A Fuzzy Comprehensive Evaluation Method for Life-span of LED Lamps Based on Rough Set Theory

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Abstract. The evaluation of led lamp life has always been a difficult problem. This paper proposes a fuzzy comprehensive evaluation of rough set theory. The results show that the method can quickly and accurately judge the four factors that affect the LED light source, driving power supply, heat dissipation system and use environment of LED lamps and lanterns.

1. Introduction
LED light source has the advantages of high luminous efficiency, long service life, no flicker, energy saving, etc. It is gradually replacing the traditional lighting fixtures. Therefore, research on the driving power source in LED lighting has become a hot topic \[1-3\].

As an emerging product, LED lamps must have corresponding standards to test its relevant parameters. At present, most of the LED lighting parameters such as color temperature, light efficiency, etc., have been strictly defined by standard test methods. However, in practical applications, people are more concerned about the reliability of LED lamps. Therefore, how to accurately predict the service life of LED lamps in a short time has become a common concern of the academic community and the industry. Foreign researchers are working on establishing a reasonable model for evaluating the reliability of LED lighting systems \[4-6\].

Rough set theory defines the decision table on the basis of the knowledge expression system, and transforms the weight question into a rough set of attribute importance evaluation questions. The weights of each index determined by it are completely obtained from the original data in the decision table. Therefore, this paper introduces the rough set theory into the fuzzy comprehensive evaluation to solve the weight problem, constructs a fuzzy comprehensive evaluation model based on the rough set theory, and applies it to the evaluation of the service life of LED lamps.

2. Rough set theory and weight determination
Rough set theory is a unique method proposed by Polish scholar Z Pawlak in 1982 to deal with fuzzy and uncertain data. The main idea is to derive the decision-making or classification rules of the problem through the knowledge reduction while keeping the classification ability unchanged. Attribute importance evaluation refers to deleting an attribute from the decision table, checking the classification of the decision table or changing the decision ability, and then obtaining the attribute of each evaluation index.
2.1 Rough Sets and Information Systems

Definition 1: Given the domain U, R is the equivalence relationship defined on U; \( [x]_R \). It is an R-equivalence class generated by the equivalence relationship R on U.

Definition 2: Using a quaternary to define an information system \( S = (U, A, V, F) \), among them: \( U = \{x_1, x_2, \cdots, x_n\} \) represents the non-empty finite set of objects to be discussed, also known as the domain; \( A = \{a_1, a_2, \cdots, a_n\} \) is a collection of attributes; \( V = \sum_{a \in A} V_a \) is a collection of property values; \( f : U \times A \rightarrow V \) is an information function. For each attribute subset B, an indiscernible binary relationship (i.e., an equivalence relation) is defined here. \( IND(B) \) that is \( IND(B) = \{(x, y) | (x, y) \in U, \forall a \in B, f(x, a) = f(y, a)\} \). Equivalent \( IND(B) (\in B \in A) \) constitute a division of the universe U, recorded as \( \frac{U}{IND(B)} \), often abbreviated as \( U^B \) \(^{[7-8]}\).

2.2 Attribute importance

Definition 1: Let \( K = (U, R) \) be a knowledge base, \( r \in R \) for an equivalence relationship. \( GD(R) \) is called a knowledge \( r \in R \) the granularity.

Definition 2: Let \( K = (U, R) \) be a knowledge base, \( r \in R \) for an equivalence relationship. \( Dis(R) \) is called a knowledge resolution of \( r \in R \), where \( Dis(R) = 1-GD(R) = 1 - \frac{|R|}{|U|^2} = 1 - \frac{|R|}{|U|^\alpha} \).

Definition 3: Let \( X \in C \) be a subset of attributes, Denote by the important for the attributes of \( X \), which is defined as \( \gamma_X(x) = 1 - \frac{|X \cup (x)|}{|X|} \) let \( \frac{U}{IND(X)} = \frac{U}{X} = \{x_1, x_2, \cdots, x_4\} \) then \( |X| = |IND(X)| = \sum_{i=1}^{4} |X_i|^2 \).

2.3 Method of Determining Attribute Weights Based on Rough Sets

In the information system \( S = (U, A, V, F) \), conditional attribute set \( C \in A \), that degree of importance of each attribute is different. The overall weight is \( \omega = \alpha q + (1-\alpha)p \), \( 0 \leq \alpha \leq 1 \) in the formula; \( \alpha \) -- empirical factors reflect the preference of decision makers for subjective and objective weights in the decision-making process. \( 0 \leq \alpha \leq 1 \) subjective weight, determined by expert experience knowledge, \( p \) —— objective weight.

3. Fuzzy comprehensive evaluation model based on rough set theory

The first layer of factors affecting the LED lamp is the light source, cooling system, driving power, and the use environment.

For each of the above factors, the degree of influence on the life of the LED lamp is different. The influence of the factor on the life of the LED lamp is defined as the weight, and the weight of the factor can be obtained by the importance level of the LED lamp. For the judgement set, according to the factors affecting the lifespan of LED lamps. We selected the more common objects and evaluated them according to the four severity levels of LED lamps. The severity of LED lamps can be divided into 4 levels, as shown in Table 1.
### Table 1 Classification of LED lamps severity

| Severity level       | Impact on the luminaire                                                                 |
|----------------------|------------------------------------------------------------------------------------------|
| Very serious damage  | Has a serious effect on lamp life, shortening its life by more than 50% of the theoretical value |
| Serious damage       | Has a greater impact on lamp life, making it 30% shorter in life expectancy theory         |
| Light damage         | Has a lighter impact on lamp life, reducing its lifetime by 10% of the theoretical value   |
| Negligible damage    | There is no direct impact on the lamp life, the lamp life can reach the theoretical value   |

According to the above table, the LED lamp life rating set is \( V = \{ v_1, v_2, v_3, v_4 \} = \{ \text{very serious damage, severe damage, light damage, negligible damage} \} \). The qualitative conclusions of the results can be expressed as poor, medium, good, and excellent, that is, \( V = \{ v_1, v_2, v_3, v_4 \} = \{ \text{poor, medium, good, excellent} \} \). The specific evaluation data intervals are \( 0.3 \leq C < 0.5 \), \( 0.5 \leq C < 0.7 \), \( 0.7 \leq C < 0.9 \), \( 0.9 \leq C < 1 \). The evaluation set of LED lamp life evaluation \( V = (0.3, 0.5, 0.7, 0.9) \).

The lifetime of the LED lamp is ultimately determined by the light source. Therefore, the final evaluation result \( C \) obtained can be interpreted as the weight of many factors affecting the life of the LED lamp. According to the above model lesson, the service life of LED lamps is obtained.

### 4. Analysis of reliability evaluation of LED lamps

The light source material of this lamp is silicon carbide. The substrate and the device made of this substrate have very good electrical and thermal conductivity, which can be used to make large-area high-power devices. The packaging material is epoxy resin, which is also the current domestic The most commonly used external packaging material; and the light source uses phosphor conversion to generate white light, this technology is easier to achieve than the three-primary white light technology \[9-10\]. The heat dissipation system of the lamps is well designed and heat-dissipated using heat pipe. This is the most effective method for heat dissipation of LED lamps. At the same time, pure heat is used to make the heat sink, the quality of the electronic devices used for the drive power supply and the device materials are all part of the scope is better. In addition, the lamp is used in the Nanchang area where the environment is mild. The area is in a good environment and the temperature is suitable. Theoretically, it will not cause serious damage to the LED lamp. The severity of the secondary influencing factors of the lamp is evaluated as shown in the table 2.

### Table 2 LED Lights Secondary Influencing Factors Severity Evaluation Results

| Influencing factors | Very serious damage | Serious damage | Light damage | Negligible damage |
|---------------------|---------------------|----------------|--------------|-------------------|
| LED light source    |                     |                |              |                   |
| Substrate material  | 1                    | 1              | 11           | 7                 |
| Light principle     | 1                    | 3              | 4            | 12                |
| Packaging material  | 0                    | 11             | 7            | 2                 |
| Cooling system      |                     |                |              |                   |
| Thermal material    | 1                    | 5              | 12           | 2                 |
| Cooling method      | 0                    | 0              | 3            | 17                |
| Drive power         |                     |                |              |                   |
| Electronic devices  | 0                    | 1              | 14           | 5                 |
| Device material     | 1                    | 4              | 10           | 5                 |

The above evaluation results are normalized to obtain a judgment matrix, which uses the analytic hierarchy process to normalize the weight vectors of all levels of factors, and use the weight vector normalized results to calculate the first-order comprehensive fuzzy judgment and reconstruct the first-order comprehensive judgment matrix. Calculate the second-order fuzzy comprehensive
judgment, select the weighted average type evaluation function, and obtain the fuzzy evaluation value \( C = B \times V^T = 0.739345 \).

5. Summary
According to the LED lamp life evaluation data set, the lamp's life level is a good level. Assuming that the lifespan of the LED light source used in this luminaire can reach 100,000 hours, and the actual life expectancy of the luminaire is predicted to be 739345 hours. The results show that the predicted life is less than the life of the LED light source, which is due to some factors such as the driving power supply, cooling system, etc., which have an impact on its life. Therefore, the actual life of the LED lamp is generally not higher than the life of the light source.

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