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Research Article

Research on the Design of Surgical Auxiliary Equipment Based on AHP, QFD, and PUGH Decision Matrix

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To improve the efficiency of medical staff in surgical operations and meet the physiological and psychological needs of surgeons, nurses, and patients during the operations, surgical auxiliary equipment is designed. This paper builds a design research model based on AHP (analytic hierarchy process), QFD (quality function deployment), and Platts conceptual decision matrix (PUGH decision matrix). Firstly, the user requirements are weighed through AHP analysis, and the design elements are prioritized based on the weight values. Then, QFD is used to analyze the design features of surgical auxiliary equipment from the aspects of structure, function, and shape, and a house of quality is established to get the significance of design features. Finally, the PUGH decision matrix is constructed to screen and evaluate multiple schemes, and the optimal design scheme is obtained. From the perspective of user requirements and product design characteristics, the significance of design elements is analyzed and calculated, which guides the design practices to complete the innovative design of surgical auxiliary equipment. The combination of AHP, QFD, and PUGH decision matrices are introduced into the innovative design of surgical auxiliary equipment, effectively avoiding subjective factors in product design, improving the scientific nature of the design, and providing new methods and ideas for the design and research of surgical auxiliary equipment and similar products.

1. Introduction

In the process of surgical operation, due to the long operation time and the complicated operation process, medical staff will bear great physical and psychological pressure for a long time [1]. Surgical auxiliary equipment can provide more accurate positioning, detailed auxiliary operation, and intuitive real-time patient information, helping doctors to complete surgical operations, reducing the work pressure of medical staff, and prolonging their professional life. Surgical auxiliary equipment is a product in the advanced medical field [2], which is mainly used in surgery, rehabilitation therapy, and medical training.

In the past 20 years, experts from all over the world have been devoted to the research of minimally invasive surgical robotic technology and have achieved remarkable results, such as Da Vinci, Zeus, and AcuBot, Aesop in the United States, Neurobot in the United Kingdom, Active Troca, and UT series [3–7]. The Probot [8] developed by the Royal Institute of Technology in 1980 is used for minimally invasive urinary surgery, and it is the first device in the true sense for auxiliary surgery. In 1999, the Da Vinci [9] surgical equipment system, which was successfully developed by Intuitive Surgical Company in the United States, was composed of a surgeon's console, a robotic arm system, and an imaging system. The worst positioning accuracy was 2.78 mm. In 2014, the Da Vinci single-hole surgical equipment developed by the American Intuitive Robot Company consists of a 3D high-definition camera and three surgical instruments. It is the only commercial single-hole surgical equipment system at present. The surgical equipment "Revo-I" [10–12] developed by Meere and Severance Hospital in 2017 includes a master console, four slave operating arms, and an imaging system. The system is more compact and basically the same in terms of surgical performance. Research on surgical auxiliary equipment in

China started late, and research on the use of robotics in assisted surgery began in 1997. At present, there are mainly research institutions such as Harbin Institute of Technology, South China University of Technology, and Nanjing University of Technology, which have put forward preliminary concepts for the design of surgical auxiliary equipment [13]. Some of the more prominent research results include the following: Fu and Pan [14] analyzed the research status of minimally invasive surgical robots, Li et al. [15] conducted experiments on the palpation function of the assisted minimally invasive surgery system, Wan et al. [16] studied the innovative design of medical devices from the perspective of fusion of form and function, and Wang et al. [17] analyzed the research progress of puncture robots in assisted minimally invasive surgery. It can be seen that the research on surgical auxiliary equipment has gradually received attention and focus, but the special needs of surgeons, nursing staff, and patients are rarely considered in the existing design research, and there is a lack of hierarchical analysis and product design for user needs. Characteristic analysis cannot effectively provide design decisions for surgical aids. Therefore, this paper will carry out research on the design of surgical auxiliary equipment, which plays an important role in reducing the work pressure of surgical medical staff and improving the working efficiency of medical staff and is of great significance to the design and development of similar surgical auxiliary products.

In addition, in most of the previous literature on product innovation design and design evaluation, questionnaires were usually used in the process of obtaining user needs and product attributes [18]. There is no doubt that this traditional method provides high-quality results, but it also has some drawbacks such as lack of objectivity and lack of quantitative basis [19–21]. However, with the integration between multidisciplinary methods and design in the context of industrial manufacturing and the information age, more and more quantitative methods are also being applied in product innovation and design, through which accurate, objective, and realistic user needs and product attributes can be obtained [22]. Some scholars have also applied different quantitative methods to product innovation design or product evaluation in the last two years. Oey et al. [23] sought a way to accommodate user requirements in their product and process improvement, Lu et al. [24] constructed a product form evolution design method integrating the TRIZ contradiction matrix to simplify the product form evolution process, Liu et al. [25] proposed a conceptual design evaluation method based on Z-numbers, Yue et al. [26] improved the evaluation system of the design of household medical products for the elderly, Zhang et al. [27] proposed a lead user identification method based on user behavior data and contribution content analysis, Wang et al. [28] proposed a product evaluation method that combines natural language processing techniques and fuzzy multi-criteria decision-making, and Wurster et al. [29] used consumers as a valuable source of information to specify features of the output of an innovative CE ecosystem. The overall comparison between this article and previous studies is shown in Table 1. In this paper, the combination of AHP, QFD, and PUGH decision matrix methods is introduced into the innovation design of surgical auxiliary equipment, which effectively avoids the subjectivity in product innovation design and improves the scientific nature of surgical auxiliary equipment design. Section 2 briefiy describes the research methodology used in this paper and introduces the proposed framework, Section 3 completes the hierarchy of needs model construction and acquires user requirements, Section 4 identifies the design elements, and Section 5 verifies the effectiveness of the framework through case analysis. The last part summarizes this research and puts forward the problems to be further researched and solved in the future.

2. Method

2.1. AHP Design Process. Analytic hierarchy process is a research method proposed by American operations researcher Satty, which is widely used in various fields related to decision-making [30]. Analytic hierarchy process uses a tree-like hierarchical structure to compare elements at the same level horizontally and vertically and compare elements at different levels vertically, so as to find the best solution [31–33]. In the system constructed by using the AHP, it is required to calculate the relative importance of the interrelated factors layer by layer, compare them in pairs, and form a judgment matrix as the basis for the calculation and analysis [34]. Judgment matrix is the process of quantifying human comparative judgments. The judgment matrix is of great significance as it is the basis for calculating the weights in AHP, which determines the relative importance of each indicator by making a two-by-two comparison of all the indicators in the indicator evaluation system. The judgment matrix is the only source of information in the AHP, and its establishment will have a decisive impact on the final results. The judgment matrix used in this paper is the most classic method in hierarchical analysis and is based on Satty's 1–9 scale [12]. According to the hierarchical structure proposed by Satty, we will analyze and compare the modeling design from the target layer, the criterion layer, and the scheme layer. In the judgment matrix, the relevant elements are compared with each other for a certain objective. The scale values of the judgment matrix are shown in Table 2.

The judgment matrix is constructed by comparing the elements of the evaluation indicators at each level. The judgment matrix is also an important basis for the calculation of the weighting. A is a judgment matrix to indicate the relative importance of each indicator at the same level. Obviously, this judgment matrix is a square matrix, and we used the square root method to calculate the weighting value of the judgment matrix. Judgment matrix (1) is obtained through a two-by-two comparison of the secondary evaluation indicators:

Table 1: An overall comparison between this proposed approach and other studies.

Author and reference	User requirement	Design characteristic	Case evaluation	Major contributions
This paper	AHP	QFD	PUGH decision matrix	Proposed a product design and evaluation method based on AHP, QFD, and PUGH decision matrix, designed a surgical auxiliary equipment to verify the scientificity and effectiveness of the method
Oey et al. [23]	KE	—	QFD	Sought a way to accommodate user requirements in their product and process improvement
Lu et al. [24]	Ergonomic simulation	TRIZ	—	Constructed a product form evolution design method integrating the TRIZ contradiction matrix to simplify the product form evolution process
Liu et al. [25]	—	Z-AHP	TOPSIS	Proposed a design evaluation method based on Z-numbers
Yue et al. [26]	—	—	AHP	Improved the evaluation system of the design of household medical products for the elderly
Zhang et al. [27]	Text-mining techniques	—	GRA	Proposed a lead user identification method based on user behavior data and contribution content analysis
Wang [28]	NLP	—	F-TOPSIS	Proposed a product evaluation method that combines NLP and fuzzy multi-criteria decision-making
Wurster et al. [29]	Online survey	Focus group	—	Used consumers as a valuable source of information to specify features of the output of an innovative CE ecosystem

AHP: analytic hierarchy process, QFD: quality function deployment; PUGH decision matrix: platts conceptual decision matrix, KE: Kansei engineering, TRIZ: the theory of inventive problem solving, NLP: natural language processing, TOPSIS: Technique for Order Preference by Similarity to an Ideal Solution, and GRA: grey relational analysis.

Table 2: Judgment matrix scale.

Scale assignment (i and j)	Importance	Scale description
1	Equally important	Metric i and j are equally important
3	Slightly important	Metric i is slightly more important than metric j
5	Clearly important	Metric i is clearly more important than metric j
7	Strongly important	Metric i is strongly more important than metric j
9	Absolutely important	Metric i is absolutely more important than metric j
2, 4, 6, 8	Median	Compromise

$$A = \begin{vmatrix} 1 & a12 & \cdots & a1i & \cdots & a1j & \cdots & a1n \\ a21 & 1 & \cdots & a2i & \cdots & a2j & \cdots & a2n \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ ai1 & ai2 & \cdots & 1 & \cdots & aij & \cdots & ain \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ aj1 & aj2 & \cdots & aji & \cdots & 1 & \cdots & ajn \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ an1 & an2 & \cdots & ani & \cdots & anj & \cdots & 1 \end{vmatrix} = (aij)_{n\times n}. \quad (1)$$

After obtaining the judgment matrix of each level, we solve the level weight vector. The summation formula is as follows:

$$ai = \sum_{k=1}^{n} eik\,(i = 1, 2, \ldots, n). \quad (2)$$

The elements of each column of the judgment matrix are normalized, and the calculation formula is as follows:

$$aij = \frac{aij}{\sum_{k=1}^{n} akj}\,(i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, n), \quad (3)$$

$$\omega i = \frac{\omega i}{\sum_{j=1}^{n} \omega j}\,(i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, n). \quad (4)$$

To get the largest eigenvector under a single criterion, we calculate the largest eigen root of the matrix; the calculation formula is as follows:

$$\lambda\max = \frac{1}{n}\sum_{i=1}^{n} A\omega i/\omega i, i = 1, 2, \ldots, n. \quad (5)$$

After solving the judgment matrix and weight of each element, to ensure the scientificity and standardization of evaluation, it is necessary to test the consistency of evaluation results. CI is the consistency index, CR is the consistency ratio, and RI is the random consistency index. The consistency index and the consistency ratio are calculated as follows:

$$CI = \frac{(\lambda \max - n)}{(n-1)}, \tag{6}$$

$$CR = \frac{CI}{RI}. \tag{7}$$

The average random consistency index *RI* was searched, and the average random consistency index in this paper are all within order 15, so a scale of average random consistency index from order 1 to 15 is given. The specific value was shown in Table 3. Here, $\lambda_{\max}$ is the maximum eigenvalue in matrix A. When $CR \leq 0.1$, the result of the hierarchical total ordering is considered to be consistent with the consistency judgment; otherwise, the judgment matrix needs to be adjusted or reconstructed until the total ordering meets the consistency judgment. Table 3 is reproduced from the study by Yue et al. [26].

2.2. QFD Method. The QFD method was proposed by Japanese quality expert Professor Yoji Akao [35]. This theory is a systematic innovation method that is driven by user requirements and transforms user requirements into various technical elements of products [36–39]. The QFD method is expressed in the form of an intuitive matrix framework that substitutes user requirements into the framework of a product design quality house, and through the quality house analysis, results in the output information such as product design characteristics assessment and priority are used to transform requirements [40]. The product design quality house is shown in Figure 1.

2.3. PUGH Decision Matrices. The PUGH decision matrix, also known as the conceptual decision matrix, is a quantitative decision analysis tool that can be used to evaluate various stages of a decision [41]. The construction of the PUGH decision matrix is to determine a benchmark scheme from the schemes participating in the evaluation, and its various indicators are set as "*S*." The higher-ranked schemes are then analyzed in detail to determine the final scheme [42]. The final score calculation formula of the PUGH decision matrix is as follows:

$$V_i = \sum_{i=1}^{n} H j V_{ij}. \tag{8}$$

2.4. Design Method Model Based on AHP, QFD, and PUGH Decision Matrix. In this paper, a design method model based on AHP, QFD, and PUGH decision matrix is constructed. First, the initial qualitative requirements of users are transformed into quantitative weight indicators through AHP, and then, QFD is applied to combine the quantitative requirements indicators and transform such requirements indicators into design characteristics. Finally, the PUGH decision matrix is used to evaluate the design solution based on such design characteristics, which guides the final product design practice. Combining AHP, QFD, and PUGH decision matrix methods can make product design more scientific and objective in the innovation process. The design method model based on AHP, QFD, and PUGH is shown in Figure 2.

Table 3: Consistency index of the average random number.

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.52	0.89	1.12	1.26	1.26	1.41	1.46	1.49	1.52	1.54

3. User Requirements Acquisition

3.1. User Requirement Hierarchy Model Construction. The user requirement of product design is analyzed based on the AHP. The hierarchical model of surgical auxiliary equipment design needs is divided into the target layer, criterion layer, and scheme layer. The target layer is the user requirements for surgical auxiliary equipment design, denoted by the letter A. The first-level criterion layer contains four indicators, which are B1 aesthetics, B2 safety, B3 usability, and B4 practicality. The second-level criterion layer is the result of the specific development of user requirements, which consists of 20 specific requirement design elements. The decision model for the design requirements of surgical auxiliary equipment is shown in Figure 3.

3.2. Solving for Index Weights. For the research at the criterion level, considering the difficulty of understanding the form of the judgment matrix and too many evaluation scales, we adopted the expert scoring method. A total of 30 scoring questionnaires were distributed, and the expert groups were from occupational surgeons and medical staff, teachers of design disciplines, and graduate students of design or medical disciplines. The following takes the weight determination of the first-level criterion layer as an example to briefly describe the process of scoring the survey results. Question 1 of the questionnaire is "How would you rate the requirement for "reasonable modeling size" in the design of surgical surgical auxiliary equipment design? A 4 points, B 3 points, C 2 points, and D 1 point." We performed a weighted average of the scoring results and the calculated data (the decimal point is rounded off) to obtain the weight values of the first criterion layer indicators. For example, the calculation and score for "reasonable modeling size" is $(12 \times 4) + (11 \times 3) + (5 \times 2) + (2 \times 1) = 93$. The results of the user questionnaire are shown in Table 4. Here, the scores in the table correspond to the number of people who chose that number. The values of the judgment matrix and weight were calculated using Yaahp software, a sufficiently sophisticated comprehensive evaluation assistant that provides model construction and analytical calculations for the decision-making process. The judgment result matrix and calculation weight of each level are shown in Tables 5–9.

The calculation results show that all judgment matrices pass the consistency test. By normalizing the weight value of the criterion layer, the comprehensive weight of the judgment matrix of the second criterion layer is obtained. The comprehensive weight of the second criterion layer is shown in Table 10.

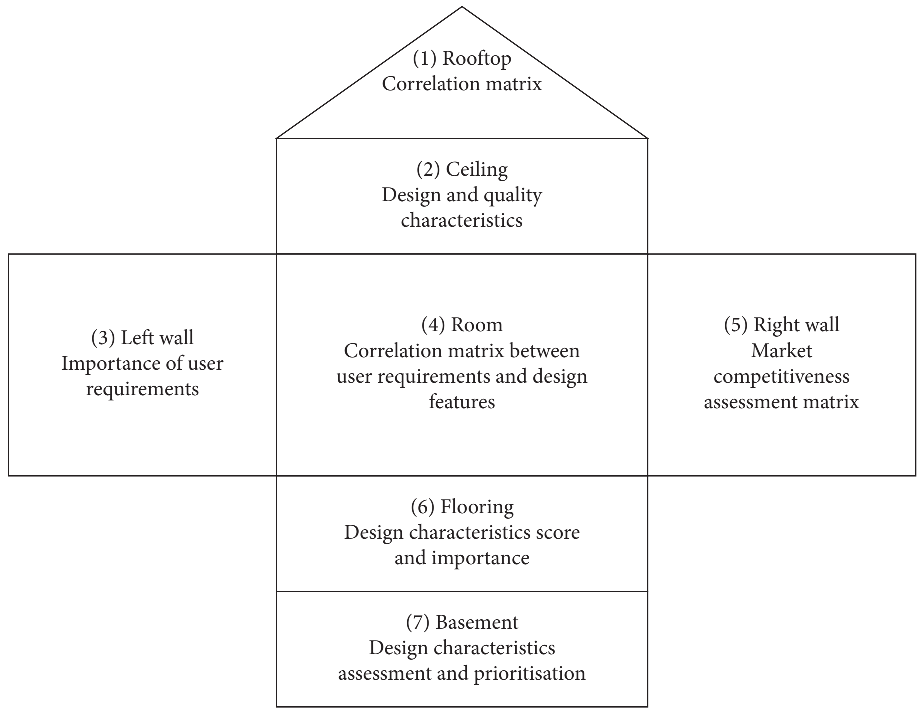

Figure 1: Product design quality house.

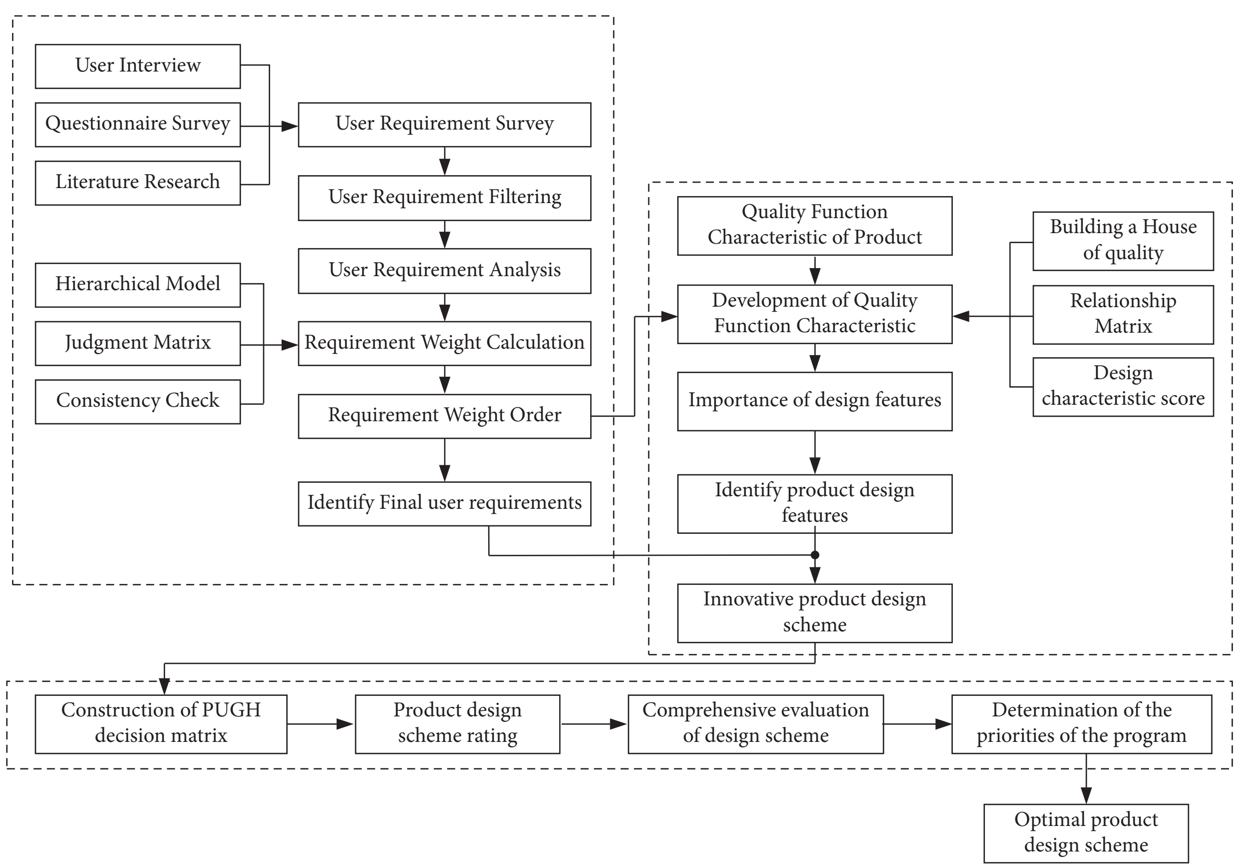

Figure 2: Design method model of AHP, QFD, and PUGH.

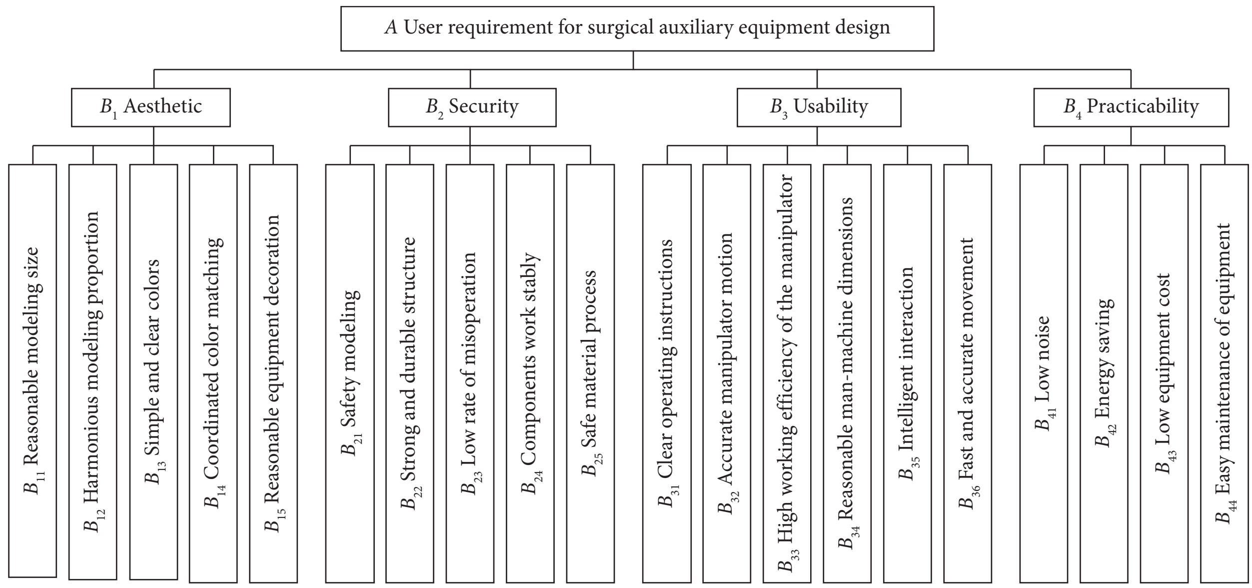

Figure 3: Decision model for design requirements of surgical auxiliary equipment.

Table 4: Questionnaire survey results.

Indicators	4 points	3 points	2 points	1 point	Scores
Reasonable modeling size	12	11	5	2	93
Harmonious modeling proportion	12	13	3	2	95
Simple and clear colors	9	7	11	3	82
Coordinated colour matching	10	8	10	2	86
Reasonable equipment decoration	7	14	6	3	85
Safe modeling	23	7	0	0	113
Strong and durable structure	13	8	7	2	92
Low rate of misoperation	25	4	1	0	114
Components work stably	13	7	7	3	90
Safe material process	8	7	10	5	78
Clear operating instructions	20	9	1	0	109
Accurate manipulator motion	17	8	5	0	102
High working efficiency of the manipulator	15	12	2	1	101
Reasonable man-machine dimensions	13	10	5	2	94
Intelligent interaction	12	10	6	2	92
Fast and accurate movement	7	10	10	3	81
Low noise	8	10	9	3	83
Energy saving	4	6	12	8	66
Low equipment cost	6	7	13	4	75
Easy maintenance of equipment	7	7	12	4	77

Table 5: Judgment matrix and weight of design for surgical auxiliary equipment.

A	B_1	B_2	B_3	B_4	Weight	Consistent results
B_1	1.0000	0.3333	0.5000	4.0000	0.1810	0.0366
B_2	3.0000	1.0000	2.0000	5.0000	0.4688	
B_3	2.0000	0.5000	1.0000	4.0000	0.2833	
B_4	0.2500	0.2000	0.2500	1.0000	0.0670	

4. Identification of Design Elements

4.1. Product Quality Function Deployment. The overall structure of the surgical auxiliary equipment studied in this paper includes an operation part, an interface display part, an equipment body, a manipulator part, and a moving part, each of which contains multiple design features. Taking the operation part as an example, the design features of the operation part include the operation form of the operating table and the size ratio of the operating table. The design features of surgical auxiliary equipment are shown in Figure 4.

4.2. Product Design Quality House Construction. Design quality house is constructed by combining user requirements and product quality function deployment to build a surgical auxiliary equipment quality house, excluding design characteristics that have less influence on the design modeling and structure, retaining the operation part, equipment

Table 6: Judgment matrix and weight of aesthetic.

B_1	B_{11}	B_{12}	B_{13}	B_{14}	B_{15}	Weight	Consistent results
B_{11}	1.0000	0.5000	4.0000	3.0000	3.0000	0.2822	
B_{12}	2.0000	1.0000	5.0000	4.0000	3.0000	0.4124	
B_{13}	0.2500	0.2000	1.0000	0.2500	0.5000	0.0574	0.0458
B_{14}	0.3333	0.2500	4.0000	1.0000	2.0000	0.1460	
B_{15}	0.3333	0.3333	2.0000	0.5000	1.0000	0.1020	

Table 7: Judgment matrix and weight of security.

B_2	B_{21}	B_{22}	B_{23}	B_{24}	B_{25}	Weight	Consistent results
B_{21}	1.0000	4.0000	0.5000	4.0000	5.0000	0.3162	
B_{22}	0.2500	1.0000	0.2500	2.0000	3.0000	0.1243	
B_{23}	2.0000	4.0000	1.0000	4.0000	5.0000	0.4172	0.0403
B_{24}	0.2500	0.5000	0.2500	1.0000	2.0000	0.0868	
B_{25}	0.2000	0.3333	0.2000	0.5000	1.0000	0.0555	

Table 8: Judgment matrix and weight of usability.

B_3	B_{31}	B_{32}	B_{33}	B_{34}	B_{35}	B_{36}	Weight	Consistent results
B_{31}	1.0000	3.0000	3.0000	4.0000	4.0000	5.0000	0.3780	
B_{32}	0.3333	1.0000	2.0000	3.0000	4.0000	5.0000	0.2335	
B_{33}	0.3333	0.5000	1.0000	3.0000	4.0000	5.0000	0.1853	0.0642
B_{34}	0.2500	0.3333	0.3333	1.0000	2.0000	4.0000	0.0983	
B_{35}	0.2500	0.2500	0.2500	0.5000	1.0000	3.0000	0.0675	
B_{36}	0.2000	0.2000	0.2000	0.2500	0.3333	1.0000	0.0373	

Table 9: Judgment matrix and weight of practicality.

B_4	B_{41}	B_{42}	B_{43}	B_{44}	Weight	Consistent results
B_{41}	1.0000	3.0000	2.0000	5.0000	0.4723	
B_{42}	0.3333	1.0000	0.5000	3.0000	0.1697	0.0191
B_{43}	0.5000	2.0000	1.0000	4.0000	0.2854	
B_{44}	0.2000	0.3333	0.2500	1.0000	0.0725	

Table 10: Comprehensive weight and consistency test of secondary criterion layer.

Primary index	Secondary index	Single weight	Combined weights	Importance ranking	Consistent results
	B_{11}	0.2822	0.0511	8	
	B_{12}	0.4124	0.0746	4	λmax = 5.2050
B_1	B_{13}	0.0574	0.0104	19	CR = 0.0458
	B_{14}	0.1460	0.0264	12	CR < 0.1
	B_{15}	0.1020	0.0185	16	
	B_{21}	0.3162	0.1482	2	
	B_{22}	0.1243	0.0583	6	λmax = 5.1805
B_2	B_{23}	0.4172	0.1956	1	CR = 0.0453
	B_{24}	0.0868	0.0407	9	CR < 0.1
	B_{25}	0.0555	0.0260	13	
	B_{31}	0.3780	0.1071	3	
	B_{32}	0.2335	0.0662	5	
B_3	B_{33}	0.1853	0.0525	7	λmax = 6.4043
	B_{34}	0.0983	0.0278	11	CR = 0.0642
	B_{35}	0.0675	0.0191	14	CR < 0.1
	B_{36}	0.0373	0.0106	18	
	B_{41}	0.4723	0.0316	10	
B_4	B_{42}	0.1697	0.0114	17	λmax = 4.0511
	B_{43}	0.2854	0.0190	15	CR = 0.0191
	B_{44}	0.0725	0.0049	20	CR < 0.1

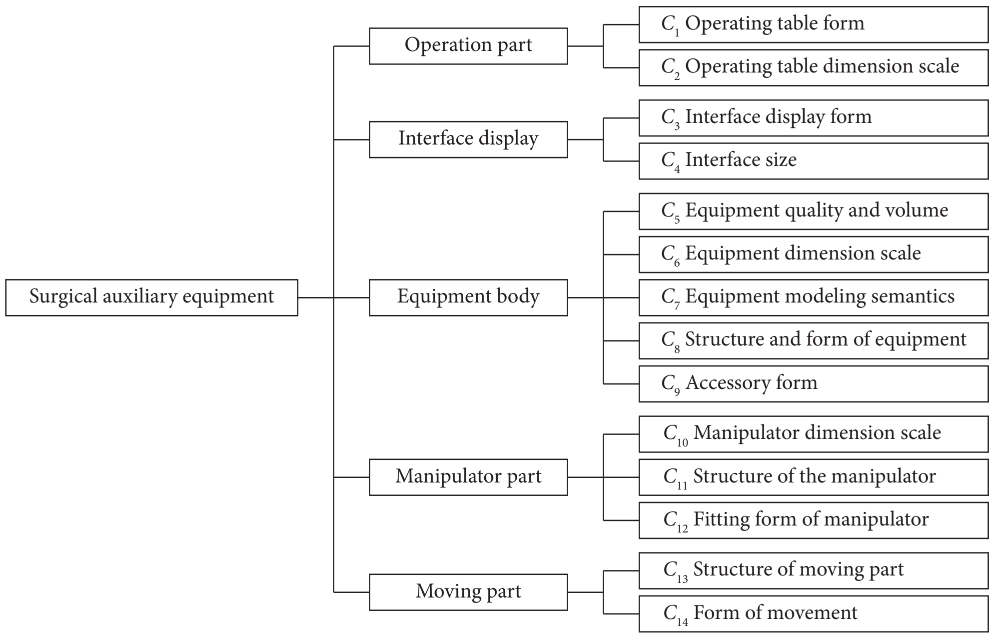

Figure 4: Design features of surgical auxiliary equipment.

body, and manipulator part as design characteristics of the quality house, and bringing them into the surgical aid design quality house together with user requirements to calculate the comprehensive weight value and design characteristic importance. The surgical auxiliary quality house is shown in Table 11, and the values are expressed on a 5-point scale.

5. Case Analysis

5.1. Selection of Design Options. A surgical auxiliary equipment was designed based on the results of user requirements and the importance of product design features. To avoid the subjectivity of the design solution, a comprehensive evaluation of the existing surgical aid devices on the market was conducted, and the evaluation group consisted of 10 experts. After initial screening and discussion by the group, four medical devices currently available on the market were identified, and these four devices and the device designed and studied in this paper together formed the evaluation scheme. After comprehensive analysis, these 5 surgical auxiliary instruments were subjected to comprehensive evaluation. The PUGH decision matrix of surgical auxiliary equipment is constructed as shown in Table 12.

We set option A as the control option and compare the other options with option A. This gives a combined net score for each option. The combined net score is calculated based on the PUGH decision matrix, and the "+," "−," and "*S*" symbols are used to rate the options, where "+" indicates that the option is better than the benchmark option in this indicator and is scored as "+1"; "−" indicates that it is worse than the benchmark option and is scored as "−1"; and "S" indicates the same and the score remains unchanged. The result of the calculation is as follows: a combined score of scheme A is "0" points, scheme B is "−2" points, scheme C is "1" point, scheme D is "−1" point, and scheme D is "2" points. The scores for each option are ranked in descending order, and the two lowest-ranked options are suspended. Based on the scoring of the options, Options B and D are suspended and Options A, C, and E are entered into the integrated conceptual design options assessment stage.

5.2. Evaluation of Design Solutions. To ensure the objectivity of the assessment, the screened solutions were rated according to the 5 levels of evaluation criteria and a concept-scoring PUGH decision matrix was constructed. Combining the corresponding weight values of each indicator, the weighted score corresponding to each scheme indicator was calculated by formula (7), and the best scheme was derived from the final scores. The results are shown in Table 13.

From the results of the combined scoring data in the table, the design options for surgical auxiliary equipment are ranked as follows: Option $E >$ Option $C >$ Option A. In order to further optimize the design options, the results of the above study were applied to the design of surgical auxiliary equipment in practice and improved in detail part by part. The analysis is presented in the following.

In the design of user consoles, low misoperation rates and clear operating instructions are the main user requirements and the dimension scale of the operating table is an important design feature. The location, size, colour, and background lighting of the keys are designed according to their function and frequency of use, with important and frequently used keys placed in the centre of the console interface, the knob or key set to a size slightly larger than other regular keys, and special background lighting given to the keys. This will improve the efficiency of the operation and reduce the rate of misuse. The overall design of the operating table has strict dimensional requirements. A small

Table 11: Design quality house of surgical auxiliary equipment.

User requirements		Operation part		Equipment body			Manipulator part			Combined weights
		C_1	C_2	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	
B_1 (0.1810)	B_{11} (0.2822)		9	9	5	7	5	9	7	3	0.0884
	B_{12} (0.4124)		9	9	5	7	7	9	7	3	0.1338
	B_{13} (0.0574)	1			7	3	1			1	0.0043
	B_{14} (0.1460)	1			7	1	3		1	3	0.0135
	B_{15} (0.1020)				3	3	7		1		0.0071
B_2 (0.4688)	B_{21} (0.3162)		5	5	7	9	7	5	9	5	0.2468
	B_{22} (0.1243)		3	3		9		3	9	3	0.0560
	B_{23} (0.4172)	9	5			1	1	1	1		0.1128
	B_{24} (0.0868)	3				3	5		3	5	0.0248
	B_{25} (0.0555)				1	5	3		5		0.0117
B_3 (0.2833)	B_{31} (0.3780)	9	7	1		1		3	3		0.0823
	B_{32} (0.2335)			1		3	5	9	9	7	0.0721
	B_{33} (0.1853)			1		3	5	9	9	9	0.0605
	B_{34} (0.0983)		9	9		5		9	5		0.0329
	B_{35} (0.0675)	9		3			1			5	0.0110
	B_{36} (0.0373)			1		3	1				0.0010
B_4 (0.0670)	B_{41} (0.4723)	1					7		1	7	0.0162
	B_{42} (0.1697)	5				3	7	1			0.0051
	B_{43} (0.2854)		5	7		5	5	3	1	1	0.0165
	B_{44} (0.0725)	1	1	3		1	7	1		5	0.0030
Importance score		3.14	4.12	2.74	2.01	4.07	3.56	3.96	4.81	2.88	
Importance ranking		6	2	8	9	3	5	4	1	7	

Table 12: PUGH decision matrix of surgical auxiliary equipment.

Evaluation indicators	Design solutions for surgical auxiliary equipment				
	Option A	Option B	Option C	Option D	Option E
					
Operation part	S	S	+	S	+
Equipment body	S	–	–	S	S
Manipulator part	S	–	+	–	+
Total "+"	0	0	2	0	1
Total S	3	0	0	2	0
Total "–"	0	1	1	1	0
Net score	0	–2	1	–1	2
Ranking	3	5	2	4	1
Whether to continue	Continue	Suspend	Continue	Suspend	Continue

size of the operating table will affect the size of the keys, while a large size will reduce the efficiency of the operation of medical and nursing staff. The design details of the user console are shown in Figure 5.

In the design of a manipulator, accurate manipulator motion and high working efficiency of the manipulator are the main requirements of the user and the structure of the manipulator is an important design feature. Increasing the number of robotic arms and their arrangement can effectively improve the accuracy of robotic arm movement and work efficiency. The number of manipulators is designed to be 4 and can complete simple operations such as picking or transferring separately, improving the working efficiency of the robotic arms. The structure of the robotic arm needs to be in line with the visual needs of the medical staff, the emotional needs of the patient, and the traditional medical robotic arm modeling rules. The design details of the manipulator are shown in Figure 6.

In the design of the equipment body, safe modeling and harmonious modeling proportions are the main requirements of the user and the structure and form of equipment is an important design features. Safe modeling is not only a requirement for the shape of the main body of the equipment but also for the details of the components, while the

Table 13: Comprehensive score of surgical auxiliary equipment.

Evaluation indicators	Importance	Design options		
		Option A	Option C	Option E
Operating table form	3.14	4	4	4
Operating table dimension scale	4.12	3	5	5
Equipment dimension scale	2.73	5	2	3
Equipment modeling semantics	2.01	2	3	4
Structure and form of equipment	3.99	4	3	4
Accessory form	3.56	4	2	3
Manipulator dimension scale	3.94	3	5	4
Structure of the manipulator	4.81	2	4	3
Fitting form of the manipulator	2.88	4	3	4
Final scores		105.75	111.32	117.74

Figure 5: Design details of the user console.

Figure 6: Design details of the manipulator.

Figure 7: Design details of the equipment body.

main body of the equipment and special components should also have clear safety markings and product indicators. The overall shape of the main body of the equipment should follow the design principles of medical product modeling. With the most widely used white as the main colour for medical products and black and gray as a secondary colour,

Figure 8: Design renderings of surgical auxiliary equipment.

the equipment can give a safe and stable image. The design details of the equipment body are shown in Figure 7.

Finally, according to the user requirements, combined with the design features and design elements, the team used brainstorming to conceptualize, discuss, and filter to determine the final design solution. The design of the optimized surgical auxiliary equipment is shown in Figure 8.

6. Conclusion

This paper combines AHP, QFD, and PUGH decision matrix methods to construct a product design method model. The AHP is used to obtain user requirement weights, the QFD is applied to obtain the importance of product design features, and the PUGH decision matrix is used to select and evaluate design solutions. The introduction of this methodological model provides a quantitative basis for product design, which can effectively improve accuracy and scientific validity. Taking surgical auxiliary equipment as an example, the user needs are filtered and analyzed from the perspectives of aesthetics, safety, aesthetics, and practicality, and the weights of user needs are ranked. Combined with the product design characteristics, the surgical auxiliary equipment is designed from the aspects of structure, function, and shape and the design scheme is completed and comprehensively evaluated to optimize the design scheme. Subsequent research can design and develop surgical auxiliary equipment from different perspectives, further reduce the pressure on surgeons, nurses, and patients, improve surgical efficiency, and make this type of equipment more efficient and intelligent. The design methodology can also be used as a reference for the design of related medical equipment. Due to the limitations of this study, this research method needs to be gradually improved in future research. According to the product type, gray system theory, TRIZ theory, structural equation model, axiomatic design, and fuzzy comprehensive evaluation can be considered to optimize and expand the design method model.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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