Green Product Design Based on Fuzzy Hierarchy Evaluation

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Abstract. Environmental problem has become a major challenge for the survival and development of human society in twenty-first Century, and it has become the consensus of the community that the green product is considered to be the only way for the sustainable development of human beings. Fuzzy AHP is an effective method to deal with the problem of mathematical model, which is difficult to be abstracted as an analytical form, or is difficult to analyze the complex problem completely. In this paper, we introduce the basic idea of fuzzy hierarchy evaluation method based on the life cycle, and apply it to the design of green product.

1. Introduction

For industrial design, the core of the green design is "4R", that is, the Reduce, Reuse, Recycle and Regenerate. This requires industrial design not only to minimize material consumption and emissions of harmful substances, but also to make products and parts easy to recycle and regenerate. It faces the whole life cycle of the product, and it is a process from the cradle to the reproduction. It emphasizes that the control measures should not be taken until environmental impact of the product happens. Prevention should be adopted at the beginning. Research shows that although the total cost of the design is only about 1%, but the contribution rate of the design for environmental protection is about 80% to 90%. Therefore, how to use the design to improve the environment performance of the product has become a problem for designers.

Usually, the main consideration of traditional product design is about the basic properties of the product, such as function, quality, life, cost, etc., and rarely takesenvironmental attributesinto account. The traditional design process in shown in Figure 1. Traditional product design is a process from the cradle to the grave.Once the design and manufacturing activities are completed, the product designers and technicians are no longer concerned about the problems in the product life cycle.According to the traditional design and production of products, when the product ends its service life, the recycling rate is low and the energy waste is serious.

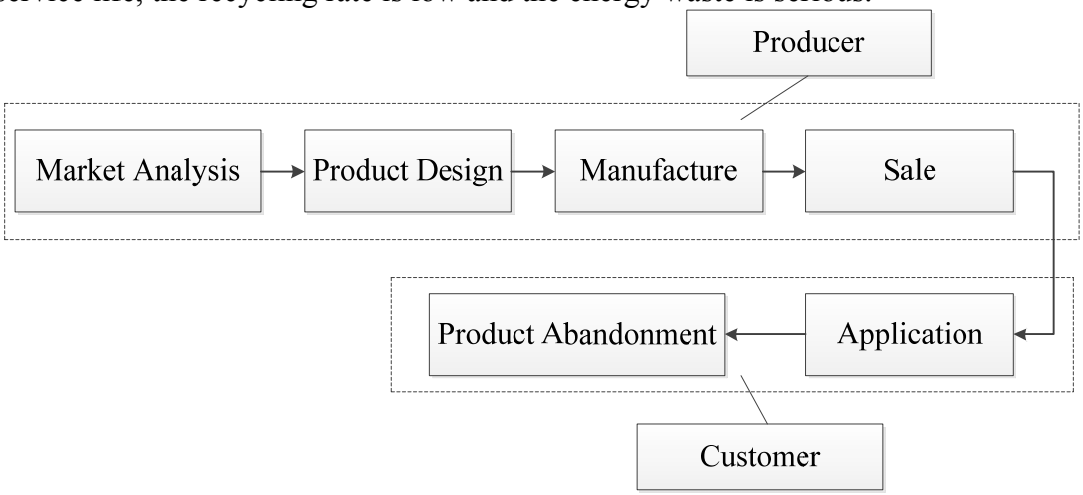

Fig. 1 The traditional design process

Green design is one of the hot spots in the industrial design. It gives higher requirements to the industrial design. So it is necessary and very challenging to carry on the evaluation of green products. From the perspective of industrial design, a product needs to make its social benefits, economic benefits and environmental benefits to achieve a comprehensive coordination in the life

cycle. At the same time, it is beneficial to the environment, human's safety and health. A good internal technology, the appearance of aesthetic and human-computer interaction are also important for the product. With the points mentioned above, these kinds of products can be regarded as the real green products. This paper is based on the ideas of green product to design the evaluation system. And according to the idea of this paper, the definition about green product includes three factors: the technical factor, the environmental factor, the ergonomic and the aesthetics factor. Three-dimensional coordinate system of green products is built in Figure 2.

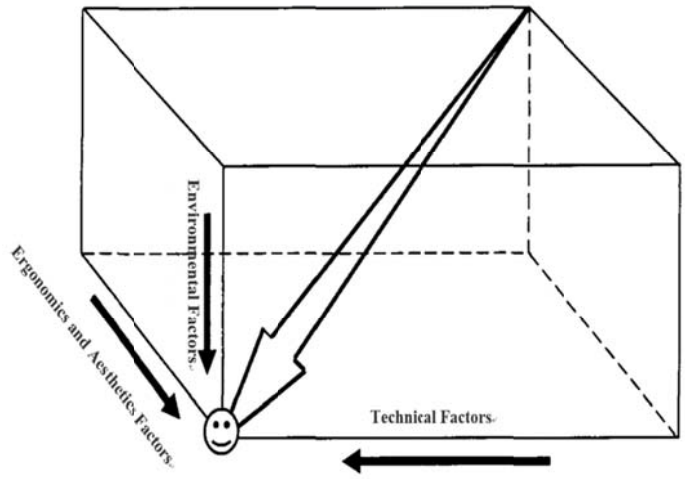

Fig. 2 Three-dimensional coordinate system of green products

The evaluation index of green product design should accord with the common standard of industrial design evaluation as a general product, and the green attribute of green product should be considered in the same time. Of course, there is a cross between the two evaluation content. Because this paper studies the industrial design evaluation system of green product, the evaluation index system should focus on the factors that affect the industrial design of green product, and also consider the green attribute of green product.Schematic design elements of evaluation index system for green product is shown in Figure 3.

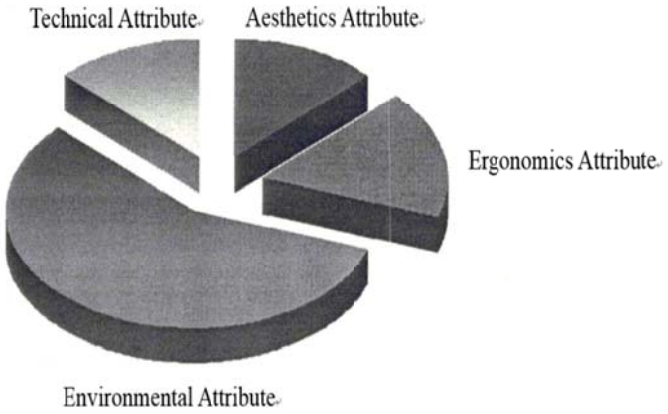

Fig. 3 Schematic design elements of evaluation index system for green product

2. The Construction of Evaluation System for Green Product Design

Evaluation of the environmental performance of green products cannot focus on one characteristic or a certain stage, which requires a comprehensive development of vision and methods. Therefore, it is necessary to introduce the life cycle assessment (Life Cycle Assessment, LCA) into the evaluation system of green products.

According to the definition of International Standardization Organization (ISO): product life cycle assessment is an evaluation for system input –output in the product life cycle and its potential

environmental impact.ISO in June 1997 promulgated the ISO14040 standard, which has become the international standard to guide enterprises to enter the ISO14000 environmental management.

The life cycle assessment in ISO14040 is divided into four steps: goal and scope definition, inventory analysis, impact assessment and interpretation. ISO adds to the interpretation of life cycle, which explains the mutual connection of the first three steps. Also, the ISO framework is more detailed and it is more helpful to guide the development of life cycle assessment. The LCA conceptual framework in ISO14000 is shown in Figure 4.

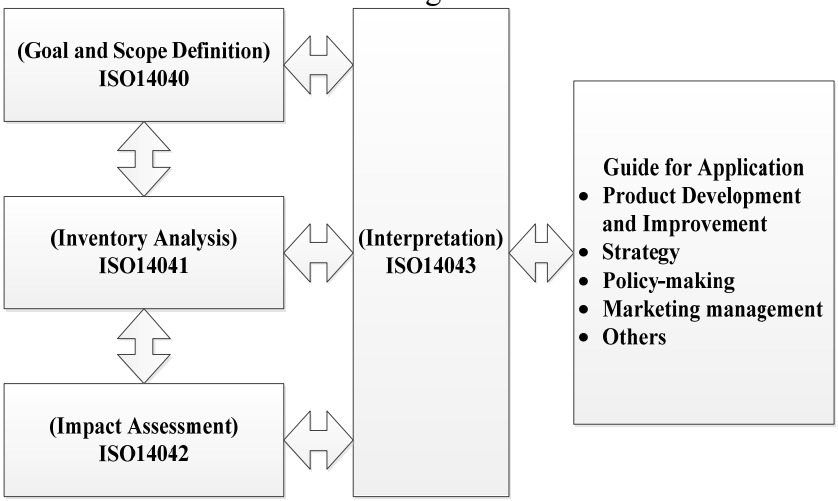

Fig.4 The LCA conceptual framework in ISO14000

(1) Goal and scope definition

Determining the object and scope is the first step of LCA research, which is the starting point and the foothold of the evaluation process. LCA firstly need to determine the evaluation target, determine the target that is clearly enough to illustrate the evaluation object. Then the purpose and reason for carrying out the LCA as well as the possible application need to be explained. It mainly contains that define the product system, determine the boundary of the product system, and define the function unit. And then according to the evaluation objectives, the function of the object, the functional unit, the system boundary, the environmental impact type can be defined. These works vary greatly from the study objective. It does not have a fixed standard pattern to be applied. But it must reflect the basic direction of the information collection and analysis. In addition, the LCA study is a repeated process, according to the collected data and information, it may modify the initial set of the scope to meet the research objectives. In some cases, the research object itself may also need to be amended as a result of a certain limitation.

(2) Inventory analysis

The task of inventory analysis is to collect data, and provide a variety of input and output of the product system, as the basis for the next step. Inventory analysis is an objective and quantitative process based on data for the energy, materials, and environmental emissions in the whole life cycle.

(3) Impact assessment

In LCA, the impact assessment is a quantitative or qualitative description of the impact of environmental loads identified in the list analysis. Impact assessment is the third stage of LCA, and it is the core part of LCA which is the key step in the implementation. It evaluates the potential environmental impact of the material by using the impact type associated with the list of results.

(4) Interpretation

The purpose of the life cycle interpretation is to analyze the results in a transparent way. The interpretation needs to explain the limitations, report the results of the life cycle interpretation, and provide a complete description of the results of the LCA study as far as possible.

In the industrial design evaluation of green products, products is regarded as the reference object, and a reasonable evaluation index system is established. By using the correct evaluation method, the comprehensive evaluation score of the product is obtained, and the basic requirements of the product are determined. According to the results, it can be helpful to improve the design and

production. The comprehensive evaluation of the industrial design for green product is a comprehensive thinking model. In this paper, a comprehensive evaluation system for green product design based on LCA is proposed. Figure 5 shows the comprehensive evaluation system for green product design based on LCA.

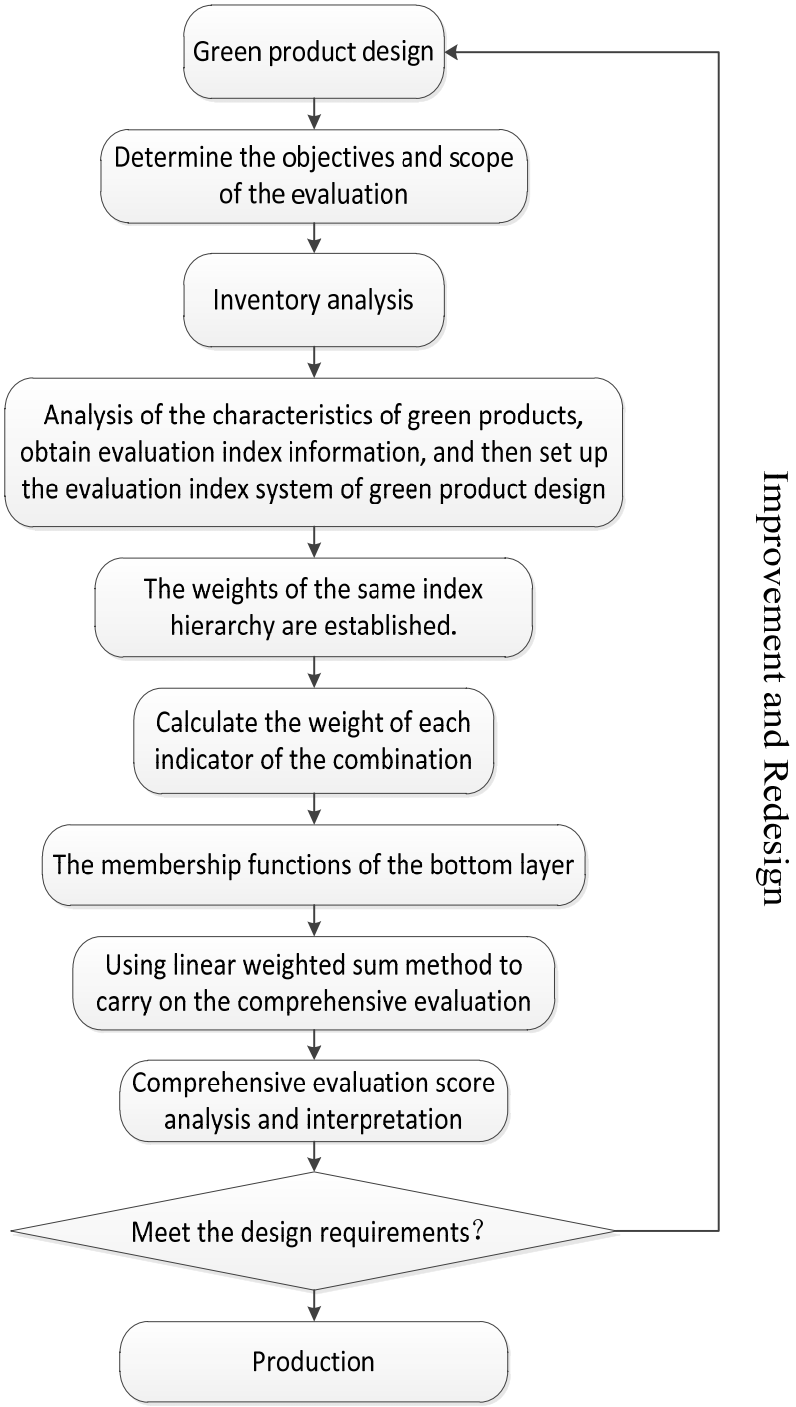

Fig.5 Comprehensive evaluation system for green product design based on LCA

3. Weights Calculation of the Fuzzy Hierarchy Evaluation

The life cycle includes the acquisition of raw materials, manufacturing, using and disposal of waste recycling. The design and manufacturing process of green product is very complex. Many factors have effects on the degree of green, and the effects are different in each stage of life cycle. Using fuzzy mathematics principle to establish the membership function for quantitative evaluation, the influence of some factors can be quantified, such as the cost of production, resource utilization, environmental standards, etc. The influence of some factors is qualitative. It must be supplemented

by qualitative judgments, such as human-computer interaction and aesthetic. These factors are difficult to be analyzed by the traditional quantitative method, which requires the introduction of linguistic variables to describe and solve the problems. And then, the fuzzy information is made by using the method of fuzzy mathematics. In short, the evaluation of green products can not only be decided by one kind of index. Comprehensive evaluation of multi index should be used.

Fuzzy hierarchy evaluation method is an effective method to deal with the problem of mathematical model, which is difficult to be abstracted as an analytical form, or it is difficult to analyze the complex problem completely. It provides a powerful support for the multi criteria decision making problem in practical application.

Determining the weights of the evaluation indexes is an important step in the fuzzy analytic hierarchy process. The determination process includes: the establishment of weight judgment matrix, weight calculation and consistency check.Figure 6 is the weight determination process chart.

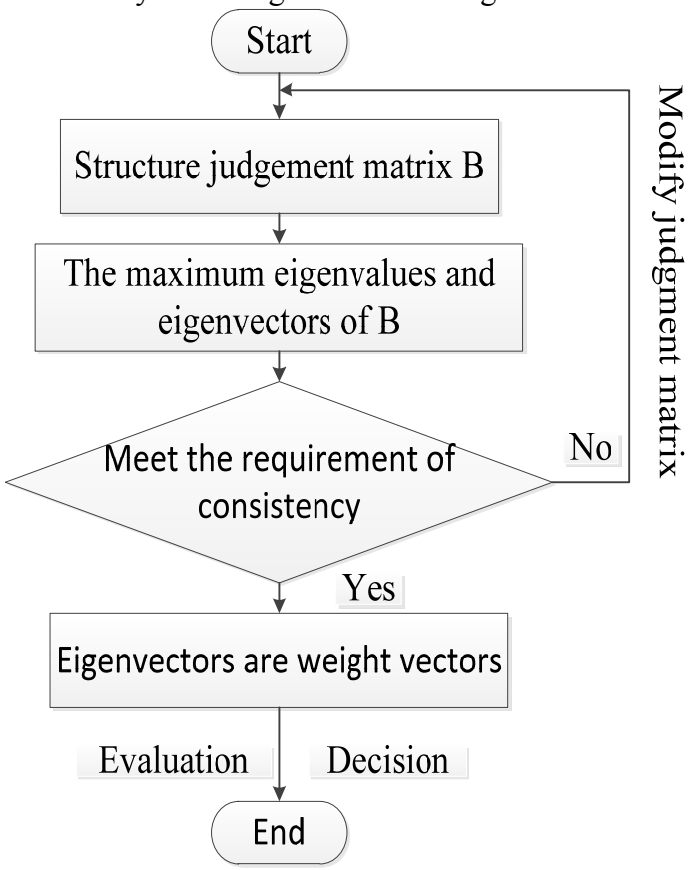

Fig.6 weight determination process

3.1 Structure Weight Judgment Matrix

In the evaluation model, one factor is decomposed into several related factors, which have different impacts on the upper factor. These factors are called weight vector. Fuzzy analytic hierarchy process compares the relative importance of the factors and gives the judgments. These judgments are represented by the introduction of appropriate scale values, which constitute a judgment matrix. The so-called judgment matrix is a matrix which is used to express the relative importance of each element in each level. The establishment of judgment matrix is a very important step in the fuzzy analytic hierarchy process.

According to the upper elements U, B_1, B_2,…,B_n are the lower elements associated with the U.To analyze the relative importance of each element in the B_i layer to, a $n \times n$ matrix can be established as follows.

Table 1 the $n \times n$ matrix

U_i	B_1	B_2	…	B_n
B_1	b_{11}	b_{12}	…	b_{1n}
B_2	b_{21}	b_{22}	…	b_{2n}
…	…	…	…	…
B_n	b_{n1}	b_{n2}	…	b_{nn}

In order to make the judgment quantitative, 1 to 9 proportional scale method, which is proposed by Saaty, is generally cited.Values of the relative importance of B_j to $B_k$are measured by 1, 3, 5, 7, 4, 6, 8, and their reciprocal. Table 2 shows the 1 to 9 proportional scale method.

Table 2 1 to 9 proportional scale method

Digital scale	Comparison between B_j and B_k	Meaning
1	B_j and B_k are equally important	$B_j=B_k$
3	B_j is slightly important	$B_j=3B_k$
5	B_j is more important	$B_j=5B_k$
7	B_j is significantly important	$B_j=7B_k$
9	B_j is absolutely important	$B_j=9B_k$
2,4,6,8	The importance of B_j and B_k in the between the description	
The reciprocal	B_j is less important than B_k	

3.2 Weight Calculation

According to the judgment matrix, the eigenvectors of the judgment matrix are calculated.Then through the normalized processing, the eigenvectors can satisfy the equation $\sum_{i=1}^{n} W_i = 1$, then the weight calculation can be obtained. The method of calculating the eigenvectors is shown as follows:

(1) Calculate the product of each line in the matrix,

$$M_i = \prod_{j=1}^{n} b_{ij}, \quad i, j = 1, 2, \ldots, n \tag{1}$$

b_{ij} in the formula is the element of the Row$i$, column j.

(2) Calculate the N root mean square of Mi,

$$\overline{W} = \sqrt[n]{M_i}, \quad i = 1, 2, \ldots, n \tag{2}$$

(3) Use normalized processing to obtain the eigenvalues

$$W_i = \frac{\overline{W_i}}{\sum_{i=1}^{n} \overline{W_i}}, \quad i = 1, 2, \ldots, n \tag{3}$$

$\overline{W_i} = (W_1, W_2, \ldots, W_N)^T$ is the eigenvector and $B_i (i = 1, 2, \ldots, n)$ is the weight.

(4) Calculate the maximum eigenvalue

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(BW)_i}{W_i} \tag{4}$$

Where B is the $n \times n$ judgment matrix and W is the weight vector.

3.3 Consistency Check of Judgment Matrix

The consistency test of judgment matrix is the fault tolerance and error analysis. It means that in the judgment matrix, the importance of the elements of the matrix is consistent, cannot appear contradictory. Because of the complexity of the objective things and people's understanding of the diversity, the establishment of the judgment matrix may not show the full consistency. It is not possible to determine the value of b_{ij}, only to estimate it.If there is an error in the estimate, it is bound to lead to a deviation of the eigenvalues.This requires the consistency check of the judgment matrix, and with the consistency check of the judgment matrix, the conflict can be avoided.In fact, in the construction of judgment matrix, it does not require a complete consistency. It means that the

equation $b_{ij} \bullet b_{jk} = b_{ik}, (i, j, k = 1, 2, \ldots, n)$ does not need to be satisfied. This is determined by the complexity of the objective things and the diversity of people's understanding.However, it is necessary to judge a general consistency.Therefore, after finding out $\lambda_{\max}$, it is necessary to carry out the consistency check, which is the guarantee condition for the conclusion. The procedure of consistency check is shown as follows.

(1) Calculate consistency index CI

According to matrix theory, in the matrix of n order, the largest eigenvalue is single and the largest eigenvalue is bigger than n. If the equation $b_{ij} \bullet b_{jk} = b_{ik}, (i, j, k = 1, 2, \ldots, n)$ is set up, the judgment matrix B has complete consistency. At this moment, $\lambda_{\max} = n, CI = 0$ and other roots of the matrix are 0. In general, $\lambda_{\max} = n$ is single and $CI \succ 0$. When the judgment matrix is not completely consistent, the characteristic root will also change.We can judge the consistency of the matrix according to the change of characteristic root.In the analytic hierarchy process, we introduce the consistency index of the judgment matrix for judgment, and the consistency index is CI.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (5)$$

Where n is the number of judgment matrixes;

$\lambda_{\max}$ is the maximum eigenvalue.

The bigger the CI value is, the greater the degree of deviation from the judgment matrix may be. The smaller the CI value is, the better consistency of the judgment matrix is gotten.

When the judgment matrix has a satisfactory consistency, $\lambda_{\max}$ is slightly bigger than n and the other roots are close to 0. At this point, the weight vector from the characteristic root method can well meet the requirements.This is the basis of the consistency index CI.

(2) Determine the average random consistency index RI

For different levels of the judgment matrix, the consistency error from people's judgment is different and the CI value is also different.Generally, when the order gets bigger, the number of elements which are needed in comparison gets bigger too. Because of the decrease of people's thinking ability, the possibility of the inconsistency of judgment increase, and the value of CI becomes higher.On the contrary, the smaller the order number n is, the less likely it is to cause the deviation. In order to measure the consistency of different order to determine whether the matrix is satisfied, the average random consistency index of the judgment matrix is introduced. RI is a coefficient and it is calculated from 500 sample matrixes in different orders. The RI values in different orders are shown in Table 3.

Table 3 RI values in different orders

Order n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

(3) Calculate the consistency ratio

For one order and two order matrix, the judgment matrix is completely consistent, and it is not necessary to calculate the consistency index. When n≥3, it needs to calculate the ratio of CI and RI.

$$CR = \frac{CI}{RI} \quad (6)$$

When CR＜0.1, it is considered that the judgment matrix has consistency. Otherwise, the matrix needs to be modified until the CR is less than 0.1.

4. Summary

Green product design is mainly engaged in the product lifecycle design in a broad sense, from demand for product, product design and manufacture to product sales, use, abandon and recovery. The influence of every stage in the product lifecycle on human beings and environment is considered equally. With the increasing deterioration of the global environment, people pay more

and more attention to the study of environmental issues. Green products and green design has become a hot research topic. There are few researches on how to evaluate the industrial design of green product. From the current research of green product evaluation, the research results are almost about engineering technology, few people stand in the perspective of industrial design to carry out comprehensive evaluation of green products. This paper is based on this kind of background and have a meaningful attempt.

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