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Design of Health Healing Lighting in a Medical Center Based on Intelligent Lighting Control System

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ABSTRACT

The intelligent lighting control system will unify the management of lighting equipment in outpatient buildings, inpatient buildings, and other buildings of the hospital, thereby improving the service quality of the hospital, providing a comfortable and relaxed working environment for medical staff, and providing a warm and comfortable treatment environment for patients. This project aims to develop a health rehabilitation environment lighting automation control system based on combining Zigbee Wide Ad Hoc Network and RFID (Radio Frequency Identification) technology. It can be customized according to the comfort needs of patients and can achieve lighting adjustments before the patient arrives. A PSO-based intelligent lighting control method has been proposed. To overcome the shortcomings of PSO such as being prone to local minima and premature convergence, a new PSO optimization method is proposed based on the inertia weight PSO and combined with genetic optimization theory. This method can not only learn experience from individuals in the group but also avoid the possibility of parent particles falling into local extremum. Compared with the original particle swarm optimization algorithm, the new particle swarm optimization algorithm can quickly find the optimal combination of lighting devices, improve computational efficiency by 6.208%, and also reduce the energy consumption of the calculated lighting devices, indicating the advantages of the new particle swarm optimization algorithm.

KEYWORDS

Health Healing, Intelligent Lighting, Medical Center, Particle Swarm Optimization

1. INTRODUCTION

To make the indoor environment more comfortable and convenient, traditional lighting control methods are no longer suitable for indoor environments, and more intelligent lighting control methods must be adopted. Modern hospitals have excellent lighting systems that can release patients' negative emotions in a bright and comfortable environment, allowing patients to wait for treatment with peace of mind, bringing positive effects to treatment, ensuring that medical

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workers can efficiently and quickly complete all work, reducing physical and mental fatigue of medical staff, and thereby improving work efficiency (Yilmaz, F. S, 2018). The intelligent lighting control system will unify the management of lighting equipment in outpatient buildings, inpatient buildings, and other buildings of the hospital, thereby improving the service quality of the hospital, providing a comfortable and relaxed working environment for medical staff, and providing a warm and comfortable treatment environment for patients. Appropriate lighting design can create a healthy, clean, and comfortable surgical setting, positively affects onpositively reducing patients' tension and improves their physical and mental health. A good lighting environment for medical staff can slow down the tense working atmosphere and improve work efficiency (Guo Yujian, et al., 2019; Tang & Zhang, 2022).

The two commonly used methods are: firstly, to modify the lighting fixtures themselves to reduce energy consumption; The second is to transform the monitoring and management mode of lighting equipment, develop intelligent lighting equipment, and make lighting equipment more convenient and energy-saving. Smart lighting control system has been put forward by experts and scholars at home and abroad, and related research and application have been carried out (Wang, S., Su, D., & Wu, Y, 2022). The management and control of lighting equipment can be divided into three stages: manual control, timer photosensitive control and computer control. Jenny et al. combined the Internet of Things technology with the lighting system, and ZigBee and WiFiZigBee and WiFi controlled the lamps controlled the lamps. The lighting lamps' start, stop and brightness were mainly studied (Jenny, & Donelan, 2016). Rubenstone uses ANN(Artificial neural network) to study the design method of intelligent lighting (Rubenstone, J, 2018). Because the artificial neural network can self-learn, it can continuously accumulate experience through training, helping designers design intelligent lighting systems, thus saving a lot of work for designers. Archer et al. improved PSO(Particle swarm optimization) and applied it to the indoor smart lighting system (Archer, G. S, 2017). When adjusting the brightness of indoor artificial light sources, PSO was used to optimize the control strategy of the intelligent lighting system, which not only ensured the lighting needs of people but also made the outdoor natural light reasonably applied and reduced the energy consumption of the lighting system. Gentile et al. used the prior information of light sensor calibration to control sunlight adaptive lighting (Gentile, N, et al., 2018). The purpose is to introduce natural light reasonably and realize energy saving. At home, some corresponding scholars study natural lighting (Dikel, E. E, et al., 2018; Iyamu, & Mlambo, 2022).

The goal of hospital lighting design is that color significantly impacts patients' psychological treatment. A good medical environment can alleviate patients' anxiety and give them enough patience to undergo examinations and treatment. Adopting an intelligent lighting control system can create a more humane and high-quality lighting environment, achieve unified and scientific management of the building lighting system, continuously improve its work efficiency, and save hospital operating costs. The light environment design is mainly based on functional lighting, biased towards technical indicators such as illuminance, color temperature, glare, etc., often with single lighting mode, too high color temperature of light source, glare (Qiao, L, 2021), and lack of health healing lighting for psychological and physiological adjustment. Given the shortcomings of the widely used lighting system, this project will develop an automatic control system for health healing lighting in medical center, which integrates Zigbee wireless ad hoc network protocol and RFID (Radio Frequency Identification) technology, can meet the individual comfort customization requirements, and can adjust the lighting before the user arrives. The lighting control strategy of health treatment in medical center studied in this paper differs from the scene lighting control in entertainment places and stages. The lighting control strategy studied in this paper pays more attention to the individual's demand for light illumination, can flexibly judge whether the personnel are in the control area, and can adjust the state of lighting equipment in time, and at the same time open or close the shutters according to the individual's needs, and use natural light sources reasonably.

2. RESEARCH METHOD

2.1. Design of Intelligent Lighting Control System

Hospital intelligent lighting control system can realize the central monitoring and control of lighting system, and make the hospital light environment achieve the desired effect. Smart lighting control technology is the product of the combination and penetration of computer technology, communication and control technology, and the crystallization of modern high technology (Zheng Bo, 2018). A nursing station is where nurses perform daily treatment, complete nursing preparations, and handle unexpected events. The lighting should create a clean and bright feeling, and built-in fluorescent lamps should generally be used. Due to the continuity of care work, night lights should also be installed on tables or walls. In this system, the LED operates according to a certain program, and employees can remotely manage through mobile phones to achieve work in multiple locations. At the same time, the lighting intensity can be adjusted according to the surrounding environments to save energy.

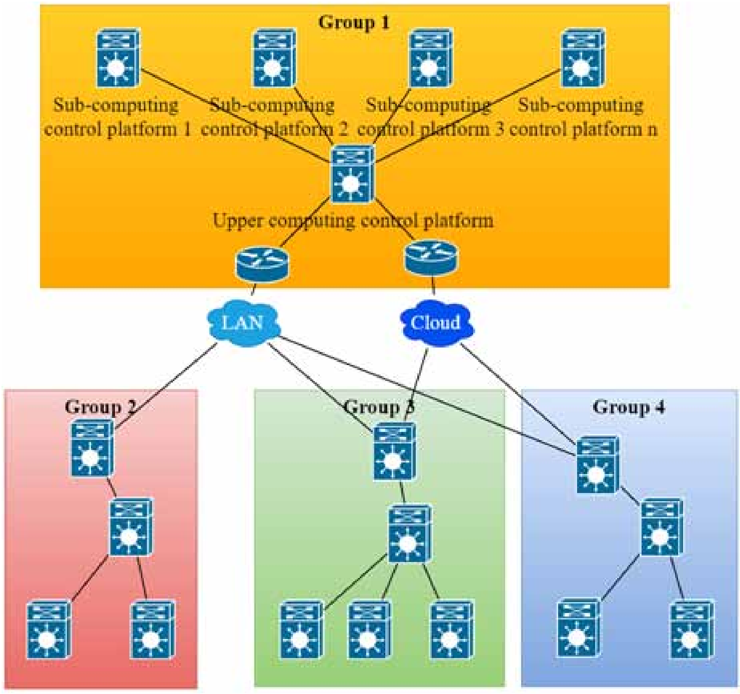
Zigbee is a wireless two-way communication technology with short distance, low power consumption, low complexity, low speed and low cost. It is mainly used for data transmission between electronic devices with a short distance, low power consumption and low speed requirements. It is widely used in data transmission of typical periodic data, intermittent data and intense reaction time. The manufacturing cost of Zigbee module is very low, and Zigbee protocol does not charge any patent fees. Low cost is also a key factor for the wide use of Zigbee (Aojia, 2019). RFID technology, also known as electronic tag and radio frequency identification, is a kind of communication technology which can identify a specific target and read and write related data through radio signals without establishing mechanical or optical contact between the system and the particular target (Sukte et al., 2022). The main advantage of RFID technology lies in non-contact identification, which can be used in harsh environments such as snow, fog, ice, paint and dirt.

In the overall lighting system, LED is selected as the lighting source to adjust the lighting intensity of its area. After receiving the dimming control amount from the upper computer, the corresponding dimming control will be carried out on the LED and other artificial light sources connected to it. Although the functions of each sub-computing control platform are different, each sub-computing control platform has its computing control module and WiFi network communication module to achieve communication with the upper computing control platform. Other modules will vary depending on the task.

With the advancement of network technology and computer hardware technology, using browsers to handle small-scale applications has become inevitable. Users only need to open a browser to log in to the system and complete related management work, eliminating the steps of downloading, installing, and configuring software and also meeting the seamless connection between different terminal systems. On this basis, an overall design was carried out for the method according to its requirements. By designing the software and hardware of the remote control, monitoring and predicting the energy consumption of the overall lighting system has been achieved. A layered energy-saving control method was proposed based on the energy consumption of the lighting fixtures, which intelligently controlled the wiring of the lighting fixtures; To facilitate users' real-time monitoring of each circuit, real-time monitoring of each course has been carried out.

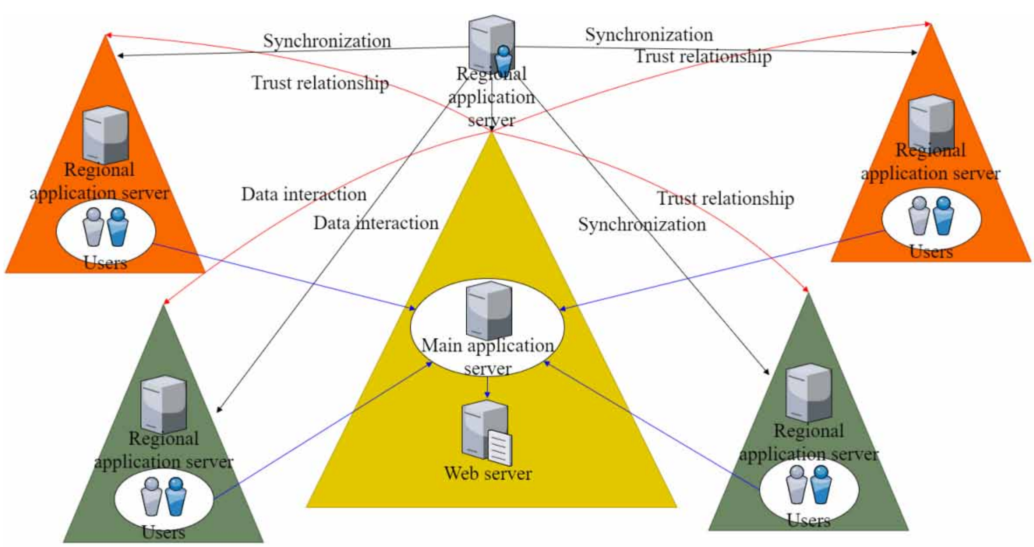
This paper will design and implement a distributed intelligent lighting system which can be applied to health healing in medical centers. The design idea is: First, the user inputs the demand instruction for the illumination intensity of the target area through the client, and then the client sends the expected value of the illumination intensity of the target area to the upper computing control platform, and then executes the corresponding instruction for the corresponding module, to continuously adjust until the illumination intensity of the target area reaches the user's set value. The architecture of the distributed intelligent lighting system is shown in Figure 1.

Figure 1. Distributed intelligent lighting system architecture



The application server is the center of the server. According to the deployment location, the application server can be divided into main and regional application servers. The main and regional application servers exchange data through the local area network. The regional application servers are independent of each other, and the main application server needs to coordinate the interactions among the regional servers. The relationship between them is shown in Figure 2.

Figure 2. The relationship of the application server



The main functions of the server are collecting equipment data, data processing, generating alarm information, logging, data storage, receiving and sending control commands, and intercepting customer requests. According to the functional requirements of the application server, the system divides the application server into data acquisition module, data processing module, a customer management module and data service module.

Some node devices in the network need to leave the network due to the interference of environmental factors, the change of network layout or the failure of hardware equipment. Therefore, the command request of equipment leaving the network is provided in the network equipment management. Through this instruction, the devices in the network can leave the current network in real-time and quickly, thus saving the network overhead. When the application data can't fit in a data packet, it is necessary to transmit the data in pieces, also called data breakpoint transmission. Through data fragmentation, each piece of data can be put into a data packet for transmission.

2.2. Realization of Intelligent Lighting Control Algorithm

The main function of an intelligent lighting control system is to automatically monitor the indoor and outdoor lighting intensity, illuminance, uniformity, and other related parameters in real-time and to independently and adaptively change the shading angle according to a certain program. It also adjusts the lighting angle and power of the lamps to meet the comfort needs of human eyes, effectively reducing overall energy consumption while ensuring indoor lighting requirements. Compared to conventional lighting regulation, intelligent lighting regulation systems often achieve precise and reasonable light intensity adjustment at different times and in different environments through "preset" methods, overcoming the energy waste of conventional lighting indoors and outdoors (Li et al., 2022).

With the deepening of people's concept of green environmental protection and energy conservation and the strengthening of personalized image, people gradually change from green energy conservation to personalized energy conservation, and the control strategy of energy-saving lighting also changes. The lighting control strategy of health healing in medical center studied in this paper differs from the scene lighting control of entertainment places and stages. The lighting control strategy studied in this paper pays more attention to the individual's demand for light illuminance, can flexibly judge whether people are in the controlled area, and can timely adjust the state of lighting equipment. At the same time, it can open or close shutters according to the individual's needs and use natural light sources reasonably.

Assuming that the coordinate of the window is $\left(x_k, y_k, z_k\right)$, the value of the illuminance meter is e_0, and $e_i^{'}$ is the illuminance of the lamp l_i at the point $\left(x_k, y_k, z_k\right)$, the actual illuminance e_k of the window light source is:

$$e_k = e_0 - \sum_{i=1}^{n} e_i^{'} \tag{1}$$

In the intelligent lighting system in this paper, all lamps are grouped, assuming that all indoor lamps are divided into n groups, and the required current of each lamp in each group is $\omega_i I$, where $0 \le \omega_i \le 1$ is the percentage of the total current.

As the LED lamps used in this paper are of the same model, ignoring the slight difference of their resistance values, assuming that their resistance values are all R, the calculation formula of the total electric energy consumed in the experiment is:

$$W = \left[\left(\omega_1 I\right)^2 m_1 + \left(\omega_2 I\right)^2 m_2 + \cdots + \left(\omega_n I\right)^2 m_n\right] Rt \tag{2}$$

$\omega_1, \omega_2, \cdots, \omega_n = 1$ and m_i represent the total number of lamps in each lamp group.

In recent years, with the continuous research and progress of artificial neural network and genetic algorithm, researchers are constantly exploring and improving the parameter optimization of PID control. Because PSO itself has good optimization characteristics, even if the initial conditions are unfavorable, it can still find the appropriate system parameters and finally meet the requirements of control objectives (Piccolo, E. L, et al., 2021); When searching in the solution space, it can keep a high speed, which can avoid falling into the local optimal solution prematurely and effectively overcome the disadvantages of searching from a single point.

In the process of iterative optimization of PSO, first of all, an initial population should be defined, in which the particles can fly randomly. For every possible solution, they are themselves a particle. Assuming that there are m particles in the N-dimensional search space, these particles form a community and j is used as the particle. The formula for updating and adjusting the speed and position of particle j is as follows:

$$v_{jn}^{t+1} = v_{jn}^{t} + C_1 \times rand\left(\ \right) \times \left(P_{jn}^{t} - Z_{jn}^{t}\right) + C_2 \times rand\left(\ \right) \times \left(P_{gn}^{t} - Z_{gn}^{t}\right) \tag{3}$$

Z_j in the formula represents the position of the jth particle; P_g represents the best searched position in the group; Said P_j particles through the best historical position; $rand\left(\ \right)$ is a random value in the range of [0,1]; v_j represents the flying speed of particles.

Assuming that the number of lighting devices in the control area is D, the population searches for the optimal solution in D-dimensional space; There are m users entering the control area, and the illumination demand of users is U_j, and the unit is lx; The number of natural light sources in the control area is n. Each lighting device can adjust the light intensity within the $\left[0, Id\right]$ range (Zou, L, 2021).

Then the PSO fitness evaluation model and constraint function of the lighting strategy in the control area are:

$$\min f\left(x\right) = \sum_{d=1}^{D} x_d \qquad d = 1,2,\cdots,D \tag{4}$$

$$s.t \left\{ \sum_{i=1}^{D} e_i + \sum_{k=1}^{n} \left(\frac{e_k \cos\varphi}{\sqrt{\left(x_k - x_j\right)^2 + \left(y_k - y_j\right)^2 + \left(z_k - z_j\right)^2}} \right) \right\} = U_j \qquad j = 1,2,\cdots,m \tag{5}$$

Within the allowable range of error, search the brightness combination of lamps with the lowest energy consumption for dimming. f represents the fitness of particles, and $\frac{1}{f}$ represents the objective function value (energy consumption of lamps). The fitness function of particles is shown in formula (6).

$$f = \sum_{i=1}^{n} \frac{1}{\left(I_i / 10^3\right)^2} \tag{6}$$

I_i Represents the luminance value of the i th lamp, dimensionless; Table n shows the number of lamps.

The smaller the particle fitness value, the better it is. When judging the individual optimal position and group optimal position of particles, we can update or keep the individual optimal particle and group optimal particle according to this principle (Tan, C., Chang, S., & Liu, L, 2017).

To address the issues of PSO being prone to local minima and premature convergence, it is necessary to increase the diversity of PSOs, preserve the interrelationships between PSOs, and enable them to have better global optimization capabilities. Based on the basic genetic algorithm theory, the inertia weight particle swarm optimization problem has been improved and analyzed.

For any i -th particle in the t -th iteration, its fitness $f_i^{(t)}$ can be calculated according to the above fitness function. If the particle fitness value is added as the last column of the particle swarm location matrix, that is, the combination matrix $particle(t)$ of particle swarm fitness and location is:

$$particle(t) = \begin{bmatrix} \Phi_{11}^{(t)} & \cdots & \Phi_{D_1}^{(t)} & f_1^{(t)} \\ \vdots & \ddots & \vdots & \vdots \\ \Phi_{1N}^{(t)} & \cdots & \Phi_{DN}^{(t)} & f_N^{(t)} \end{bmatrix} \tag{7}$$

In this matrix, t represents the matrix when the matrix is the t -th iteration, $i = 1, 2, \cdots, T$.

The optimal matrix $g_{best}(t)$ of particle swarm is:

$$g_{best}(t) = \begin{bmatrix} \Phi_{1t}^{(t)} & \cdots & \Phi_{Dt}^{(t)} & f_t^{(t)} \end{bmatrix} \tag{8}$$

PID control optimization based on PSO algorithm is to use the self-optimization characteristics of PSO algorithm to make three variable parameters KP, Ki and KD as basic particles in the solution space. Through its automatic evolution, relying on the self-optimization process, it tends to be global optimal and obtains the final result.

The basic control steps are as follows:

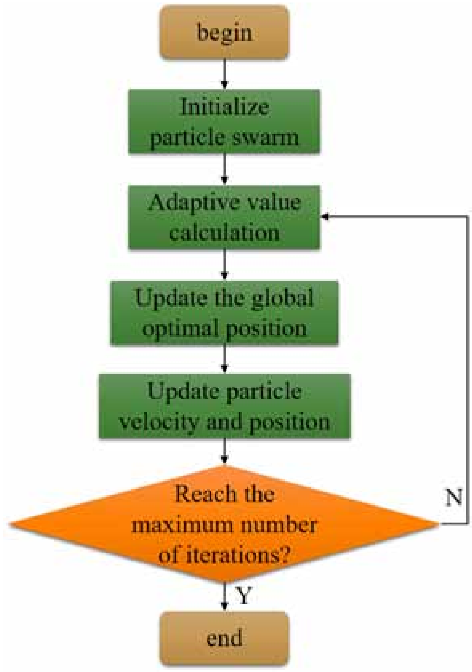
1. Three system parameters are tuned using the classical PID control parameter tuning method. Then the search range of PID parameters is determined based on these three parameters.
2. Determine the scale of PSO, and set the algebra of evolution at the same time.
3. Calculate the cost function value by using the values of the corresponding parameters of individuals in the population.
4. According to the PSO algorithm's evolutionary mechanism, particles' position is determined from the initial population and updated.

According to the results of the previous step, it is determined whether to adjust the relevant parameters of the algorithm, and the system parameters when the optimal control effect is achieved are selected according to the results of many experiments.

The specific algorithm flow is as follows in Figure 3.

The main difference between the improved PSO algorithm with crossover factor and the traditional PSO algorithm is that the particle swarm has to undergo crossover and mutation after updating the speed and position. The offspring particles generated by crossover and mutation inherit the advantages of the parent particles theoretically, which can not only learn their own experience and group experience, but also eliminate the possibility that the parent particles fall into local optimum.

Figure 3. Algorithm flow



3. ANALYSIS AND DISCUSSION OF RESULTS

I have described the setting of the relevant experimental environment in the article: In this experiment, CC2530 2.4G active RFID read-write radio frequency identification development kit is adopted, the power of the reader is less than 400m W, and the lighting equipment is energy-saving dimmable LED bulbs with bulb shape, working voltage of 220V, maximum power of 8w and warm yellow light. A radio frequency reader is arranged in the middle ceiling of each room, with a height of 2.0m from the ground; In this experiment, six ordinary desktops are used as servers, and the server configuration is dual-core processor with a main frequency of 2.0GH, memory of 2G, hard disk of 250G and operating system of Windows 10. Using SQL2008 database to store data. The client uses a notebook computer, configured as a dual-core processor with a main frequency of 2.4GH, a memory of 4G, a hard disk of 500G and a window10 operating system. Data is transmitted between server and client through Ethernet and between device and server through Zigbee network.

To verify the feasibility of the above network and system design scheme, this paper mainly debugs and tests it. In the process of black-box testing methods, we primarily searched and found that the realized functions did not meet expectations or missed functions, there were errors in the interface, the database could not be accessed, the performance did not meet the requirements, and possible errors and problems in software initialization and termination.

In this paper, the illuminance of each position in the room is sampled, and the lighting is turned on and off manually. Then, the method proposed in this topic is applied to artificial lighting. The energy-saving effect of the algorithm is shown in Table 1.

It can be seen that the energy-saving control effect of artificial lighting is not ideal, because all equal power factors are 100%, and there are 5 lights on each floor of the building. This method has a high energy consumption efficiency because it uses diodes to adjust brightness, while it covers various light sources, allowing for optimal energy consumption.

Table 1. Energy saving effect of algorithm

Illumination Area	Energy Saving Effect/%
1	70.043
2	69.25
3	66.074
4	73.762
5	67.506

On this basis, the "Smart Lighting Office" is taken as the research object, and the improved particle swarm optimization method is used to optimize the method. Experimental verification is conducted to verify the effectiveness of the method.

The experimental simulation is carried out in MATLAB environment, in which the initial particle number $M = 450$, particle iteration times $k_{\max} = 40$, acceleration factor $c_1 = 0.7, c_2 = 0.7$, inertia factor maximum $\omega_{\max} = 0.8$ and inertia factor minimum $\omega_{\min} = 0.3$.

Set and calculate in DIALux, and get the average illuminance values of 9 working faces corresponding to 10 data groups. See Table 2 for the numerical settings of the luminous flux of 10 groups of lamps, in which the first group is the case that all 5 lamps have full luminous flux and 4000lm output, and the remaining 9 groups are the luminous flux data given at random.

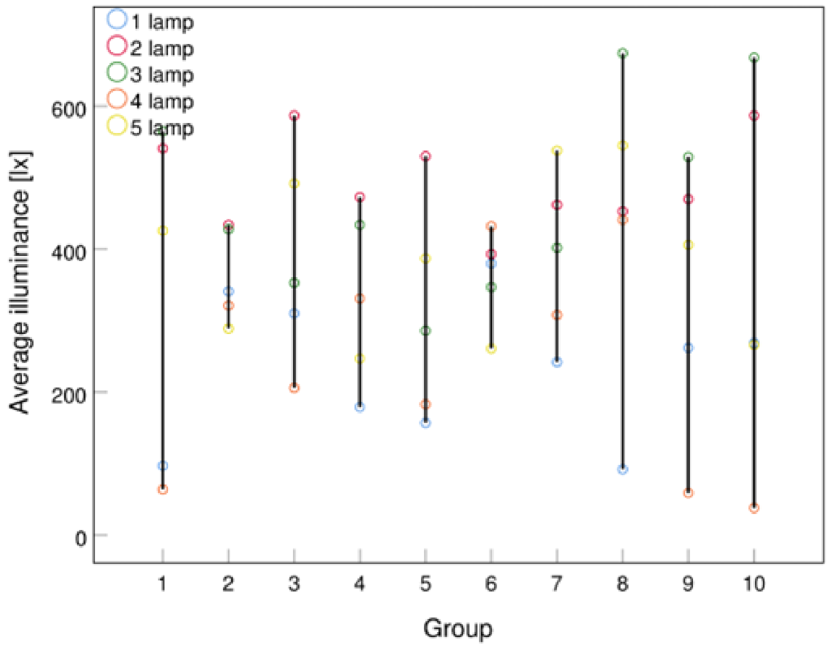
See Figure 4 for the illuminance values of 10 groups of working faces. After the data is obtained, the light transmission function matrix of the average illuminance of the working face can be calculated by the least square method, which can be used as the database in the intelligent dimming control algorithm of lamps.

To compare the performance of PSO algorithm and PID algorithm in intelligent lighting system, at present, in the above experimental platform, when there are two lamp groups and three lamp groups respectively, the user's expected illuminance in the target area is set to $y_r = 150 + 15\sin\left(0.1t\right) + 15\sin\left(0.2t\right)\text{lx}$. The PID control algorithm is used for the experiment, and then the performance of PSO algorithm and PID algorithm is compared.

Table 2. Luminous flux setting data of lamps

Group	Luminous Flux of Lamps[lm]				
	1	2	3	4	5
1	3093	2674	3314	2883	3275
2	3152	1206	2437	648	3249
3	3615	2458	1694	3403	1557
4	2679	2090	3752	2063	1267
5	2623	570	234	2004	1483
6	3111	1271	1546	3231	805
7	3263	2666	3158	2306	1894
8	3550	2050	3420	499	2536
9	3925	905	3743	1918	1580
10	3342	2369	233	1788	224

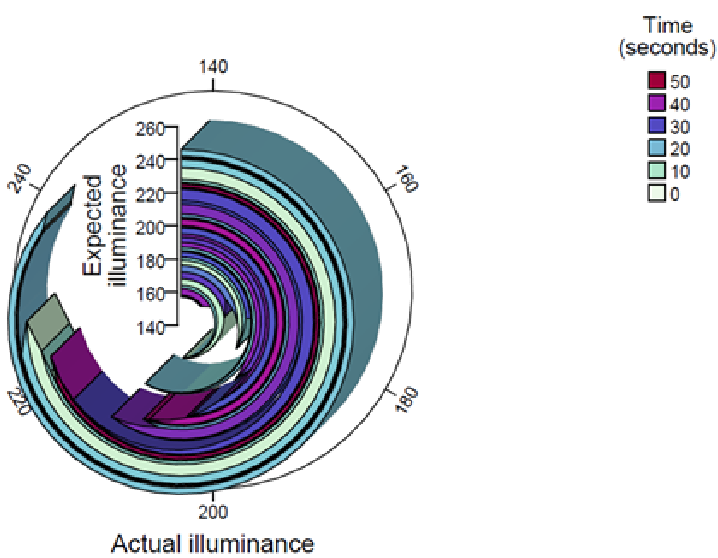
Figure 4. Simulation results of average illuminance of working face



When the LED is divided into two lamp groups, the experimental results are shown in Figure 5.

It can be seen that when two LED lamp groups are set. The expected illuminance of the target area is set as a function with a complicated change rule, the actual illuminance of the target area can basically change according to the expected illuminance rule after a while by adopting PID control algorithm. Still, compared with PSO algorithm, it is found that PSO algorithm has a smaller overshoot and shorter adjustment time.

Figure 5. Experimental results of actual illuminance and expected illuminance



When LEDs are divided into five lamp groups, the experimental results are shown in Figure 6.

It can be seen that after a while, the actual illuminance can be adjusted according to the expected illuminance using the PID algorithm. Compared with PSO algorithm, PSO algorithm is better than PID algorithm in overshoot and adjustment time. PSO has the advantages of a smaller overshoot and shorter adjustment time.

The previous simulation room model and particle swarm control algorithm are simulated in MATLAB environment, with 11: 30 noon as the measurement point, introducing natural sunlight for reinforcement, collecting the luminous flux of each lamp every 4 s, and using PSO to calculate the value of luminous flux of each lamp changing with time in one day, then the results shown in Figure 7 can be obtained.

It can be seen that during the period of 8: 00-10: 00 am, with the continuous enhancement of outdoor sunlight, the turn-on level of lamps gradually decreases, reaching the lowest level around 10: 30. Due to the influence of sufficient indoor brightness, some lamps are temporarily closed to save energy consumption; During the period from 11: 00 to 15: 00, as the sun gradually sets in the west, the natural light in the room begins to decrease, and the illuminance level of the lamps is further improved, but it is always maintained at 80% of the full load; After 16: 00, the sunlight will gradually disappear. At this time, the brightness combination of indoor lamps tends to be stable.

The results of the original PSO and the improved PSO are shown in Figure 8.

As shown in Figure 8, under the condition of meeting the illumination requirement, the improved PSO can search out the best combination of lamps and lanterns faster than the original PSO, and the efficiency is 6.208% higher than that of the original PSO. Moreover, the energy consumption of lamps searched by the improved PSO is low, proving the improved PSO's superiority.

4. CONCLUSION

To solve the energy-saving problem of lighting devices, two methods are widely adopted: one method is to modify the device itself to reduce its energy consumption; The second is to innovate the monitoring and management methods of lighting fixtures, and design a more convenient and energy-saving intelligent lighting fixture control system. Many experts and scholars, both domestically and internationally, have begun to conduct corresponding research and application on this system. A

Figure 6. Experimental results of actual illuminance and expected illuminance with 5 LED lamp groups

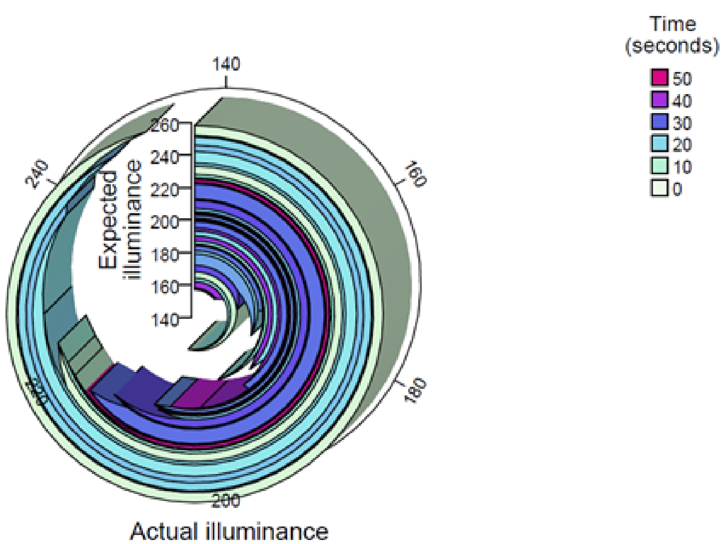


Figure 7. Brightness adjustment trend of each lamp

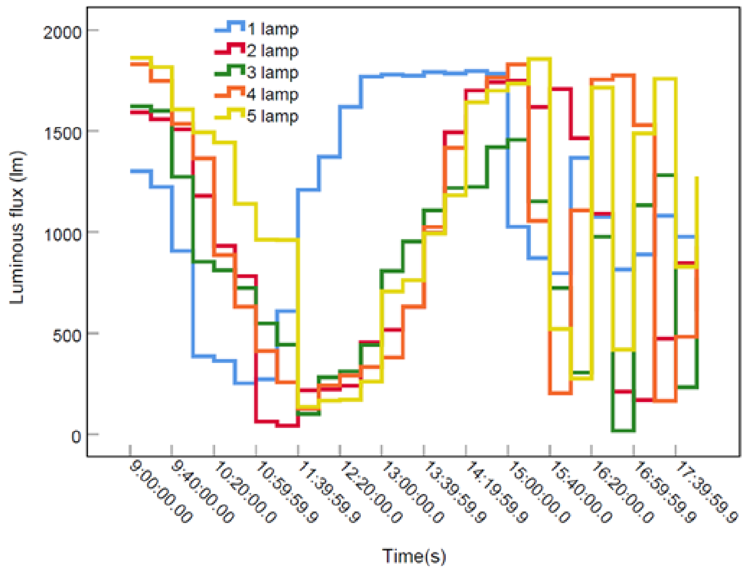
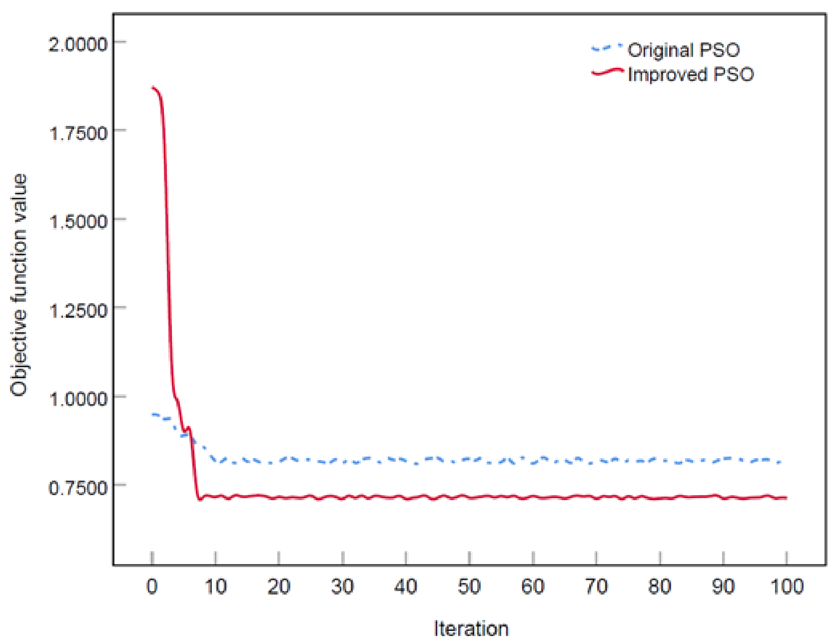


Figure 8. Evolution diagram of PSO



rehabilitation lighting design method based on an intelligent lighting control system is proposed in this context. A set of intelligent lighting systems based on particle swarm optimization was constructed using the particle swarm optimization method. According to the basic genetic algorithm theory, the inertia weight particle swarm optimization problem has been improved and improved. Experiments have shown that compared with the original PSO algorithm, this algorithm can quickly find the optimal lighting scheme, with an optimization efficiency improvement of 6.208%, and the resulting lighting equipment consumes less energy.

This system can meet the user's single illumination demand. Still, the user's state will change at different times (walking, studying, working, etc.), and the illumination demand will be additional in different States, such as the illumination demand is low when walking and high when studying or working. Therefore, in the next work, we need to study how to identify the user's state, allow users to set multi-state lighting requirements, select the user's lighting requirements and adjust the lighting control strategy according to the user's state.

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