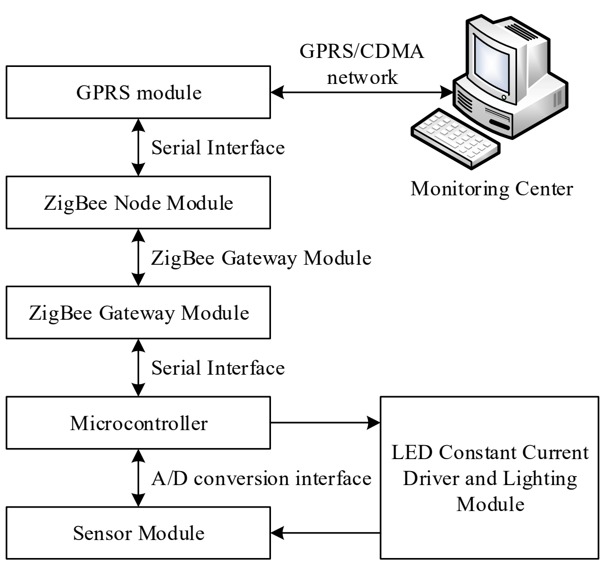


Figure 2: Overall design of the hardware system

III. A. 1) LED constant current driver design

In order to improve the service life and luminous stability of street lamps, the street lamp constant current technology based on the FT870 chip is designed. FT870 controls the MOS light-emitting diode through a specific frequency PWM signal to achieve a constant current luminous light of street lamps, which is able to guarantee the stability of the system. The LM3409HV is a typical application. The function of each pin is described as follows: EN pin is a logic level input pin, used to receive the PWM signal output from the controller, the role of the COFF pin is to set the chip's shutdown time, through the peripheral connection of resistor ROFF and capacitor COFF and ground to set the shutdown time, UVLO is a low-voltage lockout pin, and its peripheral circuit is connected to the power supply through the RUV1 and RUV2 and ground to carry out UVLO is a low-voltage lockout pin whose peripheral circuit is connected to the power supply and ground through RUV1 and RUV2 for voltage dividing and lockout operation when the voltage is lower than 1.24 V. The PGATE pin is used to drive the PFET of the peripheral circuit, and the resistor RSNS is mainly used for the detection of the peak current of the MOS tube.

When Q1 turns off, the chip maintains the off state for a certain period of time, which is set by R_{OFF} and C_{OFF} and the output voltage. At the beginning of a t_{OFF} phase, the voltage at the ends of C_{OFF} is 0 and the capacitor starts charging during the constant off time, when the voltage reaches 1.24 V, the constant off time ends and at the same time the voltage at the ends of the capacitor is restored to 0 V. The formula for this constant off time is as follows:

$$t_{OFF} = -R_{OFF} \times C_{OFF} \times \ln\left(1 - \frac{1.24}{V_O}\right) \tag{1}$$

As can be seen from equation (1), t_{OFF} is not linear and can be approximated when $t_{OFF} = R_{OFF} \times C_{OFF}$ (i.e., $V_O = 1.24V$):

$$t_{OFF} \approx \frac{1.24 \times R_{OFF} \times C_{OFF}}{V_o} \tag{2}$$

Since the current in the circuit is constant, V_O will also remain constant, so t_{OFF} can be seen as a constant.

LM3409HV works on the principle that when the level of the EN pin is low, the internal driver turns off and at the same time shuts off the current to the LED; when the input to the EN pin is high, the internal driver re-drives the current through the LED.After PWM dimming, the current flowing through the LED is:

$$I_{DIM-LED} = D_{DIM} \times I_{LED} \tag{3}$$

I_{DM-LED} for the average current through the LED, D_{DIM} for the duty cycle of the PWM dimming control waveform, I_{LED} for the rated current value of the LED.

EN pin input low level will shut down the current through the LED, due to the circuit is connected to the inductor, after a period of time to renew the current in the circuit to become 0, the circuit of the chip drive shutdown instantaneous inductor terminal voltage is V_O, then the shutdown delay time is:

$$t_f = \frac{L \times \left(I_{LED} - \frac{1}{2}\Delta i_{PP}\right)}{V_O} \tag{4}$$

Δi_{PP} is the ripple current in the indicated inductor, and I_{LED} is the rated current value of the LED.

From Fig. (4), it can be concluded that in order to be able to effectively regulate the current flowing through the LED, t_f should satisfy equation (5):

$$t_f \le \left(1 - D_{DIM}\right) \times T_{DIM} \tag{5}$$

Therefore, in the LED dimming process, the choice of dimming frequency is particularly important, if the frequency is too high will occur oscillation phenomenon, in the actual dimming process, usually compared to the fixed switching frequency, the dimming frequency to be an order of magnitude smaller.

III. A. 2) Main control chip design

In order to realise the asynchronous serial communication between the GPRS module and the ZigBee module, the main control chip MSP430 microcontroller is introduced.The P5.3 of MSP430 is used as the asynchronous serial data receiving interface of GPRS to realise the uploading function of the data.The P5.4 pin is set to be the asynchronous serial data transmitting interface of GPRS to realise the transmitting function of the control commands of the monitoring system. P3.5 of MSP430 is used as an asynchronous serial data receiving interface for ZigBee, and MSP430 sends the collected data to ZigBee. Pin P3.6 is set as the asynchronous serial data sending interface for ZigBee, which can transparently transmit wireless data to MSP430.

III. A. 3) ZigBee circuit design

The main control chip of the ZigBee circuit is the wireless RF processor CC24240, which uses the full-duplex communication mode to interact with the MSP430 for data interaction, in which the 34-interface SO, 33-interface SI, 32-interface SCLK, and 31-interface CSn are connected to the SPI communication counterparts on the MSP430 chip respectively, i.e., CSn is connected to the SET0 of the MSP430, the SCLK to the MSP430‘s SMCLK, SI and MSP430’s SIMO0, SO and MSP430's SOMI0 pins are connected to the MSP430 use the pin state changes to determine the state of the channel.

III. A. 4) GPRS circuit system design

The GPRS circuit system uses the wireless communication M23 module of KDDI, in order to improve the transmission reliability and stability M23 uses a half-duplex serial communication mode based on the conflict detection technology. Interface 33 TDX and interface 34 RDX are cross-connected with interface 32 TDX and interface 33 RDX of the MCU board of MSP430 respectively to realise the data docking between the GPRS module and MSP430. 6 Interface LEDA mainly accomplishes the verification of the LED network connection, when the LED blinks it indicates that the GPRS is working properly. Interface 11, 12, 13 and 23 mainly provide output and input communication for GPRS SIM to complete the system network access and communication.

III. B. Software system framework design

In the process of software design of LED intelligent lighting control system, we should pay attention to consider the coordination between software and hardware, and play the control function of software to ensure that the LED intelligent lighting control system plays its due role. In the software design, need to take into account the main function design and PID control algorithm.

III. B. 1) General Software Architecture Design

The street light control system software mainly contains two parts: STM32 embedded system software and remote control platform software. The embedded system software is developed by Keil μVision5 tool, written in C language and realised by STM32F103 function library based on system function design. The embedded system software is developed based on μC/OS-III micro-operating system, which adopts modular design, reduces the difficulty of software development, facilitates code management, and has good scalability at the same time. The embedded system software is divided into three main parts according to the different system functions:

(1) Main programme module. The main program module defines each function as a sub-task, and uses the μC/OS-III time slice (5ms) to reasonably schedule the sub-tasks to achieve the overall system function.

(2) Serial communication programme module. The serial communication programme module achieves orderly and coordinated communication between serial port 2 and serial port 3 through mutually exclusive signal quantities (serial port 2 mutually exclusive signal quantity: T485_MUTEX, serial port 3 mutually exclusive signal quantity: T232_MUTEX).

(3) Display and control programme module. The display and control programme module can display the environmental information collected by the sensor part and the working status parameters of the street light returned by the single-light controller, so as to achieve the local view, and at the same time, it can also be adjusted to the status of the street light and the control strategy through the way of touch screen or key press. The remote control platform is designed and realised with the help of front-end development technology (HTML, CSS, JavaScript, Vue), back-end development technology (Flask), database (MariaDB) and Ethernet communication technology.

III. B. 2) Main function design

In the process of main function design, it is necessary to design the main function after the ZigBee system is networked. Among them, the main function design includes the interface function, ZigBee module function, illuminance information and other design to meet the actual needs of the LED intelligent lighting control system.The main function design process of the LED intelligent lighting control system is shown in Figure 3, in the design of the main function of the LED intelligent lighting control system, it is necessary to pay attention to the effective grasp of the illuminance information and the temperature information, and to the acceptance node. Setting can ensure that this node scans each channel, so as to achieve effective control of PID illuminance and Red and Green components.

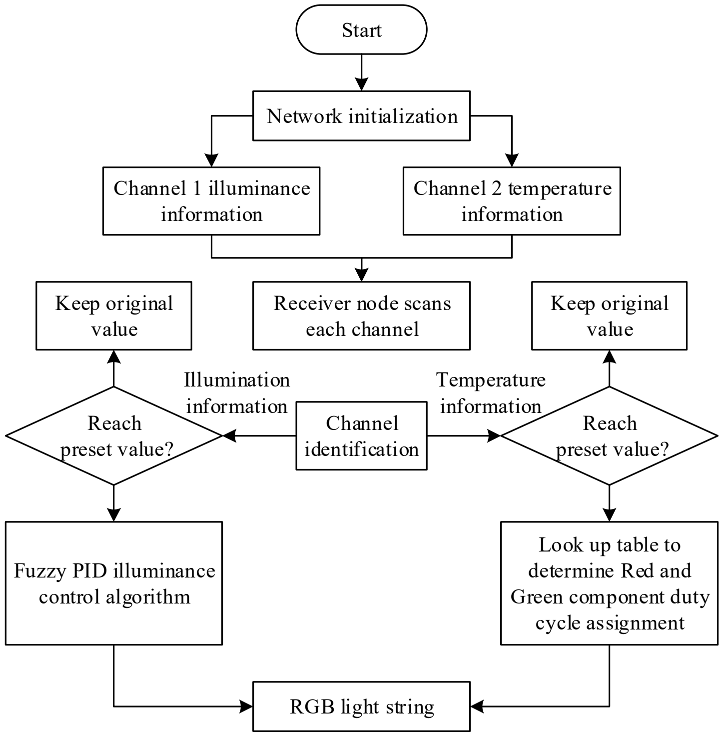


Figure 3: LED intelligent lighting control master function design process

III. B. 3) Landscape lighting intelligent control strategy

(1) Basic principle of fuzzy control

The fuzzy controller, as the core of fuzzy control algorithm, consists of four parts: fuzzification, fuzzy inference, fuzzy rule base and defuzzification. The process of fuzzy control: firstly, the input precise digital quantity X is transformed into fuzzy linguistic quantities, for example, the specific numerical information of traffic flow is transformed into linguistic quantities such as traffic flow large, medium, small, and so on, and secondly, the fuzzy linguistic quantities will be reasoned according to preset fuzzy rules to get the conclusions (fuzzy sets), and the fuzzy set merger is not a specific numerical quantity, so the fuzzy sets should be defuzzified to get the numerical quantity U at last. [23].

At present, the industrial field is more widely used and relatively mature technology of a controller for the Mamdani type fuzzy controller, this fuzzy controller control rules and human thinking is the closest, Mamdani fuzzy controller uses the fuzzy theory, combined with people's life experience to get a relatively reasonable fuzzy control rules, for the difficult to establish accurate mathematical models and affected by the influence of multiple factors of the control object has a strong advantage. The control object has strong advantages. The control rule of Mamdani fuzzy controller is similar to “If...”. Then...”, which can be expressed by the formula:

$$\begin{aligned}&R^i: IFx_1(N)isA_1^i andx_2(N)isA_2^i and,\ldots\ldots,x_m(N)isA_m^i\\&THENy(N)isB^i, i=1,2,3,\ldots\ldots,z\end{aligned}\tag{6}$$

where R^i denotes the i nd rule, z denotes the number of all rules, $x_m(N)$ denotes the inputs to the fuzzy controller, $y(N)$ denotes the outputs of the fuzzy controller, A_1^i and B^i denote the fuzzy sets of inputs and outputs of the system pre-determined, Mamdani establishes a non-linear fuzzy mapping between inputs and outputs.

The result obtained after fuzzy inference is still a fuzzy set, which cannot be further calculated, so it is necessary to convert the fuzzy quantities into digital signals (defuzzification), and the more widely used defuzzification methods are maximum affiliation method, weighted average method, and centre of gravity method. Comprehensive consideration of this paper adopts the maximum affiliation method, that is, the output fuzzy set of elements with the largest affiliation as the final fuzzy output results, the specific ideas are as follows:

When the affiliation function of the output fuzzy set O corresponding to element $x_i(i=1,2,\ldots,n)$ in set X is $\mu(x_i)$, the element with the largest affiliation in the resultant fuzzy set is selected as the output value, i.e:

$$x_o = \max\left(\mu\left(x_i\right)\right) \tag{7}$$

If the final maximum affiliation corresponds to more than one output value, the average of the multiple output values is selected as the final output:

$$x_0 = \frac{1}{n}\sum_{i=1}^{n}\mu_i \tag{8}$$

Commonly used affiliation functions include triangular, bell-shaped, Gaussian, Sigmoid, trapezoid, etc. In this paper, we use the triangular function as the affiliation function, specifically as shown in Eq. (9):

$$When\ a \le b \le c, f\left(x,a,b,c\right) = \begin{cases} 0 & x \le a \\ \dfrac{x-a}{b-a} & a < x \le b \\ \dfrac{c-x}{c-b} & b < x \le c \\ 0 & x > c \end{cases} \tag{9}$$

(2) Specific Strategies

(a) Blurring

Temperature deviation e, rate of change of temperature deviation ec, is defined in fuzzy language as NB (negative large), NM (negative medium), NS (negative small), ZO (zero), PS (positive small), PM (positive medium), PB (positive large) The range of change of e and ec is $E = \{-3,-2,-1,0,1,2,3\}$, $EC = \{-3,-2,-1,0,1,2,3\}$, $k_p k_i$ and k_d in fuzzy language as ZO, PS, PM and PB. The range of change of $k_p k_i$ and k_d is $Kp = \{0,2,4,6\}$, $Ki = \{0,0.01,0.02,0.03\}$ and $Kd = \{0,1,2,3\}$. All the above is done by using the triangular degree function is used for all of the above.

(b) Fuzzy reasoning

In practical application, according to the usual debugging experience and expert data, the fuzzy rule table is set for $k_p k_i$ and k_d respectively, which is designed in this paper by using fuzzy language statement if Aand B than C through MATLAB.

(c) Defuzzification

Defuzzification is the process of converting fuzzy variables into precise quantities. This system uses the centre of gravity method for defuzzification and the expression is shown in equation (10):

$$Z_0 = \frac{\sum_{i=0}^{n}\mu_c\left(Z_i\right)Z_i}{\sum_{i=0}^{n}\mu_c\left(Z_i\right)} \tag{10}$$

where Z_0 is the fuzzy controller output quantity, i.e. the exact value after defuzzification. Z_i is the value of the fuzzy control quantity in the domain of the fuzzy control. $\mu_c\left(Z_i\right)$ is the value of the degree of affiliation of Z_i.

The defuzzification will result in the corrected values of $k_p k_i$ and k_d, which are brought into the PID controller to perform the PID operation.

(3) Adaptive LED Brightness Regulation Based on Optimisation Methods

The main goal of adaptive lighting regulation is to minimise energy consumption while meeting the lighting standards, so the mathematical model shown in equation (11) is established. Since the energy consumption of the light source has a close relationship with its brightness level, the relationship between the energy consumed by the artificial light source (luminaire) and its brightness level will be represented by $f(\cdot)$. Of course, the energy consumption of the artificial light source is also related to the efficiency of the luminaire. Therefore, for PWM dimming, the energy consumed by a luminaire at a specific moment can be approximated as the sum of all luminaire brightness levels. That is:

$$
\begin{gathered}
Min\sum_{j=1}^{z} f\left(d_j\right) \\
s.t. E_{mean} \geq E_{mean\_linit} \\
U_0 \leq U_{o\_\lim it}
\end{gathered}
\tag{11}
$$

where z denotes the total number of artificial light sources and d_j denotes the luminance level of the j rd luminaire.

The constraints considered in the mathematical model of the optimisation method are average illuminance and uniformity, which can be achieved directly by calculating the illuminance values of the selected light sensor positions in the basket on the working surface, which greatly reduces the calculation time.

IV. LED landscape lighting system function modelling and testing

In this thesis, Matlab's Simulink tool is used for modelling and simulation of the system and debugging. The behaviour and functions of the LED street light drive system are analysed during the modelling process. The rectifier module, voltage regulator module, synchronous pulse signal generation module, street light module, current and voltage detection module and fuzzy processor module of the LED intelligent drive system are mainly modelled to verify the overall functionality.

IV. A. Fuzzy controller design based on LED landscape lighting

The inputs of the system include road illumination information and road pedestrian and vehicle condition information, that is, road information collected by illumination sensors and motion sensors as inputs to the system. The level at which the street light is about to be switched on is used as the output of the system.

IV. A. 1) Establishing the system affiliation function

The road lighting studied in this paper is mainly applied in the main road, then according to the road lighting specification standards, the average illuminance of the main road at night should meet 30lx, and its illuminance range is between 15 and 35 in order to be the most normal illuminance value. Then we define the domain of illumination sensor information as [0, 40].

The defuzzification is divided into 4 fuzzy subsets: PH, PB, PM, PL. PH means too bright illumination, with illuminance value above 40lx, PB means moderate illumination, with illuminance value between 15 and 35lx, PM means slightly dark illumination, with illuminance value between 5 and 15lx, and finally PL means too dark illumination, with illuminance value between 5 and 15lx. Finally PL refers to overly dark illumination with illuminance values between 0 and 5lx. The thesis domain of motion sensor information is [0, 24], which is divided into two fuzzy sets, one is the person or vehicle P with motion, at which time the motion sensor signal voltage ≥12V, and the other is the person or vehicle Z without motion, whose motion sensor signal voltage ≤12V.The output is the street light open brightness level, whose thesis domain is [0, 10], which is divided into 11 levels, and the defuzzification is divided into four fuzzy sets, one is PH: Large openness, street light brightness level to 8 ~ 10, two is PB: medium openness, its street light brightness level to 5 ~ 7, three is PM: micro-medium openness, street light brightness level to 2 ~ 4, four is PL: small openness, street light brightness level to 0 ~ 1 level. Its affiliation function is in the form of trigonometric function and Ma applies Matlab simulation software for testing.

IV. A. 2) Fuzzy Decision Simulation

The fuzzy control system uses Mamdani inference algorithm and the centre of gravity method is used for defuzzification.Mamdani inference algorithm is one of the most common inference algorithms used in fuzzy control systems. Matlab simulation software is applied to simulate the fuzzy controller for the fuzzy control system. Figure 4 shows the fuzzy controller simulation. For example, when the light intensity L is 20 lx, according to the maximum affiliation averaging method, the final street light brightness output value is 0.48, so when the light intensity L is detected to be 20 lx, the optimal brightness level of the street light should be 48%, which is PB.

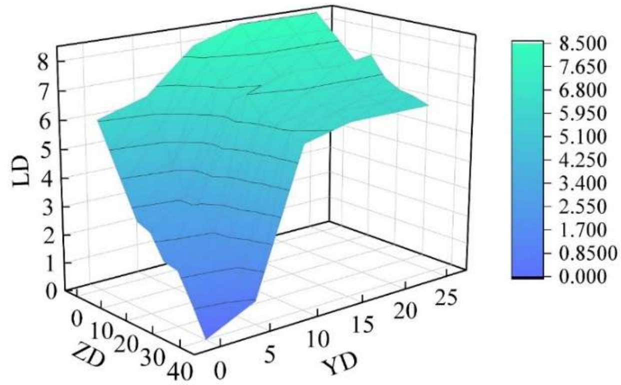


Figure 4: Fuzzy controller simulation

IV. B. LED landscape lighting control verification

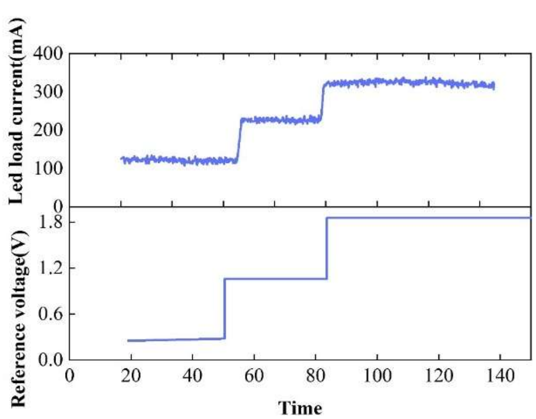
IV. B. 1) Variable Response Simulation Results

The fuzzy processors of daylight and noise variables are encapsulated into an overall model to simulate the LED landscape lighting, and Fig. 5 shows the variable response simulation results. (a) and (b) are the noise and daylight variables, respectively.

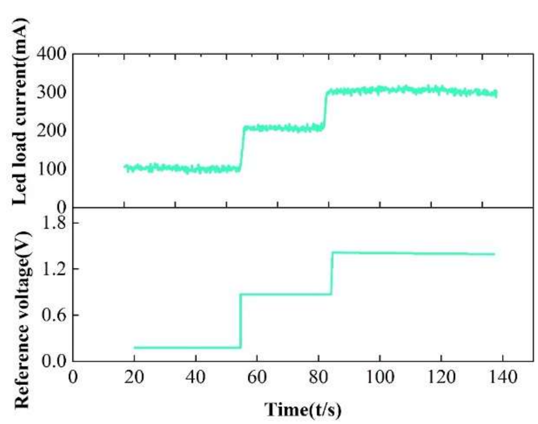
Fig. 5(a) shows the noise variable simulation, in the simulation, the second signal is the voltage signal of the noise variable, which is the input excitation of the variable with the step voltage, which is gradually increasing from 0.4V-1.6V, and the step voltages are 0.3V, 1.0V, and 1.8V, respectively. The simulation time is 140s. The first signal is the current simulation result of Street Lamp. The output current ranges from 120mA, 220mA, and 320mA.The purpose of choosing a step voltage for the noise variable instead of a continuously varying voltage is to reduce the amount of data processing in the microprocessor while choosing to regulate the noise voltage by dividing it into three voltage thresholds. This greatly reduces the amount of data processing in the microprocessor and reduces the complexity of the circuit.

Fig. 5(b) shows the simulation of the insolation variable, the second signal is the voltage signal of the insolation variable, which is the step voltage as the input excitation of the variable, which is gradually increasing from 0.2V-1.6V, and the voltages are 0.2V, 0.8V, and 1.4V, respectively. The simulation time is 140s. The first signal is the current simulation result of Street Lamp. The output current ranges from 100mA, 200mA, and 300mA.The purpose of sampling step voltages for the sunshine variable is the same as dividing steps for the noise variable. The main purpose is to reduce the amount of circuit data processing.

From the simulation results, it can be seen that the system with the change of noise variables and sunshine variables can be intelligent judgement, processing to get a reasonable response. From the results of the response, the system can realise the control of the LED street light working state under real-time environmental changes, realise the energy-saving function, and realise the dynamic control of the working state of the LED street light.



(a) Simulation of noise variables



(b) Simulation of sunshine variables

Figure 5: Variable response to the simulation results

IV. B. 2) LED landscape lighting control function test

After the microprocessor is initialised to work normally, the circuit is opened, and the photosensitive circuit and noise detection circuit are closed at the same time, to test whether the LED landscape lighting system is able to emit light normally and whether the light emission is stable. Figure 6 shows the LED street light output constant current and voltage test results. From the results of the input voltage of 220V mains, LED street lamp output voltage is 20.81V, output voltage ripple is 3.35V. LED street lamp intelligent driver output current is 304.12mA. With the change of light source intensity, the output current changes dynamically, to achieve the dimming, so as to complete the debugging of the LED cityscape lighting system.

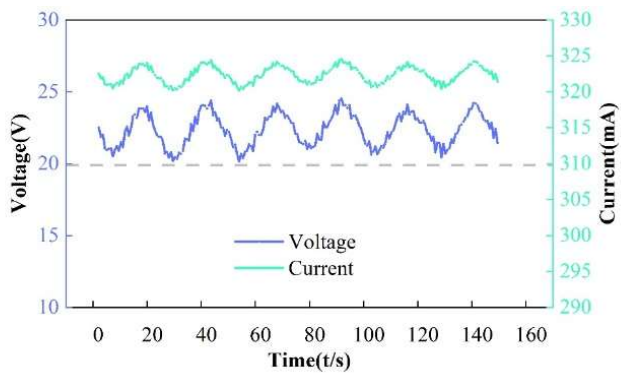


Figure 6: Test results of constant current and constant pressure of led street lamp output

IV. C. Dynamic optimisation experiments

The improved PID control algorithm can make the illuminance of the urban target area quickly reach the set illuminance value, avoiding the generation of excessive illumination, improving the efficiency of energy use, and also saving energy. The control strategy program is built in Simulink, and the joint lighting control system and street model are used for dynamic optimisation experiments. In the experiments, 11 LEDs are divided into two groups, and the LEDs within the same group are connected in parallel, and the sensor position and the layout of the light group are shown in Fig. 7, and the luminance of the LEDs within the same group is the same, and the sensors are placed in the position of area 1.

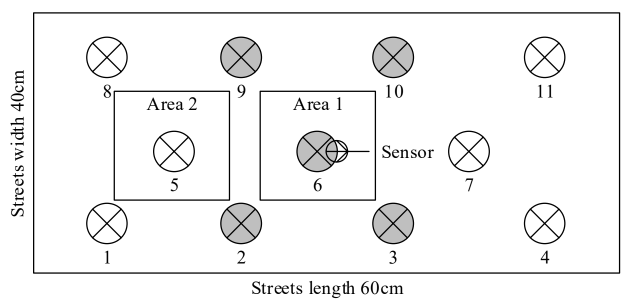


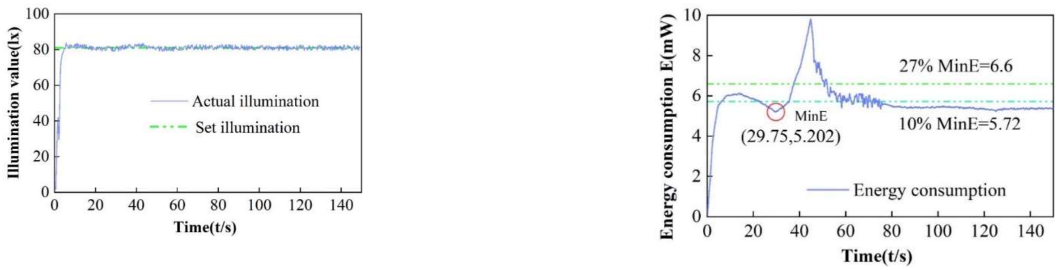
Figure 7: Sensor position and lamp set layout

The following three experiments are carried out to verify the effectiveness of the control strategy proposed in this paper, respectively, in the constant illuminance, external disturbances, variable illuminance demand when the lighting energy consumption was analysed, and the experimental results verified that the proposed control strategy has a good anti-interference ability, can avoid excessive illumination, improves the efficiency of energy use, and greatly reduces the lighting power consumption.

IV. C. 1) Constant illuminance

In order to observe the effect of adding energy consumption optimisation more intuitively, we first conducted an energy consumption traversal experiment, setting the illuminance value to 81lx, and the light and energy consumption obtained from the experiment are shown in Figure 8. The role of the first 15s is to make the light stable, because the traversal of the energy consumption experiment requires that the illuminance should first reach the set value. The traversal experiment is carried out in 15~50s to make the parameter of the control volume allocation of the light group change from 1 to 0. The minimum energy consumption minE is 5.202mW and the maximum energy consumption maxE is 9.985mW are marked in the graph, and two energy consumption lines are made in the graph with 10% and 27% more than the minimum energy consumption minE to evaluate our optimisation index. The optimisation algorithm is added at 50s, and the system energy consumption is basically stable at around 5.5mW when running to 75s.

From the figure below, it can be clearly seen that in the traversal experiment and energy consumption optimisation experiment, the illumination value one is stable at about 81lx, with good dimming effect. And it can also be seen very intuitively, after adding the optimisation algorithm, the energy consumption of LED lights for urban landscape lighting has been further reduced. The energy consumption of LED lights with the traversal of the minimum energy consumption error of 6.48%, compared with the traversal of the maximum energy consumption decreased by 47.7%. So it is also verified that the intelligent lighting control strategy proposed in this paper can meet the illumination demand while minimising the energy consumption, i.e. to achieve the set illumination level with relatively small energy consumption, which meets the user's lighting demand and further reduces the energy consumption.



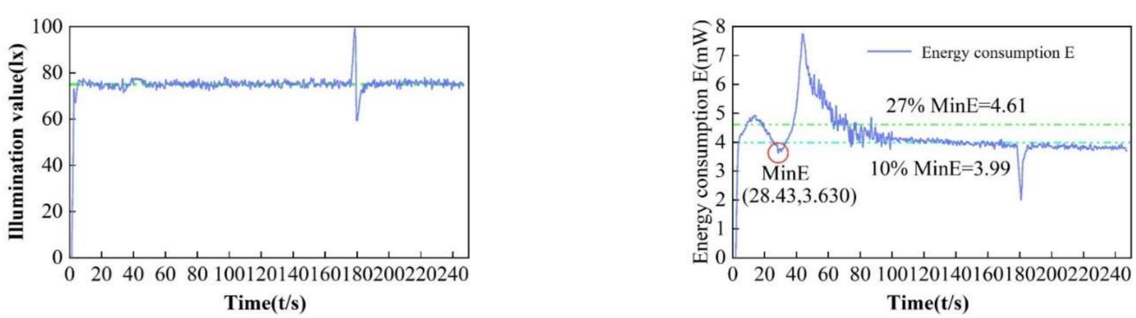
(a) Intensity of illumination (b) Light energy consumption

Figure 8: Energy consumption traversal and energy consumption optimization at 81 lx

IV. C. 2) External disturbances

On the basis of experiment (1), in order to more intuitively observe the performance of the system after being subjected to external perturbations, the illuminance value is first set to 75lx, and a disturbance with an amplitude of 33lx and a duration of 1s is superimposed on the actual illuminance in 180s, and the experimental light and energy consumption are shown in Fig. 9. The role of the first 15s is to make the light to achieve the set illuminance value, in the 15~50s traversal experiments, so that the control volume allocation parameter k from 1 to 0, and in the figure marked traversal experiments the minimum energy consumption minE is 3.630mW, the maximum energy consumption maxE is 7.742mW and in the figure more than the minimum energy consumption minE 10% and 27% to make the two energy consumption line to assess our optimisation metrics; the optimisation algorithm is added at 50s, and when it runs to 100, the system energy consumption is basically stable and within 10% of the minimum energy consumption, which is a 49.2% decrease compared to traversing the maximum energy consumption.

When the system is disturbed at 180s, the system returns to the previous state in a few seconds, and at this time, the energy consumption of the system is also stable at about 4.0mW, and the error with the minimum energy consumption is 7.69%. From this experiment, it can be seen that the system has strong anti-interference performance, the system can quickly recover to the set value after being disturbed, and the system is always able to stabilise the output with a relatively small energy consumption, which further reduces the energy consumption.

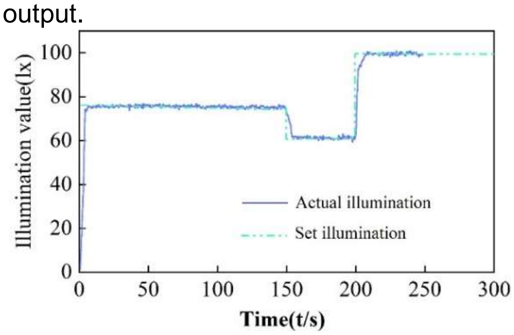


(a) Intensity of illumination (b) Light energy consumption

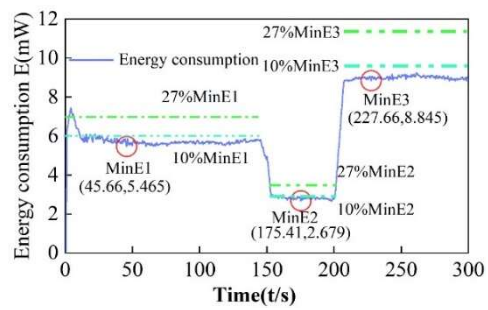
Figure 9: System illumination and energy consumption curve when disturbed

IV. C. 3) Variable illumination

On the basis of the above experiments, the experiments are carried out again: the illuminance value is set to 78lx in 0-150s, 58lx in 150-200s, and 100lx in 200-300s.The experimental light and energy consumption diagrams are shown in Fig. 10. By traversing the energy consumption experiment, we can get the minimum energy consumption under 78lx, 58lx, and 100lx are minE1 (5.465mW), minE2 (2.679), and minE3 (8.845mW), respectively. And more than 10% and 27% indicator lines of minE1, minE2 and minE3 respectively are plotted in the graph. From the actual illuminance graph, it can be seen that the actual illuminance is able to quickly track the upper set illuminance value. From the energy consumption graph, it can be seen that after about 50s, the energy consumption is stable at about 5.66mW, and the error with the minimum energy consumption minE1 is 6.88%, which is within 10% of the minimum energy consumption. At 150s, the set illuminance is suddenly reduced to 58lx, at this time, the illuminance value of the system is stable at 58lx, and the energy consumption is stable at about 2.70mW, and the error with the minimum energy consumption minE2 is 1.55%. At 200s, the set illuminance is suddenly increased to 100lx, at this time, the illuminance value of the system is stable at 100lx, and the energy consumption is stable at about 9.05mW, and the error with the minimum energy consumption minE3 is 8.01%, which is within 10% of the minimum energy consumption. From this experiment, it can be seen that the system has good dynamic performance, when the set illuminance changes, the system can respond quickly, and always be able to a relatively small energy consumption stable output.



(a) Intensity of illumination



(b) Light energy consumption

Figure 10: Energy consumption curve under varying illumination

After using the improved PID control algorithm to achieve precise control of illumination, the energy consumption is optimised while keeping the light constant. Combining the above experiments, it can be seen that with the proposed lighting control strategy, the energy consumption of the system after stabilisation is reduced by about 40% compared with the maximum energy consumption of the traversal experiments, which greatly reduces the lighting energy consumption and improves the efficiency of energy use. It can also be seen from the figure, the proposed control strategy has good dynamic performance and anti-interference ability, when the set illuminance changes or by the external uncertainty interference, the system is always able to respond quickly and achieve a good working condition, always make the city landscape lighting LED lamps and lanterns to a relatively small energy consumption to meet the people's illuminance demand, to avoid excessive lighting. Not only meets the people's demand for illumination, but also saves a lot of energy and improves the efficiency of energy use, therefore, it has certain practical significance and broad application prospects.

V. Conclusion

In this paper, under the framework of the smart city, a study was carried out on the energy saving of urban landscape lighting, breaking the traditional timed street light control system and introducing the most widely used fuzzy control in the intelligent control algorithm. Through the optimised fuzzy decision-making intelligent algorithm, the intelligent control of the optimal light intensity level of LED street lamps is obtained, which not only meets people's normal travel needs, but also saves electricity to the maximum extent. At the same time, real-time monitoring through the upper computer software saves a lot of human and material resources. As the road to smart city construction, the next step in the research of intelligent urban LED street light system is to design a version of the software programme that can be easily copied and transplanted and a hardware system that can be easily replaced, to further reduce the development cost and the design and manufacturing cost of the system.

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