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Research on Design of Intelligent Agricultural Harvester Based on QFD and AHP

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Abstract: *In order to optimize the design of intelligent agricultural harvester, improve the backward situation of agricultural machinery design in western Guangdong, and explore new research methods to guide the design of modern agricultural harvester. Using QFD (Quality Function Deployment Principle), this paper analyzes the form and functional characteristics of the intelligent agricultural harvester, and from the aspects of optimizing the product appearance, product function, product quality and man-machine optimization of the intelligent agricultural harvester, establishes a house of quality matrix suitable for agricultural harvesters in western Guangdong. This paper analyzes the mapping relationship between the quality function and the design features of the intelligent agricultural harvester, determines the design feature factor framework and weight of the intelligent agricultural harvester, and obtains the importance values of the function features and design elements, so as to establish the priority of the design resources and function configuration optimization, and then guide the example design of the intelligent agricultural harvester. AHP (Analytic Hierarchy Process) is used to verify that the characteristic factors of QFD design are consistent with the user evaluation data, which proves that the design example scheme of intelligent agricultural harvester is feasible to some extent, and provides a new research idea for the design of the same type of agricultural harvesting equipment.*

Keywords: *Product design; Intelligent agricultural harvester; Features; QFD; AHP*

1. Introduction

At present, the biggest development gap between China and developed countries has been concentrated in the development of agricultural technology, and the application research of intelligent agricultural mechanized harvester design is of great significance [1]. The design and research history of agricultural harvesters in modern developed areas such as Australia, the United States and South America is longer than that in China. The harvesters are mature in terms of function, manufacturing technology and appearance, and have entered the intelligent era. As the world's No.1 agricultural industry, the design of modern harvesters started relatively late. With the rapid development of agricultural mechanization and automation in China, more and more brands have invested in harvester research and development and achieved certain results, but there is still a big gap between the overall industrial design and the international advanced level. At present, domestic harvester design and research focus on specific mechanical technologies such as harvesting methods, cutting strength, harvesting efficiency, power control, etc. At present, these specific mechanical technologies are gradually approaching maturity. In contrast, there is little research on how to integrate intelligent factors into the industrial design optimization of the whole harvester, so how to integrate various technologies into the whole design of intelligent harvesters is an important research problem to be solved urgently [2]. In this paper, 4GQ-1 agricultural harvester, the main force of a representative leading agricultural machinery enterprise in western Guangdong Province, is taken as the research object, and the overall product industrial design optimization research is carried out. The sugarcane harvesters used in western Guangdong Province all come from the products developed by this agricultural machinery enterprise. As the main sugarcane planting area in western Guangdong, the crop output is in the leading position in China [1], but the design level of intelligent agricultural harvester is still in the middle and lower level among the same type of products in China, which is obviously behind the design level of modern large-scale industrial machinery industry. There are some problems, such as unreasonable technology integration, inaccurate function matching, low recognition of color and shape, inconvenient operation of human-computer interaction and so on. Through QFD in-depth analysis and sorting out the scores of design elements such as product shape, color, function, product quality, man-machine optimization, etc. by agricultural machinery experts, a quality function model is established to guide the industrial design optimization of intelligent

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agricultural harvester. Because the importance score of QFD functional features is subjective evaluation with certain uncertainty [3], in order to verify the rationality of case design under the guidance of QFD. Use objective and rigorous AHP data to judge the consistency of users' ratings. Thereby scientifically and rigorously transforming the requirements into design points; Make rational allocation of design resources, and assist in designing intelligent agricultural harvesters with more optimized functions.

2. Weight Analysis of Functional Features Based on QFD

2.1. QFD Principle

QFD(Quality Function Deployment) refers to the Quality Function Deployment Method, which is a product innovation design method oriented by function features. It enables every link of product design and development to be closely related to the function features, and can optimize the product quality function attributes and enhance the product competitiveness by guiding the design scheme[3]. The core way to obtain the functional characteristics in QFD method is the quality house matrix. QFD house of quality matrix is widely used in the design fields of functional feature-oriented industrial design, interactive design, and engineering design[4], which can form a mapping relationship between functional features and design elements, and construct a relationship matrix between requirements and design elements based on the weight of functional features, as shown in Table 1. Intelligent agricultural harvester is a large-scale industrial product for the specific target user group of agricultural harvesting mechanized operators. It needs to carry out innovative design with the special user group experience of intelligent agricultural harvesters as the center. The functional characteristics can be thoroughly analyzed and converted into specific design indicators by using the principle of QFD, and finally the product satisfying the users is delivered.

Table 1: Schematic diagram of QFD house of quality matrix

Design Objective	*A*			
Design Elements	D_{11}	…	D_{1n}	
	…	D_{ij}	…	
	D_{m1}	…	D_{mn}	
	Design Elements			Demand Weight
Demand of Users	R_{11}	…	R_{1n}	K_1
	…	D_{ij}	…	…
	R_{m1}	…	R_{mn}	K_{mn}
Element Weights	H_1	…	H_m	

2.2. AHP principle

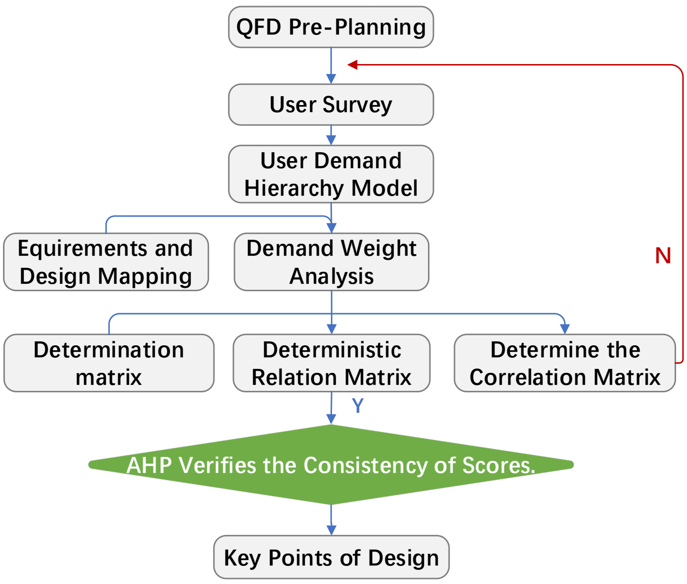

Figure 1: QFD and AHP combine product design and research process.

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AHP (Analytical Hierarchy Process) is AHP(Analytic Hierarchy Process, which uses the data analysis method to convert the semi-quantitative and semi-qualitative problems into quantitative problems and classifies the complex problems into levels for processing[5]. At the same time, the AHP method can verify the consistency of the evaluation model by statistical methods. The subjective one-sidedness of QFD method in the conversion between requirement and design objective is made up by introducing AHP method into design evaluation. At present, there is little research on the combination of QFD and AHP[6], and it is an innovative research method in China. Wang Yang et al. combined QFD and AHP to study the man-machine system for the environment in the aircraft cabin[7], while Jiang et al. combined QFD and AHP to analyze the importance of functional features[8]. In this paper, QFD is used to establish the functional feature level weight model, and AHP is used to verify the consistency of the data in the functional feature level weight model through AHP to ensure that the functional features are rigorously converted into design points and guide the design. the research process is shown in figure 1.

2.3. Determination of Functional Characteristic of Intelligent Agricultural Harvester

Based on QFD design method, taking agricultural machinery experts as the interview object, the functional characteristics of intelligent agricultural harvester were deeply understood, and the functional characteristics of intelligent agricultural harvester were analyzed and summarized according to the design goal, design criteria and the subordinate relationship between the functional characteristics elements. Taking the overall design effect to be achieved by the product as the overall target, the first level is established as the design target layer a, and in order to achieve the design target, the guidance of specific design criteria is required, so the second level is set as the design criteria layer b, and the design criteria are composed of specific functional feature points, so the third level is set as the demand index layer c, and thus a three-level QFD functional feature model for the design of the intelligent agricultural harvester is established according to the AHP method, as shown in Figure 2.

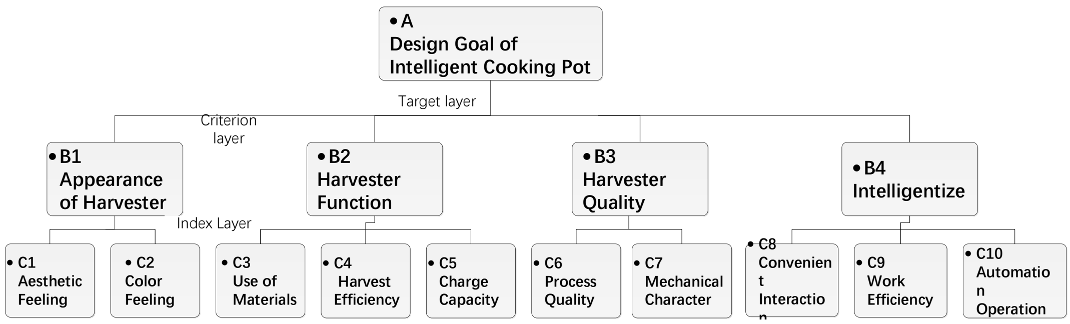

Figure 2: QFD functional feature model

2.4. Weight Analysis of Functional Characteristic Factors Based on QFD

In order to achieve the design goal, need to find meet the design requirements of the functional characteristics. The importance judgment of design requirements is the key to product innovation design. Using QFD method to count the importance of each design index and its corresponding functional characteristics can bring advantages into play and highlight key design points. The method for QFD to count the importance of design requirements is as follows: Ki is the importance value of i function feature with number, Rij is the relationship value between the need of i user with number and design elements with number j, so Hj is the importance value of j with number, and its calculation method is as follows[9]:

$$H_j = \sum_{i=1}^{n} K_i R_{ij} \quad (j = 1, 2, ..., 3m)$$

H_j——Importance.

K_i——Scoring value of the evaluation target.

R_{ij}——Relationship degree of evaluation target.

Functional feature importance Ki (i=l, 2,…, m) According to the statistical principle, it was divided into five grades. The importance degrees of requirements corresponding to 0, 1, 2, 3, 4 and 5 were very insignificant, relatively insignificant, generally important, relatively important and very important, respectively.

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R_{ij}: degree of relation -The relationship grade in the forms of 0, 1, 3, 5, 7 and 9: There is no relationship between the corresponding design elements and the functional characteristics, which is weak, weak, general, close and very close.

Functional feature weights *Ki* and *Rij* were derived from in-depth interviews with 30 agricultural machinery design experts from Guangdong. After calculation, the *Hj* values of the function features and design elements are obtained. A larger *Hj* indicates a higher degree of compliance, which means that the corresponding function features meet the design expectation. The importance values of the function features and design elements are shown in table 2.

Table 2: Schematic diagram of QFD house of quality matrix

Criterion name	Criterion Weight	Indicator Layer Name	Index layer	Heavy value
B1 Appearance	0.19	C1 Aesthetic Feeling	0.14	0.05
		C2 Color Aesthetic Feeling	0.57	0.11
		C3 Use of Materials	0.73	0.14
B2 Function	0.56	C4 Harvest Efficiency	0.24	0.13
		C5 Charge Capacity	0.95	0.53
B3 Quality	0.75	C6 Process Quality	0.21	0.16
		C7 Mechanical Character	0.83	0.62
B4 Intelligentize	0.41	C8 Convenient Interaction	0.18	0.07
		C9 Work Efficiency	0.91	0.37
		C10 Automation Operation	0.56	0.23

3. Data Consistency Analysis Based on AHP

3.1. Consistency Matrix Construction

According to the principle of AHP law, the judgment matrix is established according to the importance of the factors determined by the user's score, based on the elements of the previous layer. Construct a judgment matrix for the comparison of the importance degree of layers pairwise. Construct a judgment matrix for the comparison of the importance degree of layers pairwise A [10]:

$$\begin{Bmatrix} 1 & 1/3 & 1/4 & 1/2 \\ 3 & 1 & 3/4 & 3/2 \\ 4 & 4/3 & 1 & 2 \\ 2 & 2/3 & 1/2 & 1 \end{Bmatrix}$$

For "Appearance ($B1$)" Index layer,Construct $C1-C3$ the judgment matrix of pairwise importance comparison $B1$:

$$\begin{Bmatrix} 1 & 4 & 6 \\ 1/4 & 1 & 1 \\ 1/6 & 1 & 1 \end{Bmatrix}$$

For "Function ($B2$)" Index layer,Construct $C4-C5$ the judgment matrix of pairwise importance comparison $B2$:

$$\begin{Bmatrix} 1 & 3 \\ 1/3 & 1 \end{Bmatrix}$$

For "Quality ($B3$)" Index layer,Construct $C6-C7$ the judgment matrix of pairwise importance comparison $B3$:

$$\begin{Bmatrix} 1 & 4 \\ 1/4 & 1 \end{Bmatrix}$$

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For "Intelligentize ($B4$)" Index layer,Construct the judgment matrix of pairwise importance comparison $B4$:

$$\begin{Bmatrix} 1 & 5 & 3 \\ 1/5 & 1 & 1 \\ 1/3 & 1 & 1 \end{Bmatrix}$$

3.2. Data Consistency Evaluation

Analytic hierarchy process (AHP) verifies whether the multi-level user rating data model is consistent with the random consistency index, When $CR < 0.1$, It shows that the judgment matrix has satisfactory consistency [8] CR The calculation formula is as follows:

$$CR = \frac{CI}{RI}$$

CI ——Matrix consistency index.

RI ——See table 3 for random consistency index and its value range.

Table 3: The corresponding table of random consistency index of each order judgment matrix RI[10]

Order	3	4	5	6	6	8	9	10
RI	0.58	0.89	1.11	1.25	1.35	1.4	1.45	1.49

The weight ranking of features and design elements can be summarized as calculating the feature roots λ and feature vectors of AHP judgment matrix..The corresponding of $\lambda_{\max}$ normalization vector of is *H*, Namely that weight value of the functional feature to be analyze. For the judgment matrix *B*,According to the formula $BH = \lambda_{\max} H$,It can be calculated the Eigenvector and Eigenroot of *B*.According to the calculation principle of AHP, the square root method is used to calculate the eigenvector of the judgment matrix [11], Calculated $\lambda_{\max}$, CI , CR separately in Matlab:

$$CI = \frac{\lambda_{\max} - n}{n-1}$$

For matrices A , $\lambda_{\max}$ = 4.000, CI =0.000, CR =0.000.

For matrices $B1$, $\lambda_{\max}$ =3.018, CI =0.031, CR =0.031.

For matrices $B2$, $\lambda_{\max}$ =2.000, CI =0.000, CR =0.000.

For matrices $B3$, $\lambda_{\max}$ =2.000, CI =0.000, CR =0.000.

For matrices $B4$, $\lambda_{\max}$ =3.029, CI =0.015, CR =0.025.

The calculation results show that the above judgment matrices all meet the consistency requirements, and it can be considered that the functional characteristics and the QFD hierarchical structure model of design elements have acceptable consistency, which can be converted into design indicators and guide the innovative design of intelligent agricultural harvesters. Rank the importance of design points according to user scores, as shown in Table 4: When designing products, resources can be reasonably allocated according to the ranking of factors.

Table 4: Design elements are ranked by the importance of user ratings

Factor	C7	C5	C9	C10	C6	C3	C4	C2	C8	C1
Hj	0.62	0.53	0.37	0.23	0.16	0.14	0.13	0.11	0.07	0.05

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3.3. Design Purpose and Design Index Determination

According to the principle of QFD, each design index D is derived based on the functional characteristics C, and the functional characteristics and design requirements are mapped one by one to form a mapping relationship, so as to guide the innovative design of products. The first-level factor B is the design goal, which is guided by the second-level functional feature C, while the third-level design index is derived from the functional feature C, and the design index D is the index that ultimately guides the specific design. For example, "D1 modeling should conform to modern aesthetics and meet the requirements of agricultural machinery modeling" is inferred from "C1 modeling aesthetic feeling", "D2 color matching can conform to modern agricultural aesthetic and functional characteristics" is inferred from "C2 color aesthetic feeling".

4. Design example of intelligent agricultural harvester

4.1. Registered designs

Corresponding to the design goal "B1 product appearance design", firstly, the arrangement of all parts in the overall shape of the harvester is determined, and the suggestions put forward by experts in the interview and problems in actual production are comprehensively considered, and the final design scheme is summarized, as shown in Figure 3. The cab is all-glass designed, and the driver's vision around it is clearer. The rearview mirror is arranged on the guardrail, so the driver can see the situation behind more clearly and easily. The front and rear wheels adopt the traditional four-wheel form, and the assembly and post-maintenance costs are low. This design meets the design index D1 (see Table 4). And the middle color of green and yellow used in the roof of the car is a bright color, showing the sense of vitality, reducing the sense of pressure and fatigue of large machinery, and black as the contrast color, with strong brightness of color contrast, increasing the sense of science and technology of products, which also brings a sense of coolness to Leizhou, where the heat is unbearable, and at the same time gives others a warning function. Don't approach easily or easily cause harm during work. The right side of the fuselage is decorated with a small amount of gray and black to increase rhythm and rhythm. Color separation is carried out on the bottom of each layer to highlight the sense of layering and meet the design index D2. The overall product shape and proportion design is shown in Figure 4.

Figure 3: Final design scheme of sugarcane harvester

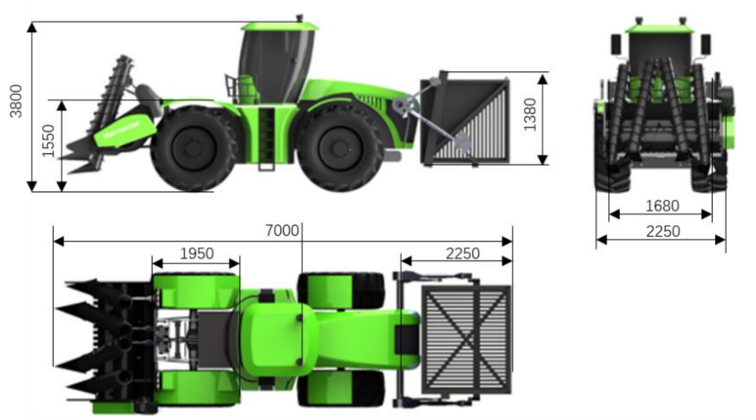

Figure 4: Design drawing of shape and proportion of sugarcane harvester

The machine cockpit and the main body cover are stamped and formed by sheet metal die, and the relevant connecting parts are fixed by welding and polished. Other functional components, such as the whole machine, the suction fan, the harvesting shovel and the collecting frame, are welded with straight steel frame profiles, which makes the structure of the intelligent agricultural machine more compact and firm, and the strip-shaped radiating holes are added at the tail of the machine body, which reduces the weight of the machine body while radiating heat, and makes the harvester look lighter. The overall material collocation reflects the sense of quality and technology required by design index D3.

4.2. Product function design

Corresponding to the design goal "B2 product function design", it is necessary to first determine the core function of this harvester, that is, what harvesting method to adopt. Modern harvesters are divided into cutting-off type and whole-pole type in terms of harvesting methods. As the mainstream harvester, cutting-off type harvester has high degree of automation, complete functions and strong adaptability, so this paper chooses cutting-off type harvesting method. Through technical integration, the core functional components of the harvester are integrated and designed and arranged inside the whole machine. As shown in Figure 5, the core functional components of the harvester are composed of a top cutter, a crop spiral separator, a feeding roller, a pressing roller, a root cutter, a top cutter, an impurity removal exhaust fan and a collecting basket. When the harvester is in operation, the topper at the front first cuts off the leaves at the top of the crop to reduce most impurities before the crop enters the machine, and then the crop spiral separator gathers and peels the intertwined crops. The feeding roller pushes the crops down, and at the same time, the pressing roller pushes the crops down, and the root cutter cuts off the crops that have been pressed down into the bottom of the harvester from the roots. The cut-off crops are lifted by the lifting roller and then flow into the feeder. After the crops are pressed down and rolled back, the impurity mixture of the cut crops is pumped out by the impurity removal exhaust fan, and then the remaining crops with high quality are directly put into the collection frame to complete the whole harvesting process.

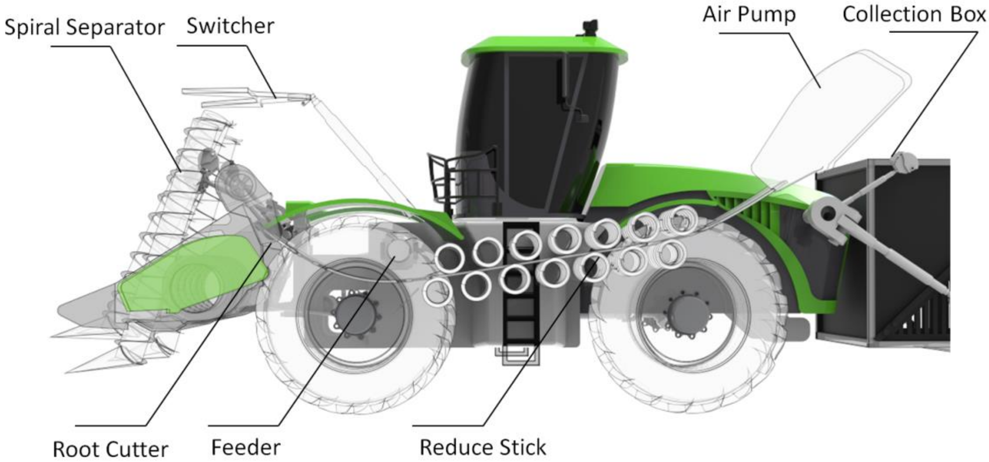

Figure 5: Design scheme of core functional parts of harvester

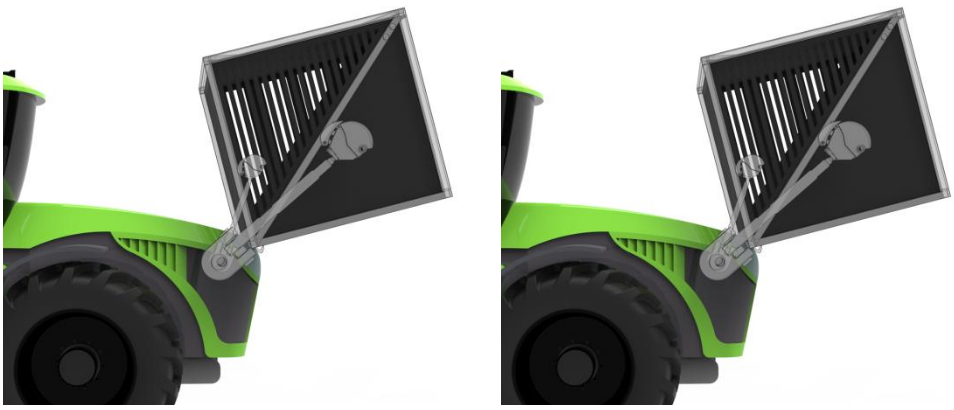

Figure 6: Schematic diagram of collecting frame loading and unloading

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When the collection frame is full and needs to be unloaded, the hydraulic rod inside the exhaust device lifts the exhaust port, then two hydraulic rods connected with the collection frame lift the collection frame, and the collection frame moves obliquely upward along the slide rail, and finally rotates backward for a certain angle when it reaches the end of the slide rail, and the rear frame door opens for unloading, as shown in Figure 6. After the collection basket is full, the crops can be unloaded to the collection truck by the field transfer loader and directly transported to the processing plant.

4.3. Product function design

Corresponding to the design goal "B3 product quality design", on the basis of meeting the safety requirements of the national standard, optimize the production process. The main appearance parts are flat sheet metal parts, and the products can be processed by bending, shearing, stamping, welding, riveting and splicing the sheet metal. Its remarkable feature is that the thickness of the same part is the same, and it has the advantages of high material utilization rate, low cost, good large-scale productivity, high labor productivity, light weight, various processing technologies and so on. Ensure the process stability of mass production and improve the stability of product quality.

Figure 7: Efficient harvesting mechanical structure

4.4. Intelligentize

Corresponding to the design goal "B4 intelligence", through QFD analysis, in the aspect of human-computer interaction, it is necessary to balance and give consideration to the optimization design from three aspects: operation conforming to the operator's machine characteristics, convenient maintenance and repair, and convenient and efficient human-computer interaction. As for the design index D8, the width and height of the cab are basically increased compared with those of traditional harvesters, for the purpose of making the driver more comfortable to drive, and the height of the steps has been adjusted from the angle of man-machine to widen the driving vision. Considering that there are many crops lodging and disorderly growth in Leizhou area, and drivers and users will be disturbed when the machine runs, a guardrail is designed in front of the cab to ensure the driver's work safety, as shown in Figure 7, which meets the design factor D8. Concerning the indicator "D9 work efficiency": the guardrail and pedal are designed on the left side of the vehicle body to facilitate the driver to get on the roof for maintenance, and the openable side cover is designed on the right side of the vehicle body for maintenance. The air outlet of the exhaust fan is welded with a straight metal plate and a circular tube, and the hydraulic rod of the opening of the exhaust fan is hidden in the body, which reduces the exposure of components and simplifies the maintenance steps. Guardrails are added on both sides, which not only serve as pedals for people to board the cab, but also extend directly to the rear collection frame to support the collection frame and link the discharge slide rail, which makes the overhaul process smoother.

5. Conclusions

In this paper, the principles of QFD and AHP are applied to the design and research field of intelligent agricultural harvesters. Guided by functional characteristics, the design elements are refined, and the

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comprehensive design optimization is carried out from the aspects of product shape, color, function, product quality and human-computer interaction, which improves the ergonomics experience of product operators for the use experience of intelligent agricultural harvesters. Based on the combination of QFD and AHP, the overall design process of intelligent agricultural harvester embodies the design idea of function quality oriented and user centered.

For complex products like intelligent agricultural harvesters, when the functional features are not clear, the research methods in this paper can be used to analyze and sort out the functional features through QFD, and the data consistency of functional features can be verified by AHP. When the consistency meets the requirements, the requirements can be transformed into design elements. This scheme scientifically and rigorously analyzes the functional features and integrates them into the design ideas and objectives, which has certain universality. The innovative research and development of large-scale agricultural harvesters can learn from the design ideas of this scheme. Follow-up research can consider QFD integrating TRIZ, SWOT and other methods to expand[12], At the same time, clustering and principal component analysis can be considered to optimize the research methods when capturing the functional features of QFD with larger sample size.

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