Demand analysis of quadcopter based on QFD

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Abstract. The quality and safety of quadcopters have always been the focus of attention in the drone industry. Carrying out safety and functional requirements analysis for it can better meet customer needs, reduce design costs, improve reliability and safety, and provide ideas for product design updates. This article uses the QFD (Quality Function Deployment) method to transform the safety and functional requirements of the quadcopter into product design, and provides guidance and reference opinions for improving product quality and safety. Based on the analytic hierarchy process, the article determines the technical difficulty through the analysis of technical characteristics, and analyzes the functional and safety requirements of the quality house model constructed after the improvement of the four-axis aircraft to provide a basis for the improvement of the quality characteristics of the four-axis aircraft.

Key Words. quadcopter, safety and functional requirements, QFD, house of quality

1. Introduction

In recent years, unmanned aerial vehicles have developed rapidly and are one of the focus areas in the aviation field. Typical representatives are quadcopters. The so-called four-axis aircraft refers to an aircraft with four engine power sources, which has strong anti-reconnaissance capabilities and can be widely used in the military field\textsuperscript{[1]}. In the past, the R&D department traditionally set what kind of product you want to develop. Such a design has brought about the diversification of the function of the drone and the occurrence of multiple failures. The reliability and safety of the drone have become people More focused goals. The QFD method is to ensure that the customer’s needs are reflected through a series of standardized methods, which is a systematic method that enables the customer's needs to be realized in the product design and production process\textsuperscript{[2]}. It transforms customer needs into corresponding technical requirements at every stage of product development and production. The Quality House Matrix turns demand into product or service design requirements and is used to plan production design, improve service quality, and ensure product quality\textsuperscript{[3]}. Compared with the previous design methods, QFD is more active in seeking goals and positioning from the design source. Its working ideas are consistent with the system design concept, and has formed a basic theory of quality control. The introduction of some advanced technologies in quality control greatly improve the scientificity and reliability.

In recent years, there have been some studies on the quality of unmanned aerial vehicles, such as applying the ANP (Analytic Network Process) to determine the importance value of customer needs to reduce the correlation between various target items and ensure the best results\textsuperscript{[4]}. Some literature proposes to use TRIZ (Theory of the Solution of Inventive Problems) theory for analysis and use standard construction coefficients, but this method is suitable for use when data information is lacking and can help find the best solution quickly\textsuperscript{[5]}. Zhou Guoxing proposed to use the QFD method to study
the quality of drones, convert the military needs of drones into their own process requirements, determine the method of controlling the technical quality of drones, and make them more used in the military\[6\]. Zhu Hu believes that the traditional quality house method has too many subjective opinions and cannot provide data with reasonable evidence. Therefore, the gray correlation degree is combined with it, and the gray correlation matrix is constructed to determine the importance degree and ensure the establishment of the quality house\[7\]. In addition, preliminary results have been achieved in the four aspects of design research using QFD model as a tool, QFD application in engineering design quality control and quality management, QFD-based design method research and QFD as an extension of the research method\[8\]. However, QFD technology is rarely analyzed in terms of the function or safety of the quadcopter. This article focuses on the development of the quadcopter's quality function as the main research content. By building the quadcopter's quality house and safety analysis, it analyzes the quadcopter's quality and functional requirements and improves the reliability and safety of the quadcopter. To improve the quality characteristics of the quadcopter.

2. Quality function deployment method
To use QFD to form and determine product requirements, you should master the following two keys: One is to reflect customer needs. According to customer needs to determine product quality requirements and technical characteristics. The second is to sort out and analyze the various needs of customers. Professional technical and management personnel will transform customer needs into product technical requirements, and produce a unified top-level technical requirements document. In order to ensure the realization of customer needs in the product.

The QFD analysis model is expressed in the form of a "house type" structure by using a matrix expansion icon, which is visually expressed as a "quality house". It includes seven parts: left wall, ceiling, room, floor, roof, right wall and basement. One of them is shown in Figure 1.

![Figure 1. The form of a house of quality.](image)

3. Construction of safety and functional requirements system for quadcopter
Taking a company’s quadcopter as the research object, the QFD method is used to study the different importance of the technical characteristics of safety and functional requirements and the output technical characteristics in the quality house, and the index system of the quadcopter is determined. Through a questionnaire survey of 100 individuals and units that have the need to purchase quadcopters and inquiries from related experts, the safety and functional requirements analysis level of the quadcopters is obtained\[10\], as shown in Figure 2.
Figure 2. Demand hierarchy diagram.

Through the YAAHP software to obtain the judgment matrix of each layer of demand indicators, taking the second layer of demand indicators as an example, as shown in Figure 3.

Figure 3. Judgment matrix of second-level demand indicators.

The weight of each layer of demand indicators calculated by the obtained customer importance is as follows:

(1) The relative weight of the second level and the first level.
Figure 4. First level single sorting diagram.

Obtained from the calculation results, the consistency ratio $CR=0.0665<0.10$, the consistency test is qualified. The relative weights of the requirements of the second level and the first level are shown in Table 1.

Table 1. Second-level demand weight table.

| Second level                  | High security and good reliability | Good flight performance | Good human nature | Good environmental protection | Good economy |
|-------------------------------|-----------------------------------|-------------------------|------------------|-------------------------------|--------------|
|                               | 0.5279                            | 0.2483                  | 0.1213           | 0.0521                        | 0.0504       |

(2) The relative weight of the third and second levels

Table 2. Third-level demand weight table.

| Third level and weight         | High security and good reliability | Good flight performance | Good human nature | Good environmental protection | Good economy                        |
|--------------------------------|-----------------------------------|-------------------------|------------------|-------------------------------|-------------------------------------|
| Low battery alarm function     | 0.1417                            |                         |                  |                               |                                     |
| long lasting                   | 0.1459                            |                         |                  |                               |                                     |
|                                | 0.1417                            |                         |                  |                               |                                     |
| The third level and weight     | 0.1399                            | 0.23                    | 0.24             | 0.43                          | 0.54                                |
| Overcharge protection          | 0.1261                            | 0.78                    | 0.43             | 0.18                          |                                     |
| Discharge protection           | 0.0236                            |                         |                  |                               |                                     |
| Low temperature operation     | 0.0359                            |                         |                  |                               |                                     |
| High temperature operation    | 0.2068                            |                         |                  |                               |                                     |
| Good stability                | 0.1381                            |                         |                  |                               |                                     |
| Self-check function           | 0.1261                            |                         |                  |                               |                                     |
It can be seen that the consistency ratio of the demand at the third level to the demand at the second level is below 0.1, indicating that it meets the requirements and is worthy of trust. By multiplying the weights of each lower-level index and the weight of the previous level index, the weight of each lower-level index in the entire index system can be obtained. The weights are shown in Figure 4.

![Figure 4. The weight of the third layer of demand indicators.](image)

### 4. Construction of a quadcopter quality house

#### 4.1 Correlation assessment between safety and functional requirements and technical characteristics

The importance of demand obtained through the above calculations is to ask experts and relevant vendors to determine the technical indicators and target values corresponding to the safety and functional requirements of the quadcopter[11]. The specific content and corresponding relationship are shown in Table 3.

**Table 3.** Safety and functional requirements and product technical indicators, technical characteristics target value correspondence table.

| Safety and functional requirements | Product Technical Index | Target value of technical characteristics of quadcopter |
|-----------------------------------|-------------------------|--------------------------------------------------------|
| Long voyage and long battery life | Life time and total battery power | 27 minutes, 4500mAh |
| Wind-resistant flight              | Maximum wind resistance GPS | Level 6, 4-5 stars |
| One-key return function real-time display | Target positioning accuracy | Decimeter level, except for airports and no-fly zones |
| Flight area restrictions           | No-fly zone              |                                                         |
| Low battery alarm function long lasting | battery power usage time | Less than 20%, 300 hours |
| Overcharge protection              | Battery charging protection function | Not more than 6.9A |
| Discharge protection               | Battery discharge protection function | |

The specific content and corresponding relationship are shown in Table 3.
4.2 Technical characteristics autocorrelation matrix

There must be a certain correlation between product design features. That is, a change in a design feature will affect other design features. This relationship represents the correlation matrix between product design characteristics, which can be represented by the roof of a quality house.

The following symbols are usually used:
"○"-positive correlation; "Х"-negative correlation; blank-irrelevant. The autocorrelation matrix of the quadcopter is shown in Figure 6.

![House of quality](Image)

**Figure 6. Autocorrelation matrix of four-axis aircraft.**

4.3 Correlation assessment between safety and functional requirements and technical characteristics

There are four kinds of relationships between safety and functional requirements and technical characteristics[12]: Strong correlation, indicated by the symbol "●"; Medium correlation, indicated by the symbol "◎"; Weak correlation, indicated by the symbol "○"; Irrelevant, indicated by a blank. The relationship between the two is shown in Table 4 with numerical values. The conclusions drawn from relevant investigations show that the correlation between the safety and functional requirements and technical characteristics of the quadcopter is shown in Figure 7.
Table 4. Relevance degree symbols and assignment.

| symbol | meaning            | Numerical value |
|--------|--------------------|-----------------|
| ●      | Strong correlation | 5               |
| ◎      | Moderately relevant| 3               |
| ○      | Weak correlation   | 1               |
| blank  | irrelevant         | 0               |

Figure 7. Correlation matrix of safety and functional requirements and technical characteristics.

4.4 Determine technical difficulty

Technical difficulty refers to the degree of difficulty in meeting various technical requirements. It is represented by a value of 1 to 5: 1-extremely low difficulty; 2-low difficulty; 3-average difficulty; 4-
high difficulty; 5—extremely difficult. For technical difficulty and whether to further develop technical requirements, the results obtained through expert consultation are shown in Table 5.

| Product Technical Index | Technical difficulty of quadcopter | Whether the technical difficulty of the quadcopter is unfolding |
|-------------------------|----------------------------------|---------------------------------------------------------------|
| Life time and total battery power | 5 | No |
| Maximum wind resistance | 3 | No |
| GPS | 2 | No |
| Target positioning accuracy | 2 | No |
| No-fly zone | 3 | No |
| battery power | 3 | Yes |
| usage time | 4 | Yes |
| Battery charging protection function | 4 | Yes |
| Battery discharge protection function | 4 | Yes |
| Maximum temperature limit | 3 | No |
| Minimum temperature limit | 3 | No |
| safety | 5 | No |
| Self-checking performance | 2 | No |
| price | 1 | No |
| Mechanical properties | 4 | Yes |
| Lowest cost | 1 | No |
| Power consumption per minute | 5 | No |
| Composite properties | 2 | No |
| Battery power | 2 | No |
| Heavy metal pollution | 1 | No |
| radiation | 1 | No |
| installation time | 1 | No |
| Response time | 1 | No |
| Customer attitude | 1 | No |
| The quantity of goods | 1 | No |

4.5 Construction of quality house for safety and demand analysis of quadcopter
Technical competitiveness analysis can help to improve the corresponding quality requirements. By conducting customer feedback, questionnaires, and industry surveys, we obtained the competition of each indicator in the technology, and expressed the value of 1-5 for the pros and cons of its competition level: 1—the competitiveness is extremely low; 2—low competitive ability; 3—general competitive ability; 4—strong competitive ability; 5—extremely strong competitive ability. By creating a safety and functional requirements planning table, as shown in Table 6, a quality house of safety and functional requirements for the four-axis aircraft is constructed, as shown in Figure 8.

| Safety and functional requirements | Importance | Improve pre-technological competitiveness | Improved technical competitiveness | Level increase rate | Revision importance | Relative importance |
|------------------------------------|------------|------------------------------------------|-----------------------------------|-------------------|-------------------|-------------------|
| Long voyage and long battery life  | 0.1277     | 5                                        | 5                                 | 1                 | 0.1277            | 0.1181            |
| Feature                          | Value 1 | Value 2 | Value 3 | Value 4 | Value 5 |
|---------------------------------|---------|---------|---------|---------|---------|
| Wind-resistant flight           | 0.0330  | 3       | 3       | 1       | 0.0330  |
| One-key return function         | 0.0285  | 2       | 2       | 1       | 0.0285  |
| real-time display               | 0.059   | 2       | 2       | 1       | 0.059   |
| Flight area restrictions        | 0.0222  | 3       | 3       | 1       | 0.0222  |
| Low battery alarm function      | 0.0748  | 3       | 4       | 1.33    | 0.09948 |
| long lasting                    | 0.077   | 4       | 5       | 1.25    | 0.09625 |
| Overcharge protection           | 0.0738  | 4       | 5       | 1.25    | 0.09225 |
| Discharge protection            | 0.0666  | 4       | 5       | 1.25    | 0.0833  |
| Low temperature operation      | 0.0125  | 3       | 3       | 1       | 0.0125  |
| High temperature operation     | 0.0189  | 3       | 3       | 1       | 0.0189  |
| Good stability                  | 0.1091  | 5       | 5       | 1       | 0.1091  |
| Self-check function             | 0.0729  | 2       | 2       | 1       | 0.0729  |
| Low cost and reasonable price   | 0.0111  | 1       | 1       | 1       | 0.0111  |
| Good material performance      | 0.0083  | 4       | 5       | 1.25    | 0.0104  |
| Low energy consumption          | 0.0034  | 1       | 1       | 1       | 0.0034  |
| Low power consumption           | 0.0276  | 5       | 5       | 1       | 0.0276  |
| Carbon fiber composite material | 0.0028  | 2       | 2       | 1       | 0.0028  |
| Low heat removal                | 0.0059  | 2       | 2       | 1       | 0.0059  |
| No lead, mercury and other heavy metal pollution | 0.0209 | 1 | 1 | 1 | 0.0209 |
| No radiation to human body      | 0.0225  | 1       | 1       | 1       | 0.0225  |
| Easy to disassemble            | 0.0448  | 1       | 1       | 1       | 0.0448  |
| Easy operation                  | 0.0375  | 1       | 1       | 1       | 0.0375  |
| Instant service and good after-sales service | 0.009 | 1 | 1 | 1 | 0.009 |
| Sufficient supply               | 0.0299  | 1       | 1       | 1       | 0.0299  |
|                                 |         |         |         |         |         |
5. Conclusion

Whether it is quality demand, quality management or quality improvement, the quality of products has always been the focus of attention in the field of product development and manufacturing. At present, there are many methods that can effectively solve the quality problems of products. The QFD method is one of the methods applied to quality problems in the field of product development and manufacturing, and has achieved certain results. This paper attempts to introduce the QFD method of quality functions into the analysis process of the safety and functional requirements of the four-axis aircraft. First, quantify the importance of safety and functional requirements through AHP, and use YAAHP software to analyze the importance of requirements; further determine the technical difficulty through technical characteristics analysis, obtain the technical characteristics autocorrelation matrix, and perform correlation between quality requirements and technical characteristics Sexual evaluation. On this basis, a technical competition analysis is carried out to establish the surrounding quality house of the aircraft, and the quality characteristics of the four-axis aircraft that need to be improved and improved during the analysis of safety and functional requirements are determined to meet the functional requirements. With the continuous development of technology and the continuous efforts of scholars, in the future, more effective methods and theories will appear in the field of product development and manufacturing to solve quality problems.

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