A Study on Indoor Light Distribution and Optimization Based on Simulated Annealing Algorithm

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Abstract: Traditional classroom illumination often employs uniform distribution of lights. However, this distribution has a disadvantage: It makes the illuminances of different areas in the classroom uneven. The central parts of the classroom are better lit, while those near the boundary are darker. Since the human eye is suited for a certain range of illuminance, the unevenness of illumination makes brighter areas too bright and darker areas too dark, which severely damages students' eyesight. To solve this kind of problem, we need to optimize the distribution of lights in classrooms. This article first sets up a mathematical model for the physical process of illumination with the core framework of the "3-D geometric projection model", the "convex polygon intersection model" and the "lattice point marking model", Secondly, based on our model, we optimized the positions of lights with the simulated annealing algorithm.

1. Introduction

With the development of modern science and technology, there is an increasing demand for people to protect their eyesight. In accordance with the investigation and research on "Intervention Research on the Effect of Classroom Light Environment Improvement on Myopia Protection of Primary And Secondary School Students" [2], "Investigation on the Relationship Between Visual Environment And Visual Health of Primary And Secondary School Students" [3], "Pay Attention to the Prevention And Control of Environmental Risk Factors of Children's Juvenile Myopia" [4], etc., it is found that poor luminous environment in the classroom is more likely to lead to poor eyesight of students. For example, Renxian Chen et al. [5] investigated a number of primary and secondary school classrooms in Fujian province and found that a large number of school classrooms were still using low-efficiency fluorescent lamps, which caused a series of problems: e.g. The illumination of desktop and blackboard in the classroom was very low, while the number of lamps in the classroom was quite different; and around half of the classrooms used bare tubes without reflectors. Meanwhile, the research of GovénT, LaikeT, et al. [6] found that under the influence of 500lx illumination, the reading speed, composition and arithmetic of students were improved compared with that in 300lx standard illumination environment.

In order to improve the illuminance in the classroom, there are three main methods. The first is to simply and rudely purchase a large number of lights to ensure that there are no lighting blind spots; the second is to increase the rated power of the lamp to make a single beam of light more intense; the third is to change the light distribution in the forward direction so as to improve the uniformity of illuminance, such as the lemniscate light distribution [7]. While our research will involve three-dimensional space. We do hope that we can find a better wider range of light distribution method which is applicable through continuous optimization. In the first two cases, simply buying more lights or buying high-power lights to make up for the illuminance will bring additional costs, and the school's funds are generally limited; considering the actual situation, our research method can change the interaction and influence between the light fields by changing the distribution of the lights in the room under the conditions of relatively low requirements for the number of lights and power required, saving, and environmental protection, thereby effectively enhancing the average illuminance in the room.

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2. Model Building

On the basis of measuring the parameters, we first made a reasonable approximation to the geometric structure of the classroom. The schematic diagram is shown below :

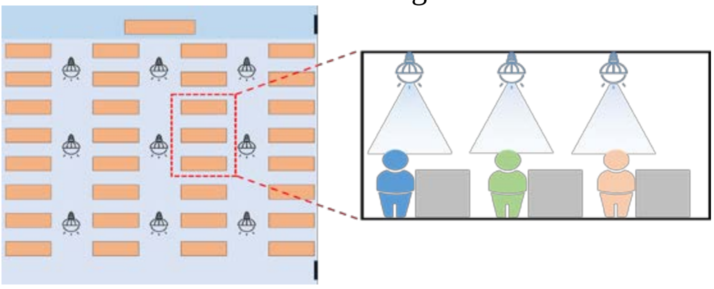

Fig.1 Schematic Diagram of Desks, Chairs and Lights in the Classroom

3. Computer Optimization Model Based on Simulated Annealing

3.1 Research on the Optimization Problem of Uniformity of Illuminance on the Desk

3.1.1 Clear Optimization Objectives

First of all, we consider a simple situation: In the case of a fixed desk layout, we want to achieve better lighting conditions on each desk: Firstly, we hope that the average illuminance between different desks is relatively even, and there will be a situation where the middle of the classroom is brighter but the surroundings are darker; secondly, due to the blockage of the human body, there will also be uneven illumination for the surface of each desk. We hope to make an effect similar to a shadow-less lamp, namely the blocking effect of the human body can be weakened by reasonable planning of the distribution of light sources, so that the stability of lighting can be improved.

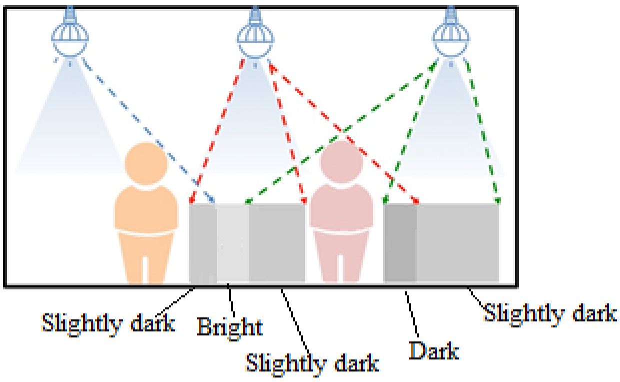

Fig.2 Schematic Diagram of the Distribution of Desks, Lights and Students in the Classroom

Then, in response to these problems, we hope to optimize the lighting conditions of the classroom by establishing a reasonable model. First, clarify our optimization goals:

1).The average illuminance of each desk in the classroom is as large as possible;

2).The illumination of each desk and between different desks is as even as possible;

3.1.2 Detailed Algorithm Flow

In order to solve such an optimization problem, the specific mathematical calculation model is shown in the following figure:

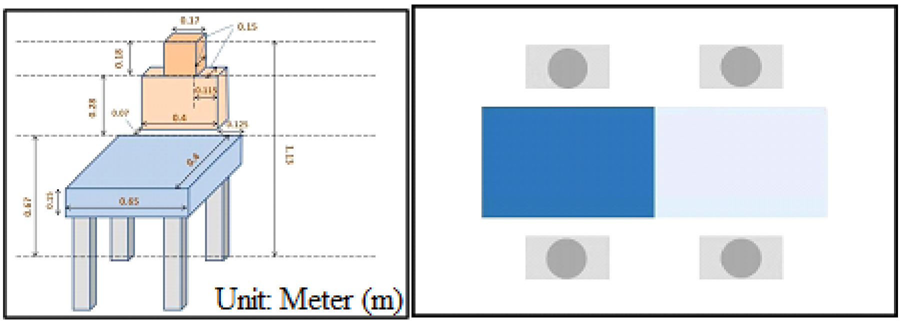

Fig.3 Schematic Diagram of Projection of Desks, Lights and Students in the Classroom

We consider the human body as a combination of two rectangles, and the specific parameters are shown in the figure. The light is opaque to the human body. Therefore, we calculate the two-dimensional geometric projection of each individual light source on the desktop after being blocked by the human body. In this model, the length and width of the rectangular area are divided into n × m lattices into units of 0.1m, and the center position of each lattice is taken as the sampling point. Each lamp is traversed. For a lamp, a total of 8 obstacle polygons of the head and body of the four people are projected onto the desktop, and the lattice points in each obstacle polygon are marked. For the lattice points that are not marked, the illuminance of the current light on the plane is calculated in accordance with Lambert's cosine law. For each point, the total illuminance is obtained by summing the illuminance. Eventually, the illuminance distribution on all desks in the classroom can be solved based on this idea.

Next, the simulated annealing method is adopted to optimize the distribution of the illumination light source. The specific calculation process is shown in the following algorithm flowchart:

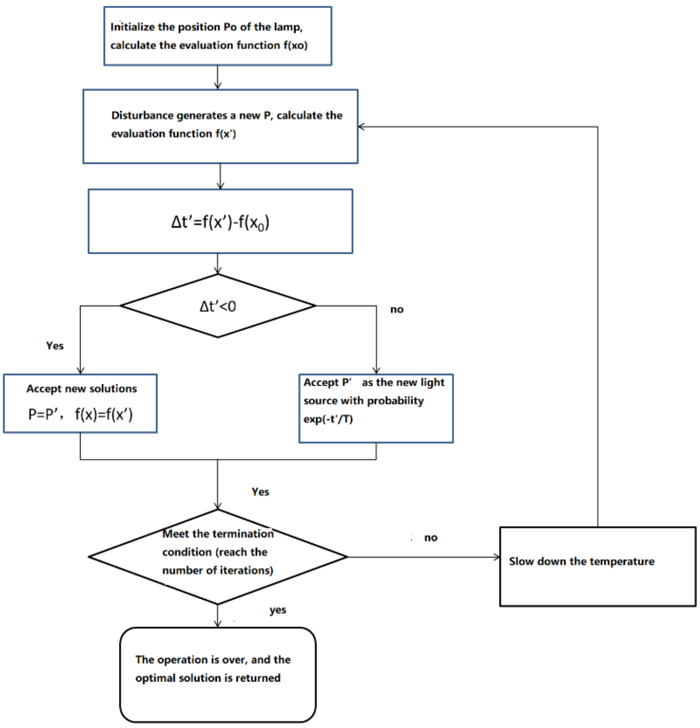

Fig.4 Schematic Diagram of Algorithm Flow

The algorithm is divided into the following steps:

1). Initialization:

Initialize the positions of lamps P0, evenly distributed, respectively (x1,y1), (x2,y2)…(xi,yi), calculate the optical field distribution on each desk i at this time based on Lambert's cosine law, and get the initial evaluation function f(x0) (the starting point of the algorithm iteration) according to the evaluation function f (x); the initial temperature T, the number of iterations for each T value is L

2). For k=1,2…L, do from Step 3 to Step 6

3). Randomly perturb the positions of lamps P, and calculate i' according to the position of the light source P' at this time, so as to generate a new evaluation function f(x')

4). Calculate the increment Δt' = f(x')-f(x0)

5). If Δt' '0, then accept f(x') as its new evaluation function and P' as its new light distribution, otherwise accept P' as its new light distribution with probability exp(-Δt' /T)

6). Perform one iteration of T (T' =…T), T decreases gradually, and T→0, then go to the second step

7). If the termination condition is met, the current P' is output as the optimal light distribution position, and the program ends. (The termination condition is k=L)

3.1.3 Optimization Results

We substituted the specific parameters and initialization conditions of the classroom, and the optimization results solved are shown in Fig. 3.4. As you can see, first of all, as the number of iterations increases, the annealing temperature in the model gradually decreases from 10° to 0°, reflecting a standard annealing process. Secondly, whether it is the total objective function after weighted modulus, or two independent objective functions, it has been well optimized during the annealing process, especially when the number of desks below the minimum lighting requirements has been reduced from 10 to only 1, which shows a very good optimization effect, and then proves that our model can be used to optimize the lighting conditions in the classroom.

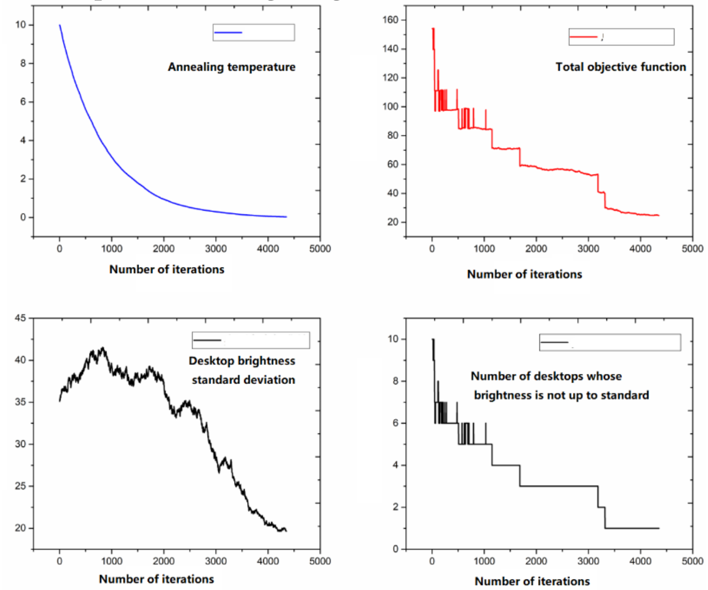

Fig.5 Temperature and Objective Function Gradually Decrease with the Increase of the Number of Iterations.

3.2 Research on the Optimization Problem of Uniformity of Illuminance on the Desk, Blackboards and Standing-Up Books

3.2.1 Clear Optimization Objectives

As shown in the figure below, we consider more specific requirements on the basis of question 1: First, the illuminance on the blackboard is included in the consideration range; second, when the book is erected at an inclination angle θ, the illuminance on the book shall also be relatively even and meet the minimum lighting conditions.

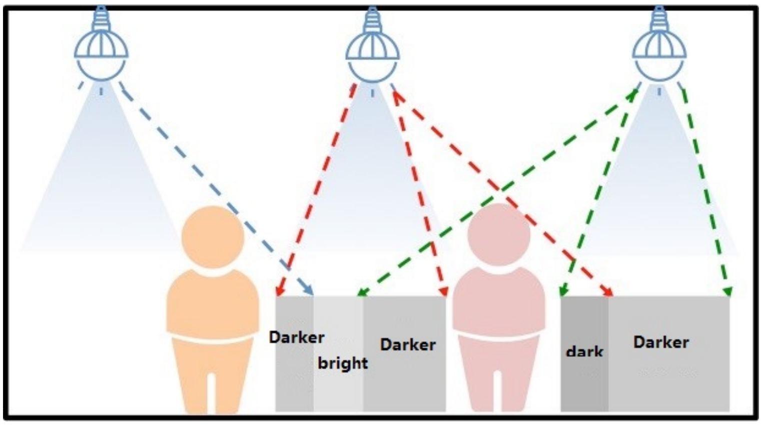

Fig.6 Schematic Diagram of Uneven Illumination of Classroom Desks

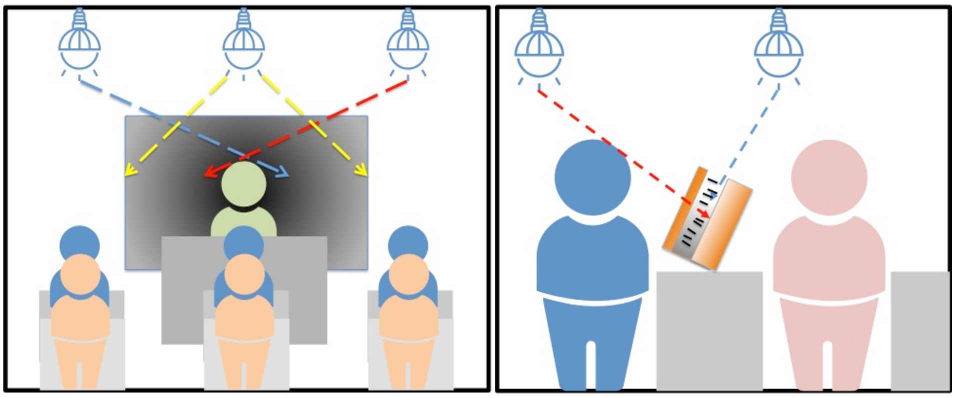

Fig.7 Schematic Diagram of Uneven Illumination of the Blackboard in the Classroom (Left), a Schematic Diagram of Illumination with Books Tilted on the Desk (Right)

In response to these problems, we hope to continue to build a reasonable model to optimize the lighting conditions of the classroom. First of all, clarify our lighting goals:

1).The lighting conditions on the blackboard are relatively even and within a suitable range

2).When the students stand up the book, the lighting conditions on the book still meet the requirements (that is, the illumination is even and within a suitable range)

3).The lighting conditions on the desk in front of the book meet the requirements, and the desk behind the book is not considered

3.2.2 Detailed Algorithm Flow

Basically, the process is the same as in 3.1.4. The only difference is that the objective function here is more diverse. Therefore, it is more difficult for the function to converge in the process of adjusting the parameters. In addition, it is necessary to supervise optimization multi-objective functions during the annealing process.

3.2.3 Optimization Results

We substituted the specific parameters and initialization conditions of the classroom, and the resolved optimization results are shown in Fig. 3.10: It can be seen that as the number of iterations increases, the total objective function decays sharply, which proves that even in the system of multi-objective functions, the simulated annealing program can still be used to optimize the entire system.

Meanwhile, in Fig. 3.11, in the optimization process of 6 separate objective functions, 5 of them show obvious optimization, and the remaining one, namely brightness standard deviation of the blackboard, also remains relatively stable, at least there is no deterioration. The optical field distribution diagram of various places with the number of iterations in Fig. 3.12 also confirms this point.

Finally, in the same way, we can clearly see through the comparison of objective function before and after optimization that even if the model we consider is complex enough, there are as many as 6 objective functions, and the three-dimensional projection relationship between each model is equally complex, but a good optimization effect has still been achieved eventually. Our optimization model provides a new idea for the design of indoor lighting in the future.

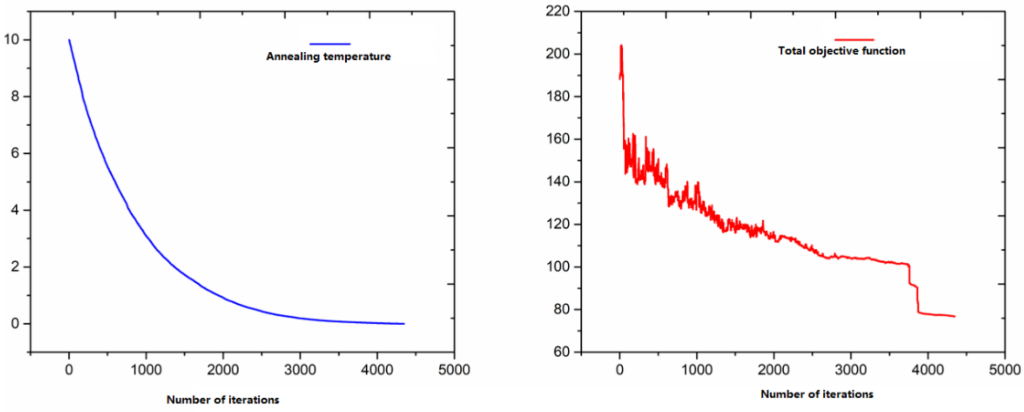

Fig.8 The Temperature and Total Objective Function Gradually Decrease with the Increase of the Number of Iterations

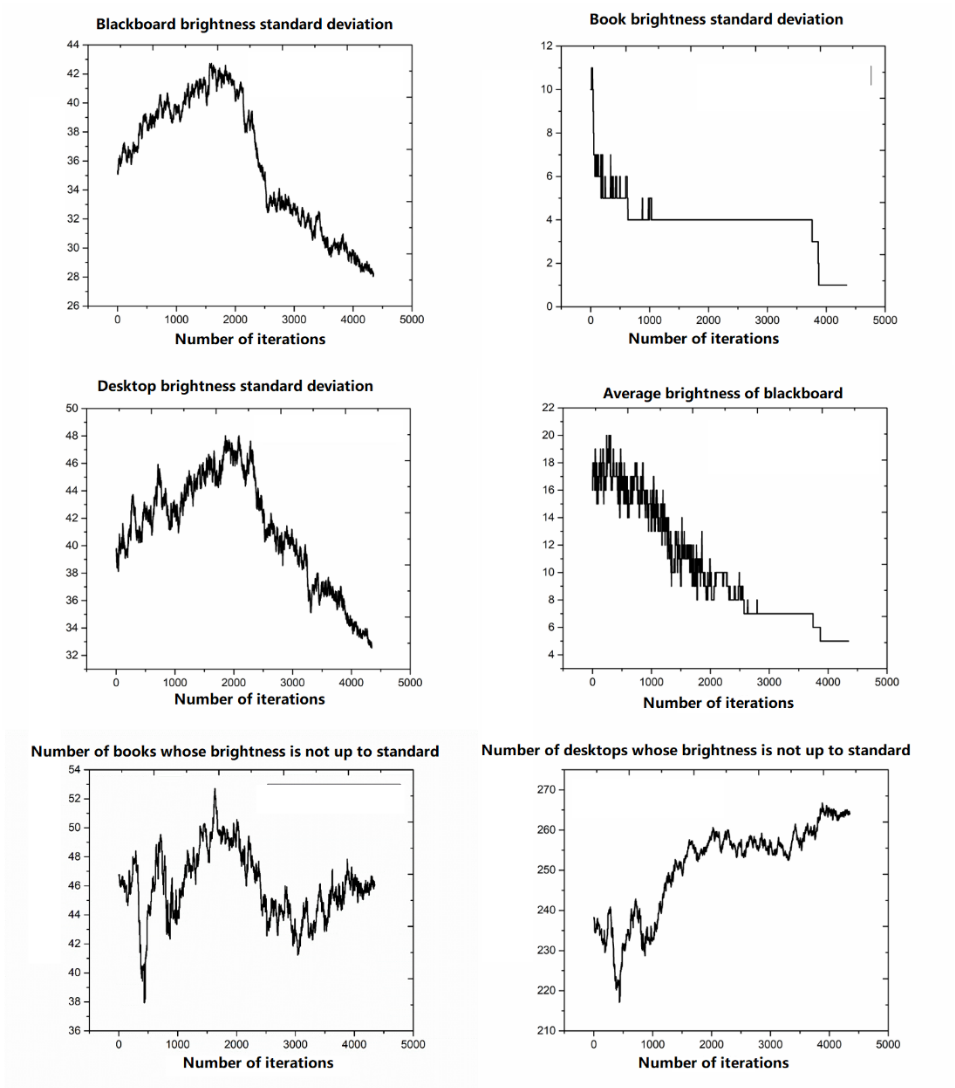

Fig.10 Changing Trends of Each Objective Function with the Number of Iterations

4. Conclusion

Our results showed that: 1) The uniform distribution of lights is indeed a suboptimal solution. 2) After simulated annealing, we could obtain a non-uniform distribution of lights, which outperforms the original, uniform solution in terms of both the average and uniformity of illuminance. 3) Through tracking the evolution process of the light field in real-time, we proved the extraordinary performance of simulated annealing, a classic optimization strategy, on the problem of light distribution. we extended the objectives of optimization. Apart from the light distribution on desks, we took the light distribution on the blackboard and books into account, which extended our plane of optimization to three dimensions. The results showed that simulated annealing still did well in the system of multiple objectives --- we got a light distribution that enhances the lighting conditions of the blackboard, desks and books, which a uniform distribution of lights could not easily achieve. Our paper provided a promising solution to the optimization of highly complex systems of illumination.

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