LED Solar Spectrum Computer Simulation Based on Non-dominated Sorting Genetic Algorithm

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Abstract. The solar computer simulation technology has been extensively applied in the fields of polymer curing test, solar cell detection and calibration, and satellite heat balance test, etc. The non-negative least-squares solution of the overdetermined equations based on the non-dominated sorting genetic algorithm (NSGA) to optimize the monochromatic light-emitting diode (LED) matching light source combination, replace some monochromatic LED with white LED to simulate the solar spectrum, and discuss several LED lights with different peak wavelengths that can be replaced by white LED. The simulation results suggest that in the range of 300 ~ 1100 nm, as the monochromatic LED types replaced by white LED increase, the total number of LEDs used is reduced, and the spectral match decreases. When LEDs with three different peak wavelengths are replaced, the correlation index in the fitting based on the algorithm is 0.9035, where the number of LEDs can be reduced by 15.6%, and the simulation spectrum is basically consistent with the target one. The proposed method has a small spectral mismatch and can be used to distinguish two absorption valleys of the standard solar spectrum AM1.5 accurately.

Keywords: Light-emitting Diode (LED), AM1.5, Genetic Algorithm, Spectral Fitting, Least-squares Solution

1. Introduction
The solar simulation technology is extensively applied in the fields of polymer curing test, solar cell detection and calibration, and satellite heat balance test, etc. [1-2] The light source of the traditional solar simulator uses bromine tungsten lamps and xenon lamps. However, it has defects such as short service life, high energy consumption, poor spectral match, non-adjustable spectrum, etc. [3] Compared with traditional light sources, light-emitting diodes (LEDs) have the advantages of long service life, accurate control, energy preservation, environmental protection, and diverse types. In recent years, scholars have based on The solar simulator of LED has carried out related research. Some scholars arranged different monochromatic LEDs in an array, changed the radiant flux of the LED by changing the current, and finally changed the ratio of various monochromatic lights [4], to simulate the solar spectrum. But This method is tedious and time-consuming. In addition, some scholars [5] proposed a genetic algorithm based on the application of a variety of different peak wavelength LEDs to synthesize the spectral distribution of AM1.5. This method can be used to distinguish the absorption
valleys more appropriately \cite{6}. Although the algorithm is simple and efficient, it consumes massive LEDs with different peak wavelengths. Based on this, this article uses the principle of spectral superposition, replacing some monochromatic LEDs with white LEDs, through a simple genetic algorithm (SGA) and solving the structure. The over-determined equations are developed to obtain the LED combination ratio and synthesize the desired spectrum.

The non-negative least-squares solution of the over-determined equations based on the non-dominated sorting genetic algorithm (NSGA) to optimize the monochromatic light-emitting diode (LED) matching light source combination, replace some monochromatic LED with white LED to simulate the solar spectrum, and discuss several LED lights with different peak wavelengths that can be replaced by white LED.

2. Spectral Structure

2.1. LED spectral radiation model

The target curve AM1.5 is continuous and can be obtained by superimposing the spectrum of a variety of LEDs with different peak wavelengths. In order to obtain a good spectral match and the optimal LED combination, a suitable LED spectral distribution function is very important. Monochromatic LEDs in their light distribution of the radiant intensity with the wavelength in the unit solid angle in the axis direction can be approximated by the Gaussian distribution function or the Lorentz function. The Gaussian distribution model is used, that is

\[
I(\lambda) = A \exp \left[ -3.2213 \left( \frac{\lambda - \lambda_c}{\Delta \lambda} \right)^2 \exp \left( -0.3 \frac{\lambda - \lambda_c}{\Delta \lambda} \right) \right]
\]

(1)

Where \( I(\lambda) \) represents the radiation intensity of a single LED; \( \lambda_c \) represents the peak wavelength; \( A \) represents the relative amplitude; \( \Delta \lambda \) represents the half-width.

2.2. NSGA

The spectral curves that are touched daily are continuous, but as long as the horizontal coordinate is small enough, it can still be fitted by discrete spectral data. The target spectrum can be written as:

\[
f(\lambda_j) = \sum_{1<j<m} S(\lambda_j)
\]

(2)

Where \( \lambda_j \) represents different peak wavelengths. Equation (2) shows that the target spectral curve can be plotted.

The vector is denoted as \( S^T = (S_1(\lambda_1), S_1(\lambda_2), \ldots, S_1(\lambda_m))^T \). Subsequently, the LED spectral matrix can be written as \( A = (S^T, S^T, \ldots, S^T) \). Remember the coefficient matrix \( X = (k_1, k_2, \ldots, k_n)^T \), the target spectral matrix \( Y = (S(\lambda_1), S(\lambda_2), \ldots, S(\lambda_m))^T \). When \( m > n \), the over-determined equation can be obtained as follows

\[
AX = Y
\]

(3)

It can be expressed as follows:

\[
\begin{bmatrix}
S_1(\lambda_1) & S_2(\lambda_1) & \cdots & S_n(\lambda_1) \\
S_1(\lambda_2) & S_2(\lambda_2) & \cdots & S_n(\lambda_2) \\
\vdots & \vdots & \ddots & \vdots \\
S_1(\lambda_m) & S_2(\lambda_m) & \cdots & S_n(\lambda_m)
\end{bmatrix}
\begin{bmatrix}
k_1 \\
k_2 \\
\vdots \\
k_n
\end{bmatrix}
= \begin{bmatrix}
S(\lambda_1) \\
S(\lambda_2) \\
\vdots \\
S(\lambda_m)
\end{bmatrix}
\]

(4)

In general, the over-determined equations do not have exact analytical solutions, but their approximate solutions can be obtained by mathematical methods. In over-determined equations, the least-squares solution is usually a generalized solution, which refers to the residual \( Y - AX \). The 2-norm of \( AX \) can reach the solution when the minimum value is reached. Meanwhile, the overall error can be
kept small.

$$\|Y - AX^*\|_2 = \min_{x \in \mathbb{R}^n} \|Y - AX\|_2$$  \hspace{1cm} (5)

Combined with the actual situation, the scale factor $k_i$ can only be greater than or equal to 0, so only the non-negative least-squares solution $X^*$ of the overdetermined linear equation system is required.

$$S = AX^*$$  \hspace{1cm} (6)

In nonlinear regression analysis, the degree of similarity between the fitted curve and the original data is characterized by the correlation index. The closer to 1, the better the fitting effect and the more accurate the corresponding solution. Here it is used to evaluate the spectral match degree, which is defined as

$$R^2 = 1 - \sum_{i=1}^{n} \frac{(S(\lambda_i) - S(\lambda'_i))^2}{\sum_{i=1}^{n} (S(\lambda_i) - \bar{S}(\lambda))^2}$$  \hspace{1cm} (7)

Where $\bar{S}(\lambda)$ represents the mathematical expectation of the target data set.

The genetic algorithm is a highly parallel, random, and adaptive global optimization probability search algorithm that draws on the natural selection and genetic mechanism of the biological world. Its standard algorithm process is shown in Figure 1.

![Figure 1. Basic process of the genetic algorithm](image)

Spectral match technology can be deemed as an optimal combination issue, i.e., to identify the optimal matching combination of target spectral distribution among many LED combinations. The genetic algorithm is used as the spectral match algorithm to obtain the optimal LED combination ratio that matches the target spectrum. Based on the general principles of the SGA algorithm described above, combined with the above problems, gives the steps to solve with the SGA algorithm [14]: 1) the generation of the initial group, using a random method to generate the initial group with a decimal code size of 200; 2) by the sum of squares of least-squares For the purpose, on this basis, establish a fitness function to evaluate the quality of the group; 3) On the basis of fitness, repeatedly perform genetic operations on the group to obtain a satisfactory or optimal solution, which is the required LED proportional coefficient.
3. Simulation and evaluation

The MATLAB software is used to perform spectral fitting on LEDs with a wavelength of 300 ~ 1100 nm. Using the equation (1) fitting function, based on the principle of spectral construction, the AM1.5 standard solar spectrum with a wavelength of 300 ~ 1100 nm is used as the target spectrum. For 35 types of monochromatic LEDs of a specific brand, according to the peak wavelength ($\lambda_c$) and half-height width ($\Delta\lambda$) data of the spectrum given by the manufacturer, use equation (1) to fit each LED spectrum, and use the obtained LED spectrum as equation (5) in A, the target spectrum is Y in equation (5), and the optimal combination ratio (R) of each LED is obtained according to a simple genetic algorithm, as shown in Table 1.

Table 1. LEDs with different peak wavelength intervals and corresponding proportional coefficients

| $\lambda_c$/nm | $\Delta\lambda$/nm | R       | $\lambda_c$/nm | $\Delta\lambda$/nm | R       |
|----------------|--------------------|---------|----------------|--------------------|---------|
| 365            | 15                 | 0.566839| 570            | 15                 | 1.296106|
| 375            | 18                 | 0.526261| 590            | 20                 | 1.308695|
| 395            | 20                 | 0.814542| 600            | 20                 | 1.215108|
| 415            | 15                 | 0.814331| 620            | 18                 | 1.265933|
| 430            | 20                 | 1.116216| 635            | 15                 | 1.078869|
| 450            | 20                 | 1.254356| 645            | 18                 | 1.153498|
| 470            | 20                 | 1.056011| 660            | 16                 | 0.829126|
| 490            | 30                 | 1.130823| 680            | 25                 | 1.311307|
| 505            | 20                 | 0.466939| 700            | 20                 | 0.860748|
| 520            | 21                 | 1.205688| 720            | 20                 | 0.817009|
| 545            | 23                 | 0.717348| 735            | 20                 | 0.454531|
| 565            | 25                 | 1.200738| 770            | 30                 | 0.856959|

The matching result of the spectrum is shown in Figure 2. In Figure 2: $\lambda$ is the wavelength, $Sr$ is the relative spectrum. From Figure 2, it can be seen that within a certain range, the fitted spectrum and the target spectrum are at two absorption valleys of 750, and 950 nm Has the same good resolving power.

The white LED of a company is used. The remote PMS0910 is applied to measure the spectral data, and import MATLAB to obtain the spectrum of the white LED, as shown in Figure 3. One to four types of monochromatic LEDs are replaced, and the principle for replacing monochromatic LEDs is as follows: in the process of spectrum superposition, the peak wavelength of the replaced monochromatic LED should be located near the peak wavelength of the white light and the primary wavelength (the relatively high part of the spectrum in Figure 3), so that the other relatively low parts of the white light are The influence of spectrum fitting will be relatively small. The matching of the solar spectrum simulated based on the genetic algorithm is high, which can be verified by simulation.

![Figure 2. AM1.5 spectral match diagram of 35 types of monochromatic LEDs](image-url)
From the results, it can be found that as the number of white LEDs replacing other monochromatic LEDs increases, the more obvious the spectral mismatch (that is, the spectral match degree becomes worse), the total number of LEDs actually used will decrease accordingly. When white LEDs replace Among the four types of monochromatic LEDs, the correlation index decreased from 0.9217 to 0.8435, a decrease of nearly 8%. Figure 4 (d) shows that an absorption valley will appear between the wavelengths of 500 ~ 600nm. The reason for Gu is: in the spectral match process based on the genetic algorithm. The white LED spectrum used is not sufficient to make up for the lack of multiple replaced monochromatic LED spectra.

In the practical selection of white LEDs to replace some monochromatic LEDs, it is necessary to ensure a high matching degree and reduce the total number of LEDs used as much as possible, so that the low cost can be reduced on the premise of ensuring the quality of the product. When the white LED replaces three different monochromatic LEDs, the correlation index fitted by the algorithm is 0.9035, and the number of LEDs is reduced by 15.6%, with a better result obtained.

4. Conclusion
In this paper, a fitting algorithm for LED standard solar spectrum light is studied. The Gaussian distribution function is used as the LED spectrum irradiation model. Combined with the practical LED types, not only the LEDs with non-uniformly spaced peak wavelengths are fitted to the standard solar spectrum, but white LEDs are also used to replace some monochromatic LEDs for the spectrum fitting of the standard solar spectrum. In addition, the replacement of several monochromatic LEDs by white LEDs is discussed in detail.

The results suggest that the proposed method can reduce the types and number of LEDs while ensuring the fitting goodness of high-spectrum, where the number of types can be reduced by up to 3. At this point, the spectral matching is 0.9035, and the number of LEDs used can be reduced by 15.6%, which is conducive to producing and arranging the solar spectrum lamp beads in the later stage and reducing the cost. The proposed method is simple and easy to operate, with a high calculation speed and fitting efficiency, laying a solid foundation for implementing the standard solar spectrum lamp based on the LED light source. The LED combination approach can be used to obtain a special light source with an adjustable spectrum, which is applicable to the fields of dental treatment, beauty care, insect capture, plant cultivation, etc.

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