A Novel Spectral Matching Algorithm to Application Environment Fitness Evaluation Method

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Abstract. The performance of the spectral matching algorithm of the solar simulator is affected by many factors, such as software performance, hardware performance, application environment and so on. The evaluation of spectral matching algorithm to application environment fitness is the premise of selecting the most suitable algorithm. The analytic hierarchy process (AHP) - fuzzy comprehensive evaluation method is used to evaluate the fitness. Firstly, the evaluation index system is established; secondly, the weight of each index is determined by AHP; finally, the fitness evaluation result is obtained by fuzzy comprehensive evaluation method. According to the comparison between the evaluation method of this paper and the experimental results of expert evaluation, it can be seen that the accuracy of the evaluation method in this paper is high, and the evaluation rules basically meet the requirements.

Keywords: Solar simulator · Spectral matching algorithm · Application environment fitness · Analytic hierarchy process · Fuzzy comprehensive evaluation

1 Introduction

Solar simulator as an important experiment and test equipment has been widely used in the field of space and solar energy utilization. At present, the solar simulator has been studied at home and abroad [1–4]. With the advantages of high efficiency energy saving, environmental protection, long life, strong controllability and mature spectrum matching technology, LED has been gradually applied to the research and development of new type solar simulator. The research of LED solar simulator has become the mainstream in the field of solar simulator [5–7].

The light source of the LED solar simulator is usually composed of many different monochromatic bands LED. The solar spectrum is combines with a superposition power, which is calculated by spectral matching algorithm [8–10]. There are many spectral matching algorithms, their requirements for computing resources are different, and performances are also different. In the practical application, they are limited by the application environment, such as the performance of computing resources, storage

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space and so on. How to select the appropriate spectral matching algorithm for the specified application environment is a question with practical significance.

In order to sort the adaptability of different algorithms conveniently, the most suitable algorithm is selected, and the adaptation of spectral matching algorithm to the application environment is represented by "fitness". The evaluation of algorithm fitness is essentially a comprehensive evaluation influenced by multiple indexes. At present, the main methods of multi-index comprehensive evaluation are AHP, principal component analysis, artificial neural network, fuzzy comprehensive evaluation and so on [11–14]. This paper adopts the combination of subjective and objective AHP - Fuzzy comprehensive evaluation method, which provides a reasonable, scientific and reliable selection standard for the selection of the most suitable algorithm.

AHP - Fuzzy comprehensive evaluation method is the combination of analytic hierarchy process and fuzzy comprehensive evaluation method. Firstly, the hierarchical structure model of algorithm performance index is constructed by AHP [15, 16]. The weights of each evaluation index are calculated, and then the fuzzy comprehensive evaluation method is used to evaluate each index synthetically, and the comprehensive evaluation results are obtained [17–19]. Thus, set up an AHP - Fuzzy synthesis algorithm fitness evaluation model.

2 Evaluation Method

2.1 Analytic Hierarchy Process

The analytic hierarchy process is proposed by Thomas L. Saaty in the mid-1970s, who is an American operations researcher [15, 16]. This method is a qualitative and quantitative, hierarchical analysis method, which can deal with complex multi-criteria decision making problems, and can effectively analyze the non-sequential relationships between levels of the target criteria system. Enable the decision maker to make a reliable analysis and judgment. In this paper, the function of AHP is to calculate the weight of different factors in decision-making. The steps are lists as follows.

(1) Build the hierarchical model: The problem is analyzed by different constituent factors and the subordinate relation among factors, which is based on the nature of the problem and the inherent relationships between sub problems. The evaluation index system and the grade standard are formed.
(2) The construction of paired comparison matrix: For each layer of elements under specified criteria, indices on the same layer have different weights. Experts compare different influencing factors and use scaling method to decide the judgment matrix A.
(3) Calculating index weight: The hierarchical ranking of the influencing factors is to calculate the relative weights required by each factor of each judgment matrix. Then the weight vector W is calculated.
(4) Check the weight consistency: Because of the inconsistency of the pairwise comparison matrix, the consistency index (CI) is used to test the consistency, and the random consistency index (RI) is introduced because of the difference in the consistency measurement of the judgment matrix of different order. The

consistency judgment is corrected according to different orders. The weight distribution of the matrix is relatively reasonable by consistent ratio (CR). If the parameters are within the range of acceptance, the weight distribution is reasonable, and the expert needs to readjust the judgment matrix beyond the range of acceptance.

2.2 Fuzzy Comprehensive Evaluation Method

The fuzzy comprehensive evaluation method is an evaluation method which is made by multiple factors together. According to the principle of fuzzy set theory, it makes an effective and comprehensive grade evaluation of many influencing factors [17–19]. The steps of fuzzy comprehensive evaluation are as follows:

(1) According to the evaluation index system, the weight set B is established. The influence degree of each influencing factor on the evaluation object is represented by its weight value, the evaluation factor set U and the evaluation set V.
(2) Experts score the algorithm of need evaluation according to the evaluation index system and get the initial data of fuzzy evaluation.
(3) Based on the initial data, each element of the fuzzy relation matrix R is calculated as the membership value of the evaluation set V by a certain influence factor of the evaluated algorithm.
(4) The comprehensive evaluation vector B is used to describe the classification degree of the comprehensive condition of each evaluated object, and the grade judgment is made according to the comprehensive scoring method [21].

3 Algorithm Fitness Evaluation Model

The construction of algorithm fitness evaluation model is divided into two parts. The first part is to construct the algorithm fitness evaluation model by analytic hierarchy process. The second part is to use the fuzzy comprehensive evaluation method to establish an index evaluation system. The evaluation model analyzes the data collected according to the evaluation system and draws the final conclusion.

3.1 Construction of Index Evaluation System

Build Hierarchical Model. In order to select the right evaluation index, the spectral matching algorithm must be correctly analyzed, and the selected index should be able to reflect the influence of various factors as much as possible. Generally follow three principles: scientific objectivity; testability and comparability; conciseness and comprehensiveness [15]. The relationship between the factors affecting the adaptability of the algorithm is intricate. The adaptability of evaluation algorithm is a multi-index and multi-attribute problem. Therefore, the hierarchical analysis of system engineering is applied to form an orderly hierarchical structure, that is, the index evaluation system, as shown in Tables 1, 2.

Table 1. Hierarchical structure of evaluation index system

Main factor		Sub factors	
U_1	Algorithm performance	U_{11}	Average Time complexity
		U_{12}	Average Space complexity
		U_{13}	Stability
		U_{14}	Algorithmic Hidden Parallel
U_2	Computing equipment performance	U_{21}	Performance of central processor floating-point units
		U_{22}	Memory read and write speed
		U_{23}	Memory capacity
		U_{24}	Adoption parallel computing Acceleration ratio
U_3	Application environment	U_{31}	Computing equipment Electromagnetic protection capability
		U_{32}	Installation space for computing equipment
		U_{33}	Power supply for computing equipment Continuation Ability
		U_{34}	Application The severity of the environment

Table 2. Range of grading index

Main factor	Sub factor	Unit	a	b	c	d	e	f
U_1	U_{11}	——	$O(n^3)$	$O(n^2)$	O (nlogn)	O(n)	O(logn)	O(1)
	U_{12}	——	$O(n^3)$	$O(n^2)$	O (nlogn)	O(n)	O(logn)	O(1)
	U_{13}	——	None	Extremely low	Low	Middle	High	Extremely high
	U_{14}	——	None	Extremely low	Low	Middle	High	Extremely high
U_2	U_{21}	FLOPS	0	1M	100G	300G	500G	1T
	U_{22}	Byte/s	0	1M	1G	3G	5G	10G
	U_{23}	Byte	0	1M	1G	4G	8G	16G
	U_{24}	——	0	1	10	30	50	100
U_3	U_{31}	——	None	Extremely low	Low	Middle	High	Extremely high
	U_{32}	cm^3	0	10	30	50	70	100
	U_{33}	day	0	1	3	5	7	Persistent
	U_{34}	——	Extremely high	High	Middle	Low	Extremely low	None

Construction Judgment Matrix and Calculate the Index Weight. By using 1–9 scale method [15], the relative comparison between each element is carried out, the judgment matrix is constructed and the eigenvalue of the judgment matrix is solved.

The corresponding eigenvector W is obtained by calculating the maximum eigenvalue λ_{max}, which is not only the ranking weight of the relative importance of each influencing factor in the same layer as that of a certain factor in the previous layer, and then the consistency test is carried out, and the calculated results are shown in Tables 3, 4, 5 6.

Table 3. Judging matrix U and the weight of each factor

U	U_1	U_2	U_3	Weight	Consistency
U_1	1	2	1/5	0.182	λ_{max} = 3.054, CI = 0.027 CR = 0.046 < 0.1 Meet the requirements
U_2	1/2	1	1/5	0.115	
U_3	5	5	1	0.703	

3.2 Establishment of Fuzzy Comprehensive Evaluation Model

Determination of Grading Index. The level of adaptability of the algorithm is divided into 5 levels, that is, the evaluation set V = (V_1, V_2, V_3, V_4, V_5) = (very low, low, medium, high, very high). In order to be easy to evaluate, different ranges are assigned to the corresponding grading indexes of different adaptability levels. The range of different grades of quantitative index is the upper and lower limit value when the index is divided into 5 grades. The representative ranges of different grades of grading indexes are: grade 1 [a, b), grade 2 [b, c), grade 3 [c, d), grade 4 [d, e), Grade 5 [e, f]. Establish different rating ranges for each index, as shown in Table 2.

Determining Membership Function. By using the knowledge of fuzzy mathematics, the membership function of the fuzzy set of each ability level is established, and the degree of each parameter belonging to the ability level is expressed by the membership degree (the value between 0–1). The fuzzy value of single factor judgment matrix (R_i) can be determined after determining the numerical value of each index. The membership function is shown in formula (1), where r_{ij} represents an element in R_i.

$$R_{i1}(x_i) = \begin{cases} 0, & x_i \in [f, +\infty) \\ \frac{f - x_i}{f - e}, & x_i \in [e, f) \\ \frac{x_i - d}{e - d}, & x_i \in [d, e) \\ 0, & x_i \in [-\infty, d) \end{cases} \quad r_{i2}(x_i) = \begin{cases} 0, & x_i \in [e, +\infty) \\ \frac{e - x_i}{e - d}, & x_i \in [d, e) \\ \frac{x_i - c}{d - c}, & x_i \in [c, d) \\ 0, & x_i \in [-\infty, c) \end{cases}$$

$$r_{i3}(x_i) = \begin{cases} 0, & x_i \in [d, +\infty) \\ \frac{d - x_i}{d - c}, & x_i \in [c, d) \\ \frac{x_i - b}{c - b}, & x_i \in [b, c) \\ 0, & x_i \in [-\infty, b) \end{cases}$$

Table 4. Judging matrix U_1 and the weight of each factor

U_1	U_{11}	U_{12}	U_{13}	U_{14}	Weight	Consistency
U_{11}	1	1	3	5	0.399	λ_{max} = 4.059
U_{12}	1	1	3	5	0.399	CI = 0.020
U_{13}	1/3	1/3	1	3	0.133	CR = 0.020 < 0.1
U_{14}	1/5	1/5	1/3	1	0.068	Meet the requirements

Table 5. Judging matrix U_2 and the weight of each factor

U_2	U_{21}	U_{22}	U_{23}	U_{24}	Weight	Consistency
U_{21}	1	3	3	5	0.535	λ_{max} = 4.218
U_{22}	1/3	1	3	5	0.267	CI = 0.073
U_{23}	1/3	1/3	1	3	0.131	CR = 0.076 < 0.1
U_{24}	1/5	1/5	1/3	1	0.067	Meet the requirements

Table 6. Judging matrix U_3 and the weight of each factor

U_3	U_{31}	U_{32}	U_{33}	U_{34}	Weight	Consistency
U_{31}	1	1	3	1/5	0.161	λ_{max} = 4.222
U_{32}	1	1	3	1/5	0.161	CI = 0.074
U_{33}	1/3	1/3	1	1/5	0.054	CR = 0.077 < 0.1
U_{34}	5	5	5	1	0.625	Meet the requirements

$$r_{i4}(x_i) = \begin{cases} 0, & x_i \in [c, +\infty) \\ \frac{c-x_i}{c-b}, & x_i \in [b, c) \\ \frac{x_i-a}{b-a}, & x_i \in [a, b) \\ 0, & x_i \in [-\infty, a) \end{cases} \quad r_{i5}(x_i) = \begin{cases} 0, & x_i \in [b, +\infty) \\ \frac{b-x_i}{b-a}, & x_i \in [a, b) \\ \frac{x_i}{a}, & x_i \in [-\infty, a) \end{cases} \tag{1}$$

4 Evaluation Application and Result Analysis

4.1 Evaluation Case

In order to verify the feasibility and accuracy of the adaptive classification model of the AHP -fuzzy comprehensive evaluation algorithm, the simple genetic algorithm (SGA) [20] is selected to test the fitness of an application environment. The application environment is the plant factory with variable spectral plant lighting source, the spectral matching of the light source is performed by embedded system attached to the light source, and the plant growth environment is high temperature and high humidity. The indexes are shown in Table 7.

Table 7. SGA performance and application environment index

Main factor		Subfactor		Unit	Value	Grade
U_1	Algorithm performance	U_{11}	Average time complexity	——	$O(n^2)$	2
		U_{12}	Average space complexity	——	$O(n^2)$	2
		U_{13}	Stability	——	Middle	4
		U_{14}	Implicit parallelism of algorithm	——	High	5
U_2	Computing equipment performance	U_{21}	Performance of CPU floating-point unit	FLOPS	1.5 M	2
		U_{22}	Memory read/write speed	Byte/s	512M	2
		U_{23}	Memory capacity	Byte	32M	2
		U_{24}	Parallel computing acceleration ratio	——	1	2
U_3	Application environment	U_{31}	Electromagnetic protection capability of computing equipment	——	Middle	4
		U_{32}	Installation space of computing equipment	cm^3	15	2
		U_{33}	Power supply life ability of computing equipment	day	Persistent	5
		U_{34}	The severity of the natural environment	——	Middle	2

From the application environment parameters in Table 7, it can be concluded that the application environment is in a high temperature and high humidity environment and requires high reliability of computing equipment. Therefore, an embedded system with high reliability is adopted to provide high reliability. The performance of embedded system is low, and it has no parallel computing ability, so it cannot play the advantage of implicit parallelism of simple genetic algorithm. Because of the above two contradictions, it is difficult to judge the adaptability of the simple genetic algorithm. The calculation process according to this method is as follows.

First, the single factor evaluation matrix is established, and the single factor evaluation matrix R_i, is determined by using the selected membership function. From the hierarchical index value and formula (1), we have:

$$R_1 = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} R_2 = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix} R_3 = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix}$$

According to the Analytic hierarchy process, the index weights of the first and second levels are as follows:

$$A = (0.182 \quad 0.115 \quad 0.703)$$

$$A_1 = (0.399 \quad 0.399 \quad 0.133 \quad 0.068)$$

$$A_2 = (0.535 \quad 0.267 \quad 0.131 \quad 0.066)$$

$$A_3 = (0.161 \quad 0.161 \quad 0.054 \quad 0.625)$$

The synthetic decision vector ($B_i = A_i \cdot R_i$) is used for hierarchical evaluation. A_i is the weight set on U_i and R_i is the single factor evaluation matrix of U_i.

$$B_1 = (0 \quad 0.799 \quad 0.068 \quad 0.133 \quad 0)$$

$$B_2 = (0 \quad 0.465 \quad 0 \quad 0.535 \quad 0)$$

$$B_3 = (0 \quad 0.786 \quad 0 \quad 0.161 \quad 0.536)$$

The evaluation matrix is as follows:

$$R = \begin{bmatrix} B_1 \\ B_2 \\ B_3 \end{bmatrix} = \begin{bmatrix} 0 & 0.799 & 0.068 & 0.133 & 0 \\ 0 & 0.465 & 0 & 0.535 & 0 \\ 0 & 0.786 & 0 & 0.161 & 0.536 \end{bmatrix}$$

From comprehensive scoring method [20], we have:

$$B = A \cdot R = (b_1 \quad \cdots \quad b_5) = (0 \quad 0.751 \quad 0.012 \quad 0.199 \quad 0.038)$$

$$H = \sum_{i=1}^{5} i \cdot b_i = 2.523$$

The fitness of the algorithm is level 3, which is consistent with the result of expert evaluation.

4.2 Evaluation Result Analysis

The AHP-fuzzy comprehensive evaluation method is used to classify the ability, and the accuracy of the method needs to be verified. In the experiment, 50 groups of application environment data were used, and the adaptability of the expert judgment algorithm was compared with the model system proposed in this paper. The following are the results of expert and system testing for 50 groups of different algorithms and application environment fitness levels, as shown in Table 8. It can be seen that the accuracy of the evaluation grade is high, the accuracy of 5 classifications are all above 80%, and the evaluation rules basically meet the requirements.

Table 8. Comparison of fitness grading

Evaluation results	Extremely low	Low	Middle	High	Extremely high
Expert evaluation	12	15	16	4	3
System evaluation	13	13	15	5	4

5 Conclusion

There are many kinds of spectral matching algorithms, which have their own merits and demerits in different application environments. It is of great practical value to quantify the judgment problems with many influencing factors without the influence of subjective factors. This paper integrates qualitative and quantitative aspects and puts forward a method of environmental adaptability evaluation based on AHP- comprehensive evaluation method, which solves the problem of different evaluation results caused by subjective factors in the process of application of the algorithm. It provides a more objective, quantitative and perfect evaluation method for evaluating the adaptability of spectral matching algorithm to the application environment.

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