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Using FCE and FAHP to Explore the multirotor drone appearance preference

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Abstract: Every year there are new products on the market for drones prompting designers to spend a lot of time collecting data and analyzing product style trends in the market. However, it takes more time for new designers to understand consumers' evolving preferences. Therefore, this study proposes an evaluation model for DRONE appearance design. The method uses Morphological Analysis to extract product appearance characteristics, and uses fuzzy comprehensive evaluation (FCE) and fuzzy analytic hierarchy process (FAHP) to establish DRONE appearance in addition to preference analysis. It obtained the degree of importance that consumers attach to each component; the result weights that consumers attach were then analyzed to determine that the overall preference for the appearance of DRONES is objective. In this way, the researchers or designers subsequently executing procedure can establish a modelling database and apply it to the process of rapid design.

Keywords: Drone; Morphological Analysis; Fuzzy Analytic Hierarchy Process, FAHP; Fuzzy Comprehensive Evaluation, FCE

1. Introduction

With the intensification of economic globalization, it is very important to make rational use of global design resources. For such a background, as the design goes deep into all aspects of the enterprise, the designer's job in the enterprise is not only to execute the design of modelling style, but also to cooperate with engineers, marketing personnel and others. However, today's market emphasizes cooperation efficiency and the rapid generation of innovative ideas. It is very important to determine whether the style trend accurately matches the preferences of consumers at the market end. Traditional design has thus entered a brand-new era of design management. On the one hand, it can save time for product development; on the other hand, it can enable new designers to understand market preferences more quickly and create designs that conform to the market. In 1922, large-

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scale drones were in the testing stage until the prototype of the four-axis drones began to appear in the United States in the 1950s. Up to now, drones have a 90-year history of development, and their early use was mainly military. In recent years, due to the influence of the Internet of Things and the integration of communication and network technologies, DRONES have been combined with at least six technologies. From consumer recreational toys to high-value applications in the fields of climate, commerce, agriculture, urban planning and national defense, drones have become a new product just around the corner. Basson et al. (2019) proposed using the instrument technology evaluation method to evaluate drone performance, and to use in-flight measuring instruments to ensure stable flight. The design elements and performance standards are discussed in terms of mechanical design, electromechanical design, flight control optimization and drone performance standards for the three basic models of drones. Saha et al. (2018) proposed the idea of using Raspberry PI for drone development; it can be used in drones with cameras to identify organisms during flight. It is very useful for military operations and surveillance in remote areas. Mahamud et al. (2016) proposed a new algorithm for drones to make it easier for drones to move across the sky, land and water. Strengthening automatic identification can reduce the complexity of interaction with the database and optimize the relationship between drones' AI and database. All the researchers mentioned above have conducted research related to the design and development of drones. This study discusses the weight and preference of each evaluation item that comprise the overall appearance of the drones, so there is no further discussion on the functional aspect.

2. Theoretical Background

2.1 Morphological analysis

Zwicky, the founder of morphological analysis, argued in 1957 that morphological analysts should eschew prejudice and remain objective. This method is used to decompose the design target into a plurality of different design elements and generate new shapes or creative ideas through arrangement and combination. During the implementation, the external structure is first analyzed, and then disassembled and the parts combined with each other. The analysis method is divided into four steps:

1. Strive to complete the description of the subject;
2. Disassemble the independent factors of the subject;
3. List the multiple elements in each independent factor;
4. Combine different elements with each other to create many new ideas.

Dragomir et al. (2016) proposed the application of morphological charts in order to ensure the best match between product characteristics and customer requirements as well as to shorten the development time for greater flexibility. Azammi et al. (2018) proposed that the application of morphological charts to vehicle engines is an effective solution to improve the classification efficiency of module components. Hsiao et al. (2016) proposed applying the

morphological charts to the design of hair dryers, an approach which can also generate new product ideas quickly.

2.2 Fuzzy Comprehensive Evaluation, FCE

Fuzzy theory is a scientific method for studying and dealing with fuzzy phenomena; it was first put forward in 1965 by Zadeh (1965, 1975), a control theorist at the University of California. This process is used to process imprecise and fuzzy data to solve decision-making problems in fuzzy environments by strict mathematical methods. The fuzzy comprehensive evaluation method is a widely used method in the field of fuzzy mathematics. Its purpose is to effectively solve fuzzy and difficult-to-quantify problems, and is suitable for solving various uncertainty problems. Hsiao (2013) proposed using the FCE method to study bicycle preferences in the market and solve the problem of bicycle stocking. Hsiao (1995, 1998) used the fuzzy theory and analytic hierarchy process to make product decisions in the automobile design stage; fuzzy theory made relevant evaluations on monochrome schemes. In addition, Hsiao et al. (1997) used fuzzy linguistics to make product decisions for automobile exterior design. The following are the implementation steps of FCE, which are divided into 6 points:

1. Give the object set of the evaluation factor target $u = \{u_1, u_2, \dots, u_n\}$;
2. Determine the indicator set $V = \{V_1, V_2, \dots, V_m\}$;
3. Establish the weight set: Since the importance of each indicator in the indicator set differs, it is necessary to assign corresponding weights to the first-level indicator and the second-level indicator, respectively. The weight set of the first level $\omega_i = \{a_{1i}, a_{2i}, \dots, a_{ni}\}$, $i = 1, 2, \dots, n_i$, the weight set of the second level $\omega_k = \{a_{1k}, a_{2k}, \dots, a_{m_k}\}$, $k = 1, 2, \dots, m_o$. Factor analysis will be used here to determine the weight: $\sum_{i=1}^f \omega_i = 1$;
4. Determine the comment set: We set the evaluation set to $v = \{\text{very important, slightly important, neutral, slightly unimportant, very unimportant}\}$
5. Find out the evaluation matrix: $R_i = (r_{ijk})$; first determine the membership function of U to v , and then calculate the membership degree of drone evaluation indicators for each level. R_i ;
6. Obtain the fuzzy comprehensive evaluation set $B_i = \omega_i \circ R_i = (b_{i1}, b_{i2}, \dots, b_{in})$ i.e., the general matrix multiplication; the final evaluation result is obtained according to the evaluation set.

2.3 Analytic Hierarchy Process, AHP

Analytic Hierarchy Process (AHP), developed by Saaty in 1971, is mainly employed to provide a quick way to reduce complicated decisions. Ulloa et al. (2018) proposed applying AHP to the appearance design of PV-T module of DRONES. Finally, Arduino was used as a model to verify and test the experimental data. Lei (2014) proposed reducing the accident rate of electric vehicle fires through AHP, strengthening the fire safety management of electric

vehicles, and assisting in the development of management systems. The following are the five steps of the implementation process, as shown in Figure 1:

- Step 1 is decomposition, which divides the complex decision-making elements into several components, subdivides these components into multiple solutions, and organizes them into a tree-like hierarchical structure diagram.
- Step 2 is weighting, giving weight to the relative importance of each part, and then analyzing the priority of each part.
- Step 3 is evaluation. For decision makers, a pair comparison matrix is created in a hierarchical structure. Table 1 presents the definition of the AHP evaluation index and score.
- Step 4 is selection. AHP can help to confirm subjective and objective evaluation measures. The consistency ratio of evaluation should be checked eventually, which is also referred to as C.R. C.I. is the consistency index; RI is a random index; λ is the maximum eigenvalue of the matrix; n is the matrix order or the number of parameters; the calculation is shown in the following formula (1). With the alternatives suggested by the team to reduce the team's decision-making mistakes, such as out of focus, no plans, no participation, etc., Hosseini et al. (2016) proposed AHP subdivides the whole problem into several less important evaluations, but still maintains the overall decision-making method.

Table 1 Evaluation score and definition of AHP

Evaluation measurement	Definition
1	Equal importance
3	Slight importance
5	Essential importance
7	Very strong importance
9	Absolute importance
2, 4, 6, 8	Intermediate value

Only when C.R. < 0.1 is satisfied and shown in the following formula (2);

$$C.I. = \frac{\lambda_{\max} - n}{-1} \quad (1)$$

$$C.R. = \frac{C.I.}{R.I.}$$

$$C.R. < 0.1 \Rightarrow \text{OK} \quad (2)$$

C.R. = Consistency ° Ratio

C.I. = Consistency ° index

R.I. = Randan ° index

Figure 1 Process of AHP

2.4 Fuzzy Analytic Hierarchy Process, FAHP

In this study, fuzzy theory and the analytic hierarchy process are combined to establish the implementation of the Fuzzy Analytic Hierarchy Process (FAHP), which can effectively deal with fuzzy problems and accurately achieve the purpose of decision-making. Grann (1980) was the first scholar to add fuzzy theory to AHP. He proposed using triangular fuzzy numbers to express the importance of elements and then calculate the fuzzy weight of decision criteria. Shen et al. (2018) used FAHP to discuss the influence of watch product elements on gender orientation. The aim is to quantify five elements and their relative importance in terms of gender orientation. Moayyedian et al. (2018) proposed multi-objective optimization for injection molding. The purpose of their study is to determine the best alternative for the best formability index and the best alternative close to the best alternative for injection molded parts in injection molding technology. Through consideration of Taguchi, FAHP and the ideal solution, Kubler et al. (2016) proposed creating statistics on the existing research papers. FAHP is mostly used in the papers on manufacturing, industry and government departments. Among them, 57% still leave much room for research and discussion, which also represents that FAHP is widely used. In this study, triangular fuzzy numbers are used to

represent the weight values; the total weight is obtained by first calculating the interviewee results and then processing them. The calculation process is as follows:

1. Establish the fuzzy pairwise comparison matrix; according to the results of the questionnaire survey, the trapezoidal fuzzy number is used to represent the comparison matrix of two fuzzy sets. $\tilde{A}$, where, $\tilde{A} = [\tilde{a}_{ij}]$, $\tilde{a}_{ij} = [a_{ij}, b_{ij}, c_{ij}, d_{ij}]$.
2. Fuzzy weight of fuzzy positive-negative matrix; $W_i = \frac{\sum_{j=1}^n a_{ij} + \frac{n-1}{2}}{n(n-1)}$
3. Consistency testing; $I(A, W) \leq A, A \leq 0.1$;
4. Level cascading and factor ordering; $W = (W_1, W_2, \dots, W_n)$

3. Case Study

This chapter includes six steps. First, identify the appearance feature components. Second, create a shape analysis diagram. The third step is to generate new combinations through the AHP questionnaire. The fourth step is then to compare the differences between FCE and FAHP. The fifth step is consistency verification. The sixth step is consistency verification. The seventh step is to create options from the morphology map. The eighth step is to verify the evaluation results obtained through the options. The ninth step is to compare the results of FAHP and FCE. If the results are equal, continue to the next step; if the results are different, the modeling questionnaire needs to be modified. The tenth step is the design and three views. The eleventh step is product performance and effect diagram. The process of the case study is shown in Figure 2.

Figure 2 Process of case study

3.1 Identify components of appearance feature

First, the overall appearance of the DRONE was functionally disassembled; it could be divided into three parts: outer frame, propeller and lifting stand. Eventually, a description table of the appearance features was established, as shown in Table 2.

Table 2 Basic menu of drone.

	Description
Frame	The outer frame of the drone covers 95% of the mechanism and is the main component of the product.
Propeller	Drone take-off parts, the shape will affect flight efficiency.
Heighten landing skid gear leg	Drone lifting and grounding components need a combination of style and function.

3.2 Establish morphological analysis chart

After the DRONE was disassembled, it could be divided into 7 outer frames, 6 propellers and 6 lifting stands. Its components are visualized here, and are shown in Table 3. In addition, an Analytic hierarchy diagram was established, as shown in Figure 3:

Figure 3 Analytic hierarchy diagram

Table 3 Basic menu of drone

	type 1	type 2	type 3	type 4	type 5	type 6	type 7
Frame							
Propeller							
Heighten Landing Skid Gear Leg							

3.3 The decision steps produce new combinations

Fuzzy comprehensive evaluation can quantify fuzzy indices of evaluation objects by establishing fuzzy subsets of grades. The fuzzy variable principle was then used to integrate each index to better solve fuzzy problems, such as the clear features of different attributes. After the final morphological chart was established, FAHP and the fuzzy comprehensive evaluation method were used to evaluate and select excellent combination programs. After the morphological chart was formed, FCE and FAHP were used to evaluate and select an excellent combination program. The results are as follows:

- Establish the factor set.
- Calculate the weight of each component.

The weight of the outer frame was 0.558, that of the propeller was 0.122, and that of the lifting stand was 0.319. Its weight ranking was outer frame > lifting stand > propeller, as shown in Table 4.

Table 4 Building a pairwise comparison matrix

	Frame	Propeller	Heighten landing skid gear leg	Weight
Frame	1	4	2	0.558
Propeller	0.25	1	0.33	0.122
Heighten landing skid gear leg	0.5	3	1	0.319

From the above table, it can be seen that the evaluation of external appearance is valued sequentially as follows: outer frame > lifting stand > propeller.

- Consistency verification of the weight of each component

$$\lambda_{\max}=3.018$$

$$C.I.=\left(\frac{\lambda_{\max}-n}{n-1}\right)=\left(\frac{3.018-3}{2}\right)=0.009$$

$$R.I.=0.58$$

$$C.R.=0.017<0.1\rightarrow\text{OK} \quad (3)$$

The consistency score was 0.017, less than 0.1, which means that each weight is consistent and shown in the following formula (3); for each factor, the consistency score was summarized into a weight set:

- Establish a fuzzy evaluation matrix

Based on the factor set, evaluation set and weight set, a comprehensive evaluation questionnaire was designed, as shown in Figure 4 below. The questionnaire involved a total of 31 respondents, including college students and professional users. Following a statistical

analysis, the fuzzy membership relation of each part is shown in Table 5. Designers and manufacturers can use Table 6 to inquire about the general consumer's appearance preference for the final drone product.

NO.	Evaluation index	Evaluation index description	Evaluation menu
1	Type P1	Frame shape score	Love it very much
2	Type P2	Frame shape score	Love it very much
3	Type P3	Frame shape score	Like it a little
4	Type P4	Frame shape score	Ordinary
5	Type P5	Frame shape score	Slightly dislike it
6	Type P6	Frame shape score	Dislike it very much
7	Type P7	Frame shape score	
8	Type P1	Propeller shape score	
9	Type P2	Propeller shape score	
10	Type P3	Propeller shape score	
11	Type P4	Propeller shape score	
12	Type P5	Propeller shape score	
13	Type P6	Propeller shape score	
14	Type H1	Heighten landing skid gear leg shape rating	
15	Type H2	Heighten landing skid gear leg shape rating	
16	Type H3	Heighten landing skid gear leg shape rating	
17	Type H4	Heighten landing skid gear leg shape rating	
18	Type H5	Heighten landing skid gear leg shape rating	
19	Type H6	Heighten landing skid gear leg shape rating	

Figure 4 Establish a fuzzy evaluation questionnaire

Table 5 Building Fuzzy Membership Table

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7
Frame	0.104	0.248	0.149	0.255	0.227	0.219	0.186
Propeller	0.139	0.201	0.055	0.103	0.265	0.257	
Heighten landing skid gear leg	0.182	0.155	0.243	0.072	0.069	0.022	

Table 6 Morphological chart for IDEA 1-3

	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7
Frame	0.104	0.248	0.149	0.255	0.227	0.219	0.186
Propeller	0.139	0.201	0.055	0.103	0.265	0.257	
Heighten landing skid gear leg	0.182	0.155	0.243	0.072	0.069	0.022	

IDEA 2 IDEA 1 IDEA 3

In order to further study the credibility of the research results, the first two parts with the highest fuzzy membership degree were selected from Table 6: concept 1 and concept 3 respectively. Concept 1 consisted of F4, P5 and H3. Concept 3 consisted of F1, P3 and H6. The part with the lowest fuzzy membership was IDEA 2, which consisted of F2, P6 and H1, so as to form the following three different DRONE exterior designs, as shown in Figures 5-7.

Figure 5 IDEA 1

Figure 6 IDEA 2

Figure 7 IDEA 3

- The weight matrix of primary index is

$$A=[0.558 \ 0.122 \ 0.319]$$

- The weight matrix of secondary index respectively can be written as

$$w_1=[0.104 \ 0.248 \ 0.149 \ 0.255 \ 0.227 \ 0.219 \ 0.186]$$

$$w_2=[0.139 \ 0.201 \ 0.055 \ 0.103 \ 0.265 \ 0.257]$$

$$w_3=[0.182 \ 0.155 \ 0.243 \ 0.072 \ 0.069 \ 0.022]$$

- The secondary fuzzy comprehensive evaluation matrixes are as follows

$$R_1=[0.104 \ 0.103 \ 0.022]$$

$$R_2=[0.248 \ 0.257 \ 0.243]$$

$$R_3=[0.149 \ 0.139 \ 0.069]$$

- Finally the Fuzzy comprehensive evaluation matrixes set is as below.

$$\tilde{R}=\begin{bmatrix} 0.255 & 0.104 & 0.248 \\ 0.267 & 0.103 & 0.257 \\ 0.243 & 0.022 & 0.182 \end{bmatrix}$$

- Comprehensively evaluate the fuzzy evaluation matrix which is built according to Table 5; the evaluation results are:

$$\tilde{B} = \tilde{W} \circ \tilde{R} = (0.426 \ 0.027 \ 0.219)$$

Based on this evaluation result, the order of priorities should be IDEA 1, IDEA 3, and IDEA 2. Generate new combinations with FAHP decision steps, as shown in Table 7. Applying normalization to the above vectors, the final vector could be obtained as follows: IDEA 1 equaled 0.449, IDEA 2 equaled 0.203, and IDEA 3 equaled 0.347. Based on these evaluation results, the priority order should be IDEA 1, IDEA 3 and IDEA 2, sequentially.

$$w = (0.449 \ 0.203 \ 0.347)$$

Table 7 FAHP Relation Table for Three Ideas

	IDEA 1	IDEA 2	IDEA 3
Frame	0.472	0.19	0.338
Propeller	0.516	0.175	0.308
Heighten landing skid gear leg	0.393	0.188	0.42

3.4 Verification results

This step was to compare the results of the fuzzy comprehensive evaluation with the preference statistics of the actual interviewees. It can be seen from the results in Tables 5 and 6 that the results were the same: IDEA 1 > IDEA 3 > IDEA 2; this shows that designers can use the hierarchical evaluation item weights (Table 7) and the fuzzy membership weight statistics (Table 5) in this study to reorganize different new options and obtain preference scores for each appearance combination, so that designers can also obtain pre-reference instructions on consumer appearance preferences.

3.5 Appearance design and three views

The conclusions drawn in the previous section can be used by designers to design and create three views, as shown in Figure 8.

Figure 8 Design of IDEA 3

3.6 Product performance and rendering diagram

The ideation design IDEA 3 obtained in the previous section can use three-dimensional software and rendering software KeyShot, which can be subsequently used as a product proposal, as shown in Figure 9.

Figure 9 IDEA 3 product rendering proposal

4. Results and Recommendations

The results of this study show that among the three evaluation items (outer frame, propeller and lifting stand), the first choice for general consumers who chose drones according to appearance was the appearance of "outer frame", which had the evaluation result of 0.426 among all the evaluation items. The conclusion is that the results of this study using FCE and FAHP are all IDEA1, IDEA3, and IDEA2, so this result is reliable. Secondly, they considered the appearance of the "lifting stand" and expressed it with the evaluation result of 0.219. Thirdly, the evaluation result of the "propeller" was 0.027. Among these items, there are many accessories that can be added to the lifting stand on the market. For example, amphibious drones can add sponges to the lifting stand to enhance the buoyancy on the water surface. Therefore, the lifting stand will have new shapes and functions according to different purposes. The appearance of drones affects consumers' purchasing behavior. Even in daily life, the outer frames of drones with different numbers of axes seen by general consumers are very limited, mainly with four axes. With more and more drones of different purposes, they have evolved from three-axis drones to six-axis drones. For example, six-axis drones that carry goods to remote areas or high mountains, pesticide spraying drones or amphibious military drones reflect all the preferences and needs that can be further explored in the future. The weights of the evaluation items and the fuzzy membership degree of the parts in this study provide an objective reference for designers and manufacturers to determine the priority of different appearance designs or parts selection in the drone design stage. These three evaluation items cover 95% of the visual area of the drone's overall appearance; the application of this research method can overcome the

shortcomings of evaluating individual items instead of the overall appearance, as in the past. Since drones with new appearances are introduced every year, it is suggested to collect various appearances from time to time and increase the number of styles in each evaluation item, so as to observe the trends of the consumer market.

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